

**A PROCEDURE FOR EVALUATION OF
FIRE STATION LOCATIONS AND DEPLOYMENT**

EXECUTIVE DEVELOPMENT

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ABSTRACT

The placement of fire stations and equipment has a dramatic impact on the effectiveness and efficiency of services provided by the fire department. The problem addressed by this project was as the City of West Covina has grown and changed, the fire department needed a consistent and repeatable method to evaluate the response capability and protection levels provided.

The purpose of this research project was to develop a procedure for ongoing evaluation of fire station locations and equipment deployment. Historical and action research methods were employed to answer the following questions:

1. What is the current accepted standard utilized by the fire service to determine urban fire station locations?
2. What are the informational requirements to accomplish an effective fire station location and deployment analysis?

The procedures used in this study included a review of alarm records, City of West Covina documents and literature written by Fire Service and Geographic Information System professionals. Digital maps provided distance measurements. Computer hardware and software was used for data manipulation, calculations and graphic presentation of data.

The results of this study produced a draft standard operating procedure for the ongoing evaluation of fire station locations and deployment. In addition a limited sample study was undertaken. Tables and maps were produced to help

evaluate the effectiveness and efficiency of the first-due district of a single fire station in the City of West Covina.

Recommendations included the adoption of a standard operating procedure for the regular reevaluation of station location and deployment effectiveness. The purchase of software that uses advanced Geographic Information System features to optimize the delivery of fire services was also recommended.

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INTRODUCTION

During the past 26 years the City of West Covina has experienced population growth, increased residential housing and expansion in the commercial business and retail sales sector. During this time frame the city has not relocated or opened any additional fire stations. In June of 1999 it was determined that the oldest fire station in the City of West Covina, Fire Station 1, was in need of a major renovation. The community has changed dramatically since West Covina Fire Station 1 was built approximately forty-five years ago. This has led the Fire Chief, City Manager and the City Council to agree that a complete reevaluation of the site is required.

The problem is the West Covina Fire Department does not have a standardized, systematic procedure to determine the effectiveness and efficiency of current fire station locations. The purpose of this research project was to develop a procedure for ongoing evaluation of fire station locations. Historical and action research methods were employed to answer the following questions:

1. What is the current accepted standard utilized by the fire service to determine urban fire station locations?
2. What are the informational requirements to accomplish an effective fire station location analysis?

BACKGROUND AND SIGNIFICANCE

The City of West Covina Fire Department currently provides fire and emergency medical services for 106,000 residents in an area of approximately seventeen square miles. The City of West Covina Fire protects the community with personnel and equipment housed in five fire stations. The department uses a three-platoon system to staff five four-man engine companies, a three-man truck company, and a Battalion Chief position. The community is primarily comprised of residential housing with a median home value of over \$200,000. The community assets protected by the West Covina Fire Department includes approximately 31,000 homes and over 2,000 acres of commercial properties. These properties include an enclosed shopping mall of over 1,000,000-square feet, an office complex of over 180,000-square feet, and a 90,000-square foot retail complex. Also included are numerous auto dealerships, a community hospital, a 4,000-seat theater, several retail strip mall complexes and various small businesses.

In the past 26 years the West Covina Fire Department has not relocated or opened any additional fire stations. There have been numerous demographic changes during this time within the City of West Covina. Currently the oldest fire station, West Covina Fire Station 1, is 45 years old and in need of major renovation. This facility is on a site shared with City Maintenance, City Garages, a City Yard and fuel dispensing facilities.

Major changes to the area surrounding Fire Station 1 and changes within the community have occurred. It was determined that a reevaluation of the

current site be made before renovation begins. Prior to any renovation or redesign of the current facility it must be decided if this site meets the current and future emergency service response needs of the community.

This study is to identify specific criteria involved in the analysis of fire station locations and their application. The Fire Chief intends to make recommendations to either relocate, rebuild on the same site or refurbish the current structure. The final decision will be based on several factors, including the findings of the appropriateness of the current site.

By assessing the qualities of the current site the fire department will be able to plan for equipment, personnel needs and evaluate innovative solutions to meet the future fire protection requirements of the community. Furthermore, the experience gained from this study will provide the West Covina Fire Department the ability to reevaluate the locations of the other fire stations sites and how they meet community demands. The research problem area of relevance to the Executive Fire Officer Program (EFOP) course "Executive Development" can be found in *Executive Development Student Manual* "Unit 9 – Outside Elected Official and City Manager" and "Unit 10 – Service Quality/Marketing". This project provides the opportunity to exchange ideas on fire service issues and concerns with local elected officials and the city manager. These ideas include an assessment of service delivery and efficiency, which reflects a commitment to the stated goals and philosophies of the West Covina Fire Department.

LITERARY REVIEW

Planning the location of fire stations and their actual design has become increasingly important. Proper fire station distribution is a major factor in efficient, economical fire protection (Gratz, D.B., 1972). The determination of fire station locations or more accurately the deployment of fire companies and personnel has traditionally been a matter of professional judgment and intuition. In the past, fire stations were placed on or near thoroughfares and in areas with excessive response distances from existing stations. Site locations were based on opinions. This is no longer an accepted methodology. Even though cities may appear the same on a map, a more thorough analysis is required to determine deployment. Adding or removing companies or stations may have little impact in one community but may have an enormous affect in another of similar size and population. The implementation of a more analytical process has been required as a result of greater fiscal constraints and expanding professional fire service demands (Granito, J. A., 1986).

Response Area Coverage

The number and location of fire stations in a community is usually based on the distance between stations, the population served, and the hazards at particular locations (Gay, W., & Siegel, A., 1987, pp. 3). The fire department has contradictory objectives in placing fire companies. These objectives are equalizing coverage area and minimizing total travel time. The solution to this dilemma typically involves making equipment and personnel allocations that are

compromises between the two extremes. By placing more companies in high hazard and demand areas, yet still assuring that all regions receive an acceptable level of coverage, communities are finding the balance between these two objectives (Walker, W. E., 1979, pp. 78).

The first step in analyzing fire station location coverage involves determining what constitutes a reasonable response distance for the first arriving fire company? This distance determination is dependent upon numerous factors (Holba, M., 1979). Because of this, the question has been restated: What constitutes a reasonable response time for the first arriving fire company? The response time criteria must be provided for engine companies, ladder companies, and EMS units, if this service is provided. This is typically a policy statement of acceptable time frames. The theory that a rapid response is essential to protecting life and property is widely accepted in the fire service. This same theory is also the basis for determining fire station locations because fire spread is largely a function of time (Gay, W., & Siegel, A., 1987, pp. 3).

A measure of how well a deployment policy succeeds in providing fire protection is how often specific locations within a region have nearby fire units available. This is referred to as "coverage". The process of estimating coverage can be accomplished by assuming all units are available and estimating average travel times to a given region of the city. Another more accurate means of estimating coverage is made determining the amount of time a fire company is unavailable (Walker, W. E., 1979). The measure of success or failure of the deployment is then how often the coverage can successfully provide fire

companies to an emergency scene within response time constraints set by policy.

In order to determine coverage, the deployment of equipment and the number of stations that will house them must be known. This allows the response areas to be calculated. Once these areas are known, coverage calculations can be accomplished to determine the adequacy of a given deployment strategy (Walker, W. E., 1979). The number of fire stations and the locations of the stations are related to the area covered and the occupancies within that designated area.

The use of time rather than distance to can be used to judge coverage quality (Holba, M., 1979). Through the use of actual response times it can be shown that the location of the fire station influences the level of protection in the response area. The location of a station directly influences the response distance, which in turn impacts response time. The National Loss and Control Service Corporation determined this time-based system is more accurate than a distance-based system for determining coverage quality because of its simplicity. Calculations for variables such as acceleration of vehicles, traffic conditions and patterns, weather and road conditions are not necessary using this method.

The time interval between a call for assistance and the arrival of assistance is influenced by the location of the fire stations (Holba, M., 1979). It must then be understood that changing a fire company's location effects only the travel time component of response time (Walker, W. E., 1979, p. 82).

Response Modeling

The general subject of deployment analysis includes a variety of topics, some of which can be addressed using mathematical models and others that cannot. A model is a simulation of a real world environment. Experimentation and manipulations may be performed in a model without danger or cost. The output predicts the values of one or more performance measures that would occur if a policy were implemented (Walker, W. E., 1979, p.89). A good model will produce answers to questions asked of it. Most of the issues that can be analyzed using mathematical models concern the manner in which fire companies are located and dispatched.

The goal of researchers has been to create models that reflect accurate relationships with the real world and provide information that can be used in the decision making process. High quality models are the key to an effective fire station site analysis, but they cannot replace common sense and good judgment (Walker, W. E., 1979).

Developing a foundation for community fire protection based on empirical findings and sound decision processes is important. The use of models for deployment and response calculations provides a logical means to arrive at fire station location decisions. The use of travel time and distance models, as well as allocation models, allows for the estimation of the effectiveness for given station sites at stated staffing levels before they are relocated or built. Formulas to calculate approximate travel distances and time provide a systematic approach to recognizing fire protection deployment problems. Modeling fire department

problems is a way to increase the likelihood that changes will be improvements (Blum, E. H., 1979, pp. 6).

The process of modeling with real data can be used to judge the effectiveness of a particular station location. Both frequency of alarms and travel times are important for the evaluation of station locations (Van Bowen, J. 1991).

The first step to beginning any spatial analysis is the determination of a systematic method of representing locations (Chou, Y.-H., 1997, p. 83). Point features, such as a fire station or the location of an emergency must be able to be recorded on a two-dimensional plane to implement any of the empirical formulas involving time and distance. This is accomplished by expressing location through the use of a coordinate system. A Cartesian coordinate system is used to properly measure between points in the empirical models and the street network models. Use of a Cartesian coordinate system enhances problem-solving capabilities (Van Bowen, J. 1991).

A Cartesian coordinate system appears very similar to city blocks. The "Manhattan distance" evaluates the distance based on a grid system similar to city blocks (Chou, Y.-H., 1997, p. 105). This measurement technique is also called travel distance (Walker, W. E., 1979). By determining the coordinates of (x_i, y_i) for point i and (x_j, y_j) of point j with respect to a right angle coordinate system the travel distance can be calculated.

Stated as a formula:

$$d_{ij} = |x_i - x_j| + |y_i - y_j|$$

The right-angle distance from i to j , d_{ij} , would be the sum of the absolute values of the differences in the coordinates (Chou, 1997, p.105), (Kolesar, P. J., 1979, p. 162). An example of this would be a total driving distance of two miles by driving one-mile east, turning and traveling one-mile north.

If a straight road directly connected two points the use of the Manhattan distance would not apply. The distance between two points on a Cartesian plane is evaluated by Euclidean distance (Chou, Y.-H., 1997, p. 104), (Kolesar, P. J., 1979, p.162). Stated as a formula:

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

This is the formula for the distance of a straight line (Chou, Y.-H., 1997).

For approximating travel distance within a city using the straight-line method, an empirically determined constant that scales the Euclidean distance has been determined. This adjustment takes into account the geographic obstacles, such as a hill, that a roadway would go around or over. Stated as a formula:

$$d_{ij} \cong k \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

The constant $k = 1.15$ has produced acceptable distances in a number of cities (Kolesar, P. J., 1979, p.163).

If a community is laid out in circular or random street patterns the use of a constant to adjust estimates may accomplish the task or a more complex distance function may need to be developed (Kolesar, P. J., 1979).

The use of a compass to draw a response area with a given radius has been used by fire departments in the past (Coleman, R. J., & Granito, J. A.

(Eds.), 1988),(Barr, R. C., & Caputo, A. P., 1997) as a means of determining deployment. In the article *An Equation for Station Location*, the author Pieter Sybesma points out that fire personnel cannot reach an emergency scene "as the crow flies." The argument was presented that in fact a diamond is a far more accurate way to represent a response district. When the fire station is placed at the center of the diamond, the distance from the center of the diamond to the outer corners of the diamond correlates to the response time selected by the community. An argument based on time and distance can be used to show that a diamond more accurately represents the response area for responding units than does a circle. Responding units are able to reach any location in the diamond within the designated response time provided the streets are in a somewhat rectangular pattern. The corners of the diamond are aligned with the street system and the fire station is placed in the center. By making the distance from the center to each corner correspond to the required response distance, the area contained within the diamond will reflect all addresses within the required distance. Using a diamond to determine response distances is a simple technique that does not require a street network.

In *Travel Time and Travel Distance Models* (Kolesar, P. J., 1979), the author presented the same argument. The concept of a diamond rather than a circle to develop an equation for average travel distance was used. This equation is referred to as the "square-root law for estimating travel distances." A major result of the Rand research involving fire company deployment was this simple calculation to estimate the average travel distance in a region. The formula is

designed to model estimated average distances in a region over an extended period of time. It was explained by E. H. Blum and P. J. Kolesar, “The square-root law actually reflects the basic dimensional relation that area is proportional to distance squared, which implies that distance is proportional to the square root of the area” (Kolesar, P. J., 1979, p.183).

In simpler terms the square-root law can be used to calculate the average distance traveled by the first-arriving fire company. Where the average number of fire stations having at least one available engine company is represented as $E(N)$, the expected travel distance for the n^{th} arriving engine company is $E(D_n)$, k_n is the constant of proportionality and A is the area of the region, the formula is:

$$E(D_n) = k_n \sqrt{A/E(N)}$$

The constant of proportionality k_n depends on the street configuration and how the companies are distributed in the region. Studies in several cities have found that a value of 0.55 has produced good estimates (Kolesar, P. J., 1979, p.158), (Walker, W. E., 1979, p. 93).

Average travel distances for second arriving units can also be estimated using the square-root law. For second-arriving units the value of k , is approximately 1.0 (Kolesar, P. J., 1979, p.158).

The square-root law for estimating travel distances is an example of a descriptive model. Descriptive models are derived mathematically and simplifying assumptions are made so the models do not become too complex mathematically (Walker, W. E., 1979, p. 93). A descriptive model is used to identify options that appear acceptable and eliminate inferior options. The

square-root law for estimating travel distances provides a simple calculation to determine approximate distances.

Another way to accomplish the objective of determining response distances is to actually measure the distance by driving it. Although the easiest to accomplish it is also the most time consuming. Each route to locations within the city from a given point of origin must be driven and the distance recorded.

An estimate of the number of fire engines required in an area can be calculated using the square-root law model in a prescriptive mode. Instead of predicting the average travel distance for the first arriving engine in a region from the density of engine companies, it is possible to determine the smallest number of engine companies needed to provide a given average first-arriving engine travel distance with the following equation. Letting N be the number of engines needed and B the average number of engines that are busy. The area of the region is represented by A. Solving for N,

$$N = B + A [\text{constant} / \text{average travel distance}]^2$$

This equation can be used to calculate ladder companies and EMS services also. Each type of service is calculated separately (Walker, W. E., 1979, pp. 95-96).

The estimation of time from known travel distance has been empirically calculated and in most instances provides very good travel time estimates. The formula for converting distance into time is:

$$E(T_{ij}) = 2.10 \sqrt{D_{ij}} \quad \text{if } D_{ij} \leq 0.38 \text{ miles}$$

or

$$E(T_{ij}) = 0.65 + 1.70D_{ij} \quad \text{if } D_{ij} \geq 0.38 \text{ miles}$$

T_{ij} is measured in minutes and D_{ij} is measured in miles. This equation does not provide an exact estimate of the travel time for every response but instead represents the typical response (Kolesar, P. J., 1979, p.159).

The software models and manual methods investigated used either prescriptive or descriptive models. Prescriptive models predict the performance values produced by a given policy. These models are used to optimize performance measures and produce a single measure of performance. A prescriptive model would be used to determine the number of fire stations a community would need to meet predefined response time criteria.

The Fire Station Location Package (FSLP) software developed by Public Technology, Inc. (PTI) uses a street network to find the route that takes the least amount of time. FSLP is a computer program that sorts and processes a community's fire and street related data. Incorporating the ability to apply hazard and demand factors to fire service areas the computer program produces detailed information about response routes and times (Benton & Carpenter, 1987).

The FSLP is based on a generalized fire incident sequence. It specifically attempts to optimize travel time. Travel time is the segment in the fire incident sequence that the fire department has the most influence over. The authors of *A Computerized Approach To Fire Station Location* (Benton, S. B., & Carpenter, N. D., 1987), propose that knowledge of local coverage requirements and special community circumstances combined with the FLSP analysis leads to the best

configuration of station sites. This agrees with the position of Warren E. Walker in *An Introduction to Deployment Analysis* (1979), where he states:

In performing most deployment analyses, the analyst uses descriptive models to supply quantitative information about a policy, which can then be used together with the judgment and intuition of those involved in reaching a decision. In this way, decisions can be made using the best information available, while taking all relevant constraints, judgments, and other considerations into account (Walker, W. E., 1979, p. 96).

In a comparison of the Firehouse Site Evaluation Model (FSEM), developed by the Rand Corporation, to the Fire Station Location Package (FSLP) developed by PTI, it can be stated that both are descriptive models that can predict the values for performance measures (Granito, J. A., 1986). The two packages use completely different methodologies to accomplish a site analysis.

Both the FSLP street network model and FSEM empirical model approach break a community into small regions. The models assume that each region has a demand for fire service at only one point. The assumption is also made that travel time in the region will be calculated from that point. Both models allow the assignment of hazard values.

FSEM estimates travel distance between two points using coordinates assigned to the points. These point coordinates are then manipulated with empirical formulas to estimate travel distance and travel time.

FSLP calculates travel distance through the use of a street network. The use of a street network requires a more complex database. Until recently the use of a street network database required many hours of development time. With the introduction of Geographic Information Systems (GIS), street network databases have become more accessible because of lower prices.

Maps are graphic depictions used to convey real world geographic relationships, concepts and information. A GIS provides the same capabilities and more. In addition to graphic capabilities a GIS has the ability to analyze the associated data in a more efficient and convenient way than is possible with a common map (ARC/INFO, 1994). The electronic basemap that a GIS uses is often referred to as an “intelligent” or “smart” map because of the additional information the GIS attaches to the objects on the map. These additional pieces of information are called attributes. Attributes describe an object’s features and may thus be regarded as the computer’s “knowledge” of the object (Bernhardsen, 1992, p.39).

Topology explicitly defines spatial relationships. The three major topological concepts are (a) Connectivity, (b) Area, and (c) Contiguity. Topology allows a computer to determine the relationship of the points, lines and polygons on a map. Advantages to this include more efficient data storage, the ability to identify adjacent, connected or overlapping features and the analytical functions that topology allows.

The use of Thiessen polygons can involve all three concepts of topology. Thiessen polygons are used to define areas of influence. Thiessen polygons are

polygons that are of irregular size and shape. Given an irregularly spaced set of points [such as fire stations] Thiessen polygons show a system of territories delineated with equal influence between adjacent points. These polygons show areas dominated by the given data points (Chou, Y.-H., 1997, p.347). The use of Thiessen Polygons can be used in fire station location and deployment analysis in the same way it is applied in marketing studies.

Connectivity allows the computer to “see” points as connected, forming a line. This in turn can be used to define routes. Routes define paths along sets of linear features like a street network. Routes are based on arcs. Arcs can go from one point to another, begin and end in the same location forming a circuit, or be disconnected line segments (ARC/INFO, 1994).

Modern fire station location packages use street network data that includes the topology of the street network. This data set is called the basemap. The basemap is typically created using TIGER files produced by the U.S. Bureau of Census (Barr, R. C., & Caputo, A. P., 1997). TIGER files contain street address ranges along line segments. It also provides census tract and block boundaries. The descriptive data can be used to associate address information and census/demographic data. (ARC/INFO, 1994).

A street network provides the distance of each street segment. Travel distance is the sum of all street segments between the point of origin and the given arrival location. Another advantage of a street network is the ability to store impedance information (Chou, Y.-H., 1997). The impedance information would typically be the response speed of each street segment. This allows accurate

estimates of travel time. The ability to purchase street network data is making the use of this approach more common, especially in communities that have a number of natural and manmade barriers to travel or unusually shaped areas.

Time and Distance Standards

The Insurance Services Organization (ISO) uses the Fire Suppression Rating Schedule (FSRS) to classify fire departments on a scale of 1(highest) to 10 (lowest) based on three topics. These topics are receiving and handling fire alarms, the fire department, and water supply. The FSRS provides a means to evaluate public fire suppression facilities, equipment, and programs. Engine Company and Ladder Company deployment along with the location of fire stations, significantly impact the maximum amount of credits under the FSRS. The resulting classification may be used to establish commercial and residential fire insurance rates. Other criteria such as automatic sprinklers, building construction, occupancy and exposures factors also may impact insurance rates.

In *Fire Suppression Schedule Rating Handbook* (Hickey, 1993), the author provides information and explanations about the items contained in the ISO Fire Suppression Rating Schedule. It is the placement of equipment in the fire station that makes the location of the fire station a critical factor in the overall evaluation process. The ISO recommendation states; The built upon area of the city should have a first-due engine company within 1.5 miles and a ladder service company within 2.5 miles (Insurance Services Office, 1998, p.28).

The NFPA has recommended in the past that a first due engine company in urban areas should be located within 2-miles of residential areas requiring less than a 2000 gpm fire flow, 1½-miles of commercial areas requiring less than a 4500 gpm fire flow, 1-mile of commercial areas requiring a 5000 to 8500 gpm fire flow, and within ¾-mile of buildings that require a 9000 gpm fire flow or greater. Also that ladder companies should be located within 3-miles of residential areas, 2-miles of commercial areas requiring less than a 4500 gpm fire flow, 1½-miles of commercial areas requiring a 5000 to 8500 gpm fire flow, and within 1-mile of buildings that require a 9000 gpm fire flow or greater (McKinnon, G. P., & Tower, K. (Eds.), 1976, pp. 9-78 - 9-79). The fire history of a particular area, the amount of built-in protection and the housing density all affect how these recommendations might be implemented. These recommendations do not take into account any fire department services other than fire suppression. The final decision of what is an acceptable response distance has been left to local community leaders. The NFPA pamphlet 1201, *Developing Fire Protection Services For The Public*, stipulates that each community must assess the level of risk that it is willing to accept relative to the fire suppression resources that it is capable of maintaining (National Fire Protection Association, 1994).

William Gay and Alan Siegel stated “The location of fire stations are based on the theory that a rapid response is essential to protecting life and property since fire spread is largely a function of time” (Gay, W., & Siegel, A., 1987, p.3). This statement is supported by the findings of the NFPA and presented in the

"Page Not Available. Please visit the Learning Resource Center on the Web at <http://www.lrc.fema.gov> to learn how to obtain this report in its entirety through Interlibrary Loan."

rescue or emergency medical services (Barr, R. C., & Caputo, A. P., 1997). This ability to respond in a minimum amount of time to a call for assistance is the basis for determining the location of fire stations.

A community may choose to define different response time standards for different locations. These standards will typically require the development of risk and hazard factors to determine a weighted value for target hazards. This is known as a minimum travel time deployment. By providing several response time standards, locations with a higher community risk will have shorter travel distances, which generally equate to a shorter response time (services (Barr, R. C., & Caputo, A. P., 1997, p. 10-252). Adaptive response policies are designed to ensure that high potential risk and actual risk locations receive a more rapid response to minimize the overall impact to the community. Improving the allocation of resources to match supply and demand in an area may be the easiest way to improve response time to high-risk areas (Walker, W. E., 1979).

Part of the risk assessment process is the determination of unit availability. Unit availability indicates how often the alarms in a company's first-due area will suffer a travel time delay due to companies responding from outside of the first-due area. This can be determined from actual data or by reasonable estimate (Walker, W. E., 1979). Unit availability is influenced by demand for protection.

Demand for protection takes two forms. First is potential demand, which is the potential for loss. When fires occur potential demand becomes realized demand. Realized demand is when the fire department is required to respond

and extinguish the fire (Walker, W. E., 1979). The demand for protection may take into account potential impact on the community such as a loss of jobs, loss of revenues, fire hazards, incident rate or high demand for resources services (Barr, R. C., & Caputo, A. P., 1997).

The demand for protection is used to determine hazard zone ratings in deployment models. Criteria for hazard zone ratings must be defined. There are numerous rating schemes. The NFPA has a simple system that can be used for this purpose. This system consists of 3-types of hazard occupancies (Granito, J. A., 1986, p. 15-92). The three occupancies hazards are

High-Hazard. Schools, hospitals, nursing homes, explosives plants, refineries, high rise buildings, and other high life hazard or large fire potential occupancies.

Medium-Hazard. Apartments, offices, mercantile and industrial occupancies not normally requiring extensive rescue or fire fighting forces.

Low-Hazard. One, two or three family dwellings and scattered small businesses and industrial occupancies.

Developing a grid template of the fire station service area provides a means to assign hazard zone ratings and to determine effectiveness of a fire station site (Sybesma, P., 1995). The use of these smaller areas considerably reduces the calculations required to determine coverage (Walker, W. E., 1979). Each individual rectangular area in the grid is assigned a value for hazard level and frequency of alarms.

A community may also decide to provide station locations that meet a single response time standard for all risk. This is an “equal coverage” deployment. This deployment provides the same level of first-due response to all areas throughout the community (Barr, R. C., & Caputo, A. P., 1997).

In summary the reviewed literature identifies (a) necessary information to determine areas of coverage, (b) procedures to calculate response distances and (c) ways to measure the effectiveness and efficiency of different deployment strategies. Alternative methods of response-area calculation and presentation found in the literature may be used to create the principal result and output of this project.

PROCEDURES

Definition of Terms

Arcs. An ordered string of vertices (x, y coordinate pairs) that begin at one location and end at another. Connecting an arc’s vertices creates a line.

Base map. A map containing geographic features used for locational reference.

Coverage. A measure of how well a deployment policy succeeds in providing fire protection.

Euclidean distance. Measures the straight-line distance between two points on a plane.

Geocode. The process of assigning coordinates to a geographic feature given some other location description, such as an address or ZIP code.

Hazard factor. The rate at which an emergency response escalates. The hazard factor is a measure of a region's potential demand. The hazard factor times the average travel time equals the average risk.

Manhattan distance. Measures the distance based on a grid system similar to city blocks. Distance is measured along the x and y-axes.

Performance Values. Criteria used to measure effectiveness, efficiency or both.

Prescriptive Model. A model that will produce from a large set of potential fire station sites the smallest subset that meets predetermined criteria.

Primary Public Safety Answering Point (PSAP). Dispatch center for emergency services where incoming calls are received.

Street Network . An interconnecting set of arcs representing possible paths for the movement of resources from one location to.

Thiessen polygon. Also known as proximal polygons, are polygons generated from a set of point features. The polygons are derived in such a way as to represent the catchment area of each point. The boundaries between two polygons are drawn along lines of equal influence or equal dominance.

TIGER.The Topographically Integrated Geographic Encoding and Referencing data format used by the U.S. Census Bureau to support census programs and surveys. The TIGER files contain street address ranges along lines and census tract/block boundaries.

Topology. The spatial relationship between map features.

Research Methodology

The research procedure used in this study began with a literary review conducted through the Riverside County Library System. The Inter-Library Loan process that is provided through the Learning Resource Center (LRC) at the National Emergency Training Center was used. Additional information was collected from the City of West Covina Fire Prevention Bureau, West Covina Fire Record Management System, City of West Covina Fire Department Standard Operating Procedures Manual and from the author's personal library. A telephone interview was conducted with the Vice President of Corporate Partnerships at PTI. Also an interview was conducted with the Public Safety Marketing Manager at ESRI.

The literary review was used to gain an understanding of the underlying processes that are required to determine optimal fire station sites. The literary review focused on the different techniques used to produce both quantitative and qualitative results.

A limited study involving only the Fire Station 1 first-due response district was undertaken to understand the factors that must be considered during a complete station location and deployment analysis.

Data was collected for the previous 3-year period that involved the first due engine, number of alarms and the types of alarms occurring in each map section within the City of West Covina. This data was imported into Microsoft Excel Software and manipulated. ArcView software, manufactured by Environmental Systems Research Institute (ESRI) was used to produce the

circular response area, the Thiessen polygon response area and the distribution maps. The City of West Covina street basemap was produced by Geographic Data Technology (GDT) and purchased over the Internet.

This research was historical in that the information from the literature review was used to understand the current capabilities of a fire station location analysis and how the results of the analysis can be interpreted and understood. Hazard zone value assignments are based on the recommendations provided in *Fire Protection Handbook 16th Edition* (Granito, J. A., 1986)

Acceptable response times and distances were policy statements of the West Covina Fire Department.

The action methodology was used to produce a draft standard operating procedure and a limited study of Fire Station 1 response district. Response area tables and maps were developed by utilizing data gathered from both the City of West Covina Business License Database and the Fire Department Records Management System.

The West Covina Fire Department map sections are rectangular in shape and are laid out in a grid system. Using the map section boundaries allows the calculation of frequencies of emergency responses in each map section. These boundaries also provide the ability to determine the center of each map section for distance calculations.

The data from several text-delimited files was used for the time validation and map section calculations. This data was imported into a spreadsheet for easier data manipulation. The resulting files were organized and fields were

formatted to provide usable data. The files were then imported into a database application and combined to form one file containing over 52,000 records.

The data in this file was then parsed, sorted and queried to calculate information for the map district tables in Appendix B.

Distance calculations in Appendix B were made with the adjusted straight-line calculation, the K factor was 1.15. A time estimation equation was also used in these tables. Both empirical formulas are well documented in *Travel Time and Travel Distance Models* (Kolesar, P. J., 1979) and cited in this study.

ESRI ArcView software was used to produce Appendix C through Appendix F. A geocoded address file was produced for each appendix and addresses were shown as individual points on the map of the Fire Station 1 first-due response district. It should be noted that this software has additional extensions available that allow raster-based grid analysis and street network route analysis. These products were not available for use by this author.

The City of West Covina street base map was produced by Geographic Data Technology (GDT). This data set was used with ArcView software to create Appendix C through Appendix F.

The Thiessen polygons in Appendix C were used to calculate response districts by their spatial relationship. Appendix C shows how Thiessen polygons would set boundaries by geographic areas of influence.

The circular and diamond shaped response areas in Appendix D also used this data and software. The distance boundaries of both figures were set at 1.0-miles, 1.5-miles and 2.0-miles.

Appendix G represents the fire and EMS response distribution throughout the Fire Station 1 first-due response district. It can be easily interpreted that the distribution of alarms are not clustered in any general area and appear to be evenly dispersed.

Appendix H shows the distribution of commercial occupancies by hazard rating. This was accomplished by querying the business license records by location and then assigning a hazard rating using the rating system presented in the *Fire Protection Handbook 16th Edition* (Granito, J. A., 1986). The distribution provides a simple representation of the relationship of hazard and location within the Fire Station 1 first-due response district.

Assumptions and Limitations

Assumptions included confidence in the accuracy of stated formulas and proofs provided in the literature.

All adjusted distances were rounded to the nearest one-tenth mile. The center of each map section was determined geometrically, not by a central tendency calculation of all points contained within each map section. It was assumed that the straight-line distance calculations by ArcView software were correct. The product of the ArcView straight-line value and the constant K provided the distance value for each map section in Appendix D.

Limitations included the data file time format provided to the author. Some records did not have completed time entries. As a result these records were not considered in the calculation of averages.

RESULTS

A draft standard operating procedure for deployment evaluation is shown in Appendix A.

Answers to Research Questions

Research Question 1. Is there an accepted standard utilized to determine fire station locations?

Time and distance are the accepted standards for determination of fire station locations. By providing an accurate objective assessment using time and distance, information about level of protection can be determined. As a result the likelihood of a successful fire company deployment strategy is greatly enhanced. ISO and the NFPA publish response time and distance recommendations. There are many unique conditions that each community has to weigh in order to provide optimal fire protection. Because of this a community is not required to meet the time and distance recommendations of these organizations. A decision about acceptable response time and distance can be reached most effectively by combining deployment strategies, cost factors the community considers acceptable and the level of risk the community is willing to accept (Peterson, C., 1986).

Research Question 2. What are the informational requirements to accomplish an effective fire station location analysis?

The following enumerated items are required to accomplish an effective fire station and deployment analysis:

1. Specify general strategy of deployment; equal coverage or minimum travel time
2. Specify response time criteria
3. Specify hazard zone rating criteria if using minimum travel time deployment.
4. Specify number of fire stations and equipment housed in station
5. Determine unit availability, demand for protection and hazard zone ratings if using minimum travel time deployment.
6. Develop a grid system of fire protection area
7. Street network data if using GIS approach.
8. If using in-house data to quantify effectiveness and efficiency of current coverage, at least three years of emergency response information, broken down by category is needed.

DISCUSSION

Use of the Rand Corporation technique produces an output derived from empirical modeling. The Public Technologies Incorporated Fire Station Location Package uses a street network system to produce its output. Provided the street network data is correct for the given region, the estimates of distance and time will be more accurate if the street network approach is used. Both techniques produce satisfactory results. In this author's research it was found that both fire station location packages are no longer being marketed. Public Technologies

Incorporated is evaluating the marketability of an updated version of the Fire Station Location Package that will take advantage of current computing power and graphics capabilities. It was stated that it would be based on the proven algorithms of the past product and would use an enhanced graphic user interface (C. Kahan, personal communication, October 20, 1999).

It is important to understand that the outcomes of different policies are statistically based estimations: not absolute answers. Deployment and coverage policies are more likely to produce the desired result if good judgement and experience are combined with detailed information about the results that each policy decision will have.

The empirical formulas produced usable information. The addition of historic emergency response data in Appendix D: Map Section Tables, helped to validate the results produced by these formulas in the limited Fire Station 1 district analysis. Using these techniques to determine the coverage of a fire company district and the manpower deployment configuration is very time intensive. The use of software to assist with the calculation and presentation of information is imperative if the analysis is to be accomplished on a regular basis. In order to produce a thorough station location and deployment analysis on an ongoing basis it would be very cost effective to purchase an analysis software package specifically designed for this purpose.

Appendix E shows how Thiessen polygons can be used to set boundaries by geographic areas of influence. In this map a point represents each of the City of West Covina Fire Stations. Each of the Thiessen polygons were calculated

from these points. These polygons coincidentally approximate the boundaries of each first-due response district. Fire Station 1 first-due district streets are shown.

Appendix F is a representation of West Covina Fire Station 1 first-due response district. Fire Station 1 was used as the center point for the circles and diamonds. Distances are drawn at 1.0 mile, 1.5 miles and 2.0 miles for the circles and diamonds. These distances correspond with the NFPA and ISO recommendations. The area within the boundaries of each diamond is approximately 32% of the corresponding circle.

Appendix G shows the distribution of fire and EMS responses in Fire Station 1 first-due response district. The distribution of fire and EMS responses that took over 5-minutes is also shown.

The distribution of commercial occupancies in Fire Station 1 first-due response district is shown by hazard rating in Appendix H. Using the geocoded addresses of these occupancies and presenting them on street segments produces a more concise representation of the distribution. More information can be interpreted in this fashion than by generalizing all map sections by the dominant hazard.

The work product of the empirical formula methodology took hours to create. In a demonstration of GIS products at ESRI, the Public Safety Marketing Manager established that in a matter of minutes, software designed for this purpose could produce a graphic presentation with accompanying statistics (R. Johnson, personal communication, October 20, 1999). The presentation demonstrated that graphic output combined with lists and tables are superior

over tabular data alone. Also the results are more accurate using a street network methodology.

Although manual techniques for the determination of fire station site locations and coverage analysis have proven themselves useful, technology is rapidly making the use of these empirical formulas applicable for only the most general of situations. The introduction of computers, sophisticated databases and modeling software has produced a pace of change unlike anything before (Hall, J. R., Jr. and Cote, A. E., 1997). The use of estimations and assumptions are becoming limited with the ability to collect or purchase substantial amounts of data from numerous sources. The automation of fire record and reporting systems is now common place. Computer storage and manipulation of data is rapidly becoming the standard in every business, including the fire service. The ability to rapidly reevaluate the deployment of resources is a necessity within a progressive fire department. An accurate analysis of changes in staffing and an understanding of the impact on currently offered services are required for the long-term success of any coverage policy.

Optimization of scheduling, coverage and response capability has always been necessary. Now through the use of computers and available data this capability has achieved a new level of detail not attainable in the past without an enormous investment of time and money. The pace of change and the demands for cost-effectiveness are increasing. It is imperative that the fire service utilizes current technology and techniques to provide the most efficient and effective service available. Furthermore, the knowledge and skills necessary to

understand and apply information system tools must be promoted and encouraged throughout the fire service.

RECOMMENDATIONS

Based upon this research, the following recommendations are made.

1. The City of West Covina Fire Department should adopt a standard operating procedure to reevaluate deployment and coverage for fire response districts on a regular basis. A reevaluation should occur prior to major construction projects and prior to the implementation of any new fire department services or programs that may effect deployment.
2. City of West Covina Fire Department should budget for the purchase of software to accurately evaluate the impact to deployment and coverage capabilities that any proposed fire station site, manpower changes, or additional apparatus will have. By utilizing advanced GIS features such as grid analysis and network analysis delivery of service can be optimized.
3. Provide a more complete study utilizing statistics and graphics available in software packages before final determination of a site for Fire Station 1 is made. This will dramatically reduce the time required for a comprehensive departmental study. The use of graphic output from current fire analysis software will also provide a means to present the information in a more understandable visual format.

4. The initial investment in software and training is an obstacle to implementation. The possibility of providing this type of analysis to other local fire departments of similar size to cover the investment for software and data should be investigated.

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APPENDIX A

DRAFT

Deployment Evaluation Procedure

Purpose:

To provide for the evaluation of fire station locations, proposed location changes of personnel and equipment whether caused by scheduling, assigned out-of-district activities, or permanent relocation. The results of the evaluation will be measured against the current response time and deployment standards of the West Covina Fire Department.

Policy:

It is the policy of the West Covina Fire Department to respond quickly, efficiently and safely to all emergency incidents. Recognizing a rapid response is essential to the protection of life and property the West Covina Fire Department has adopted a standard that the first-due engine company will arrive at scene in less than 4.5 minutes 90% of the time. This standard applies to both emergency medical responses and fire related calls.

This procedure provides specific information to be used in the evaluation of response capabilities as they relate to time and distance. Engine company and ladder company response capabilities are not synonymous and are not judged by the same response criteria.

Principles:

The proper distribution of fire companies and personnel is a major factor in efficient and economical fire protection. Furthermore the location of resources are based on the theory that a rapid response is essential in the protection of life and property.

The NFPA Standard 1201, The State of California Emergency Medical Services Authority Standards and Guidelines #101, and the West Covina Fire Department Standard Operating Procedures Manual 210.01 cover these principles.

Procedure:

The West Covina Fire Department has made a commitment to use the most effective means to determine fire company and personnel effectiveness as well as efficiency. The current process requires time and distance calculations.

The following enumerated items are required:

1. Specify the general strategy of deployment; equal coverage or minimum-travel time coverage. The strategy used by the West Covina Fire Department is equal coverage. If on a temporary basis additional companies are being put into service, or special hazards are designated a minimum travel time coverage may be desired.
2. Specify response time criteria. Calculate distances to the geographic center of each map section. Approximating travel distance within the city will be accomplished by using the straight-line method. An empirically determined constant that scales the Euclidean distance will be used to produce an adjusted distance. This adjustment takes into account the geographic obstacles, such as a hill, that a roadway would go around or over. The constant $k = 1.15$ shall be used produce distance approximations.

$$d_{ij} = k \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

If the straight-line distance between points is known, the adjusted distance is the product of the straight-line distance and 1.15.

Time approximation calculations shall be made using the following empirical formulas:

$$E(T_{ij}) = 2.10 \sqrt{D_{ij}} \quad \text{if } D_{ij} \leq 0.38 \text{ miles}$$

or

$$E(T_{ij}) = 0.65 + 1.70D_{ij} \quad \text{if } D_{ij} \geq 0.38 \text{ miles}$$

T_{ij} is measured in minutes and D_{ij} is measured in miles. This equation does not provide an exact estimate of the travel time for every response but instead represents the typical response.

3. Specify hazard zone rating criteria if using minimum travel time deployment. The rating should be assigned to the appropriate Fire Demand Zone (FDZ). The following general guidelines may be used, but professional experience, special background knowledge and good judgement are essential in the final determination of the ratings.

High Hazard Occupancies	Schools, hospitals, nursing homes, explosives plants, refineries, high rise buildings, and other high life hazard or large fire potential occupancies
Medium Hazard Occupancies	Apartments, offices, mercantile and industrial occupancies not normally requiring extensive rescue or fire fighting forces.
Low Hazard Occupancies	One, two or three family dwellings and scattered small businesses and industrial occupancies

4. Specify the number of fire stations and equipment housed in each station.
5. Determine demand for protection and hazard zone ratings if using minimum travel time deployment.
6. For standardization purposes the predefined map section boundaries used by the West Covina Fire Department should be used to develop a grid system of fire protection areas if possible. This grid system can be used for frequency calculations or Fire Demand Zone (FDZ) rating.
7. Determine unit workload. Workload shall be stated as a percentage of 10,000 emergency responses per year. This provides for the comparisons of workloads between fire companies. This also will provide an indication of the increase of alarms per fire company, per year. The figure 10,000 is an arbitrary number larger than the current number of emergency responses experienced per year.
8. Availability will be stated as percentage of 525,600. The total number of minutes in the previous 365 days that a company has been unavailable due to alarms or other causes will be used for this calculation. This value will reflect time the unit was unavailable. This value is subtracted from 1.0 to depict the available time.

9. Three years of emergency response information, broken down by category, if using in-house data to quantify effectiveness and efficiency of current coverage. The results shall be compared to the appropriate response time standard. The results of the comparison will be stated as PASSED or FAILED.
10. For the determination of map section assignments along first-due engine company boundaries, workload and availability factors will be considered.

Failure to meet defined standards will warrant further investigation.

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APPENDIX B

Fire Growth Curve and Response Sequence Chart

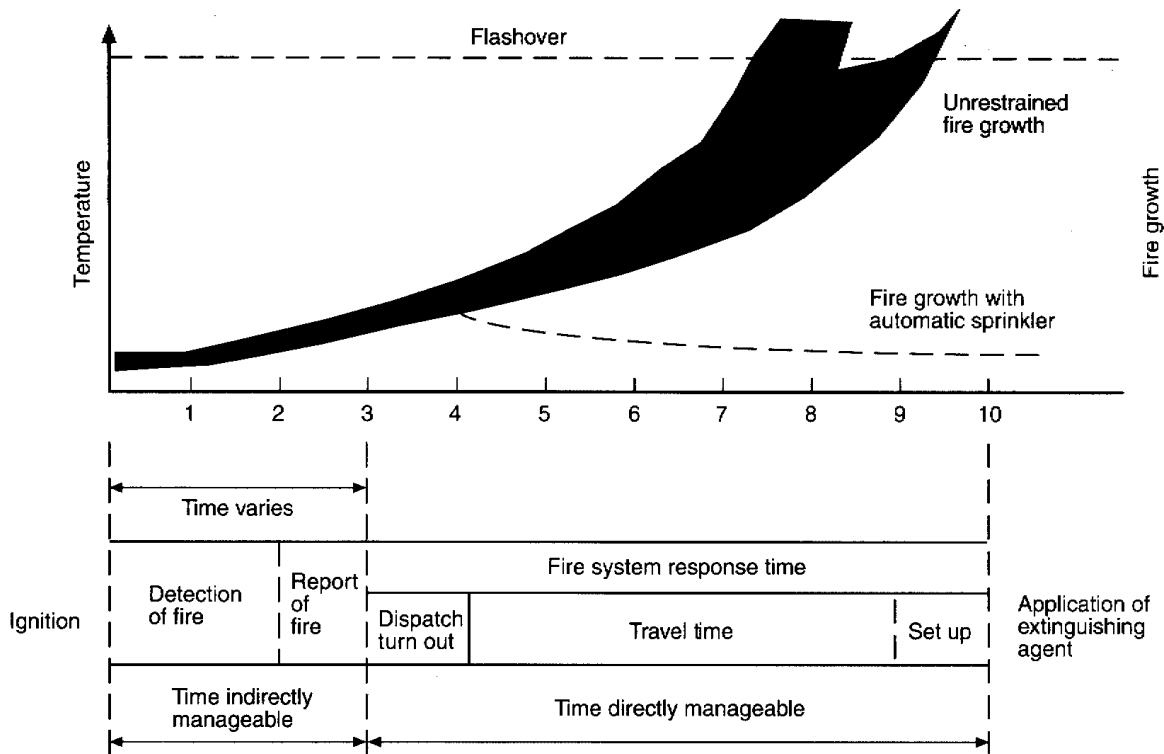


Figure B-1: Fire Growth Curve and Response Sequence Chart (Barr, R. C., & Caputo, A. P., 1997, Pg. 10-251).

APPENDIX C

The State of California Emergency Medical Services Authority (EMSA)

EMS System Standards and Guidelines Section 4.05

Each local EMS agency shall develop response time standards for medical responses. These standards shall take into account the total time from receipt of the call at the primary public safety answering point (PSAP) to arrival of the responding unit at the scene, including all dispatch intervals and driving time. Emergency medical service areas (response zones) shall be designated so that, for ninety percent of emergent responses,:

- a. the response time for a basic life support and CPR capable first responder does not exceed:
 - Metro/urban-5 minutes
 - Suburban/rural-15 minutes
 - Wilderness as quickly as possible
- b. the response time for an early defibrillation-capable responder does not exceed:
 - Metro/urban - 5 minutes
 - Suburban/rural - as quickly as possible
 - Wilderness - as quickly as possible
- c. the response time for an advanced life support capable responder (not functioning as the first responder) does not exceed:
 - Metro/urban - 8 minutes

Suburban/rural -20 minutes

Wilderness - as quickly as possible

- d. the response time for an EMS transportation unit (not functioning as the first responder) does not exceed:

Metro/urban - 8 minutes

Suburban/rural - 20 minutes

Wilderness - as quickly as possible.

APPENDIX D

Map Section Tables

SL-DIST = Straight line distance measurement.

ADJ-DIST = Adjusted distance using constant of 1.15.

CALC-T = Calculated time.

AVG-T = Average time using actual fire and EMS response data.

RESULT = PASS where CALC-T is less than or equal to 4.5 minutes.

MAP 111

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.30	0.3	1.15	1.30	PASS
STATION-2	2.80	3.3	6.20		FAIL
STATION-3	1.00	1.2	2.68		PASS
STATION-4	2.50	2.9	5.60		FAIL
STATION-5	3.80	4.4	8.10		FAIL

MAP 112

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.73	0.8	2.08	1.73	PASS
STATION-2	2.19	2.5	4.93		FAIL
STATION-3	1.17	1.3	2.94		PASS
STATION-4	2.46	2.8	5.46		FAIL
STATION-5	3.75	4.3	7.98		FAIL

MAP 113

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.40	0.5	1.43	1.73	PASS
STATION-2	2.70	3.1	5.93		FAIL
STATION-3	0.80	0.9	2.21		PASS
STATION-4	2.50	2.9	5.54		FAIL
STATION-5	3.90	4.5	8.27		FAIL

MAP 114

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.20	0.2	1.01	1.67	PASS
STATION-2	2.88	3.3	6.28		FAIL
STATION-3	1.41	1.6	3.41		PASS
STATION-4	2.32	2.7	5.19		FAIL
STATION-5	3.60	4.1	7.69		FAIL

MAP 116

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.62	0.7	1.86	2.13	PASS
STATION-2	3.15	3.6	6.81		FAIL
STATION-3	1.74	2.0	4.05		PASS
STATION-4	2.51	2.9	5.56		FAIL
STATION-5	3.60	4.1	7.69		FAIL

MAP 118

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.86	1.0	2.33	2.66	PASS
STATION-2	3.43	3.9	7.36		FAIL
STATION-3	1.94	2.2	4.44		PASS
STATION-4	2.68	3.1	5.89		FAIL
STATION-5	3.71	4.3	7.90		FAIL

MAP 121

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.22	0.3	1.06	1.37	PASS
STATION-2	2.49	2.9	5.52		FAIL
STATION-3	1.11	1.3	2.82		PASS
STATION-4	2.14	2.5	4.83		FAIL
STATION-5	3.50	4.0	7.49		FAIL

MAP 122

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.31	0.4	1.25	1.35	PASS
STATION-2	2.64	3.0	5.81		FAIL
STATION-3	1.43	1.6	3.45		PASS
STATION-4	2.08	2.4	4.72		FAIL
STATION-5	3.32	3.8	7.14		FAIL

MAP 123

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.40	0.5	1.43	2.27	PASS
STATION-2	2.32	2.7	5.19		FAIL
STATION-3	1.03	1.2	2.66		PASS
STATION-4	2.08	2.4	4.72		FAIL
STATION-5	3.32	3.8	7.14		FAIL

MAP 124

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.41	0.5	1.45	1.64	PASS
STATION-2	2.73	3.1	5.99		FAIL
STATION-3	1.58	1.8	3.74		PASS
STATION-4	2.11	2.4	4.78		FAIL
STATION-5	3.30	3.8	7.10		FAIL

MAP 125

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.72	0.8	2.06	1.68	PASS
STATION-2	2.13	2.4	4.81		FAIL
STATION-3	0.86	1.0	2.33		PASS
STATION-4	2.10	2.4	4.76		FAIL
STATION-5	3.55	4.1	7.59		FAIL

MAP 126

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.68	0.8	1.98	1.93	PASS
STATION-2	2.96	3.4	6.44		FAIL
STATION-3	1.85	2.1	4.27		PASS
STATION-4	2.18	2.5	4.91		FAIL
STATION-5	3.30	3.8	7.10		FAIL

MAP 128

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.92	1.1	2.45	2.96	PASS
STATION-2	3.16	3.6	6.83		FAIL
STATION-3	2.09	2.4	4.74		FAIL
STATION-4	2.29	2.6	5.13		FAIL
STATION-5	3.25	3.7	7.00		FAIL

MAP 131

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.49	0.6	1.61	1.83	PASS
STATION-2	3.05	3.5	6.61		FAIL
STATION-3	0.94	1.1	2.49		PASS
STATION-4	2.77	3.2	6.07		FAIL
STATION-5	4.11	4.7	8.69		FAIL

MAP 132

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.46	0.5	1.55	2.02	PASS
STATION-2	3.13	3.6	6.77		FAIL
STATION-3	1.15	1.3	2.90		PASS
STATION-4	2.75	3.2	6.03		FAIL
STATION-5	4.08	4.7	8.63		FAIL

MAP 134

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.61	0.7	1.84	2.84	PASS
STATION-2	3.33	3.8	7.16		FAIL
STATION-3	1.36	1.6	3.31		PASS
STATION-4	2.89	3.3	6.30		FAIL
STATION-5	4.10	4.7	8.67		FAIL

MAP 136

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.68	0.8	1.98	2.76	PASS
STATION-2	3.42	3.9	7.34		FAIL
STATION-3	1.55	1.8	3.68		PASS
STATION-4	2.89	3.3	6.30		FAIL
STATION-5	4.05	4.7	8.57		FAIL

MAP 138

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.95	1.1	2.51	3.53	PASS
STATION-2	3.65	4.2	7.79		FAIL
STATION-3	1.88	2.2	4.33		PASS
STATION-4	2.99	3.4	6.50		FAIL
STATION-5	4.03	4.6	8.53		FAIL

MAP 141

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-11	0.50	0.6	1.63	1.85	PASS
STATION-2	2.31	2.7	5.17		FAIL
STATION-3	1.42	1.6	3.43		PASS
STATION-4	1.80	2.1	4.17		PASS
STATION-5	3.12	3.6	6.75		FAIL

MAP 142

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.58	0.7	1.78	1.67	PASS
STATION-2	2.34	2.7	5.22		FAIL
STATION-3	1.56	1.8	3.70		PASS
STATION-4	1.75	2.0	4.07		PASS
STATION-5	3.03	3.5	6.57		FAIL

MAP 143

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.63	0.7	1.88	2.26	PASS
STATION-2	2.10	2.4	4.76		FAIL
STATION-3	1.22	1.4	3.04		PASS
STATION-4	1.81	2.1	4.19		PASS
STATION-5	3.23	3.7	6.96		FAIL

MAP 144

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.65	0.7	1.92	2.81	PASS
STATION-2	2.61	3.0	5.75		FAIL
STATION-3	1.76	2.0	4.09		PASS
STATION-4	1.86	2.1	4.29		PASS
STATION-5	3.02	3.5	6.55		FAIL

MAP 145

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.86	1.0	2.33	2.60	PASS
STATION-2	1.94	2.2	4.44		PASS
STATION-3	1.02	1.2	2.64		PASS
STATION-4	1.91	2.2	4.38		PASS
STATION-5	3.40	3.9	7.30		FAIL

MAP 146

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-11	0.82	0.9	2.25	2.70	PASS
STATION-2	2.81	3.2	6.14		FAIL
STATION-3	1.97	2.3	4.50		FAIL
STATION-4	1.98	2.3	4.52		FAIL
STATION-5	3.03	3.5	6.57		FAIL

MAP 147

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.12	1.3	2.84	3.05	PASS
STATION-2	1.70	2.0	3.97		PASS
STATION-3	1.14	1.3	2.88		PASS
STATION-4	1.80	2.1	4.17		PASS
STATION-5	3.33	3.8	7.16		FAIL

MAP 148

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.99	1.1	2.59	3.00	PASS
STATION-2	2.92	3.4	6.36		FAIL
STATION-3	2.15	2.5	4.85		FAIL
STATION-4	1.99	2.3	4.54		FAIL
STATION-5	2.95	3.4	6.42		FAIL

MAP 154

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.82	0.9	2.25	2.85	PASS
STATION-2	3.52	4.0	7.53		FAIL
STATION-3	1.42	1.6	3.43		PASS
STATION-4	3.08	3.5	6.67		FAIL
STATION-5	4.31	5.0	9.08		FAIL

MAP 156

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.00	1.2	2.61	3.34	PASS
STATION-2	3.73	4.3	7.94		FAIL
STATION-3	1.69	1.9	3.95		PASS
STATION-4	3.21	3.7	6.93		FAIL
STATION-5	4.35	5.0	9.15		FAIL

MAP 158

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.15	1.3	2.90	4.21	PASS
STATION-2	3.87	4.5	8.22		FAIL
STATION-3	1.90	2.2	4.36		PASS
STATION-4	3.28	3.8	7.06		FAIL
STATION-5	4.36	5.0	9.17		FAIL

MAP 161

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.82	0.9	2.25	2.65	PASS
STATION-2	1.95	2.2	4.46		PASS
STATION-3	1.49	1.7	3.56		PASS
STATION-4	1.53	1.8	3.64		PASS
STATION-5	2.94	3.4	6.40		FAIL

MAP 162

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.82	0.9	2.25	2.68	PASS
STATION-2	2.12	2.4	4.79		FAIL
STATION-3	1.68	1.9	3.93		PASS
STATION-4	1.48	1.7	3.54		PASS
STATION-5	2.82	3.2	6.16		FAIL

MAP 163

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.86	1.0	2.33	2.81	PASS
STATION-2	1.87	2.2	4.31		PASS
STATION-3	1.27	1.5	3.13		PASS
STATION-4	1.68	1.9	3.93		PASS
STATION-5	3.14	3.6	6.79		FAIL

MAP 164

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.83	1.0	2.27	2.78	PASS
STATION-2	2.47	2.8	5.48		FAIL
STATION-3	1.91	2.2	4.38		PASS
STATION-4	1.66	1.9	3.90		PASS
STATION-5	2.81	3.2	6.14		FAIL

MAP 184

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.01	1.2	2.62	3.70	PASS
STATION-2	2.12	2.4	4.79		FAIL
STATION-3	1.93	2.2	4.42		PASS
STATION-4	1.35	1.6	3.29		PASS
STATION-5	2.60	3.0	5.73		FAIL

MAP 336

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.57	0.7	1.76	2.59	PASS
STATION-2	3.08	3.5	6.67		FAIL
STATION-3	0.89	1.0	2.39		PASS
STATION-4	2.84	3.3	6.20		FAIL
STATION-5	4.17	4.8	8.80		FAIL

MAP 354

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	0.82	0.9	2.25	3.50	PASS
STATION-2	3.38	3.9	7.26		FAIL
STATION-3	1.03	1.2	2.66		PASS
STATION-4	3.13	3.6	6.77		FAIL
STATION-5	4.44	5.1	9.33		FAIL

MAP 356

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.61	1.9	3.80	3.38	PASS
STATION-2	3.52	4.0	7.53		FAIL
STATION-3	0.80	0.9	2.21		PASS
STATION-4	3.68	4.2	7.84		FAIL
STATION-5	5.13	5.9	10.68		FAIL

MAP 431

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.24	1.4	3.07	3.52	PASS
STATION-2	1.56	1.8	3.70		PASS
STATION-3	1.23	1.4	3.05		PASS
STATION-4	1.75	2.0	4.07		PASS
STATION-5	3.30	3.8	7.10		FAIL

MAP 432

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.22	1.4	3.04	3.52	PASS
STATION-2	1.55	1.8	3.68		PASS
STATION-3	1.32	1.5	3.23		PASS
STATION-4	1.63	1.9	3.84		PASS
STATION-5	3.17	3.6	6.85		FAIL

MAP 434

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.17	1.3	2.94	3.27	PASS
STATION-2	1.56	1.8	3.70		PASS
STATION-3	1.60	1.8	3.78		PASS
STATION-4	1.31	1.5	3.21		PASS
STATION-5	2.81	3.2	6.14		FAIL

MAP 436

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.26	1.4	3.11	3.14	PASS
STATION-2	1.58	1.8	3.74		PASS
STATION-3	1.83	2.1	4.23		PASS
STATION-4	1.12	1.3	2.84		PASS
STATION-5	2.60	3.0	5.73		FAIL

MAP 637

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.39	1.6	3.37	4.00	PASS
STATION-2	2.32	2.7	5.19		FAIL
STATION-3	2.39	2.7	5.32		FAIL
STATION-4	1.20	1.4	3.00		PASS
STATION-5	2.22	2.6	4.99		FAIL

MAP 639

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.21	1.4	3.03	3.71	PASS
STATION-2	2.23	2.6	5.07		FAIL
STATION-3	2.16	2.5	4.90		PASS
STATION-4	1.27	1.5	3.20		PASS
STATION-5	2.42	2.8	5.41		FAIL

MAP 711

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.47	1.7	3.52	3.39	PASS
STATION-2	3.68	4.2	7.84		FAIL
STATION-3	2.63	3.0	5.79		FAIL
STATION-4	2.69	3.1	5.91		FAIL
STATION-5	3.41	3.9	7.32		FAIL

MAP 713

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.35	1.6	3.29	3.00	PASS
STATION-2	3.60	4.1	7.69		FAIL
STATION-3	2.47	2.8	5.48		FAIL
STATION-4	2.66	3.1	5.85		FAIL
STATION-5	3.48	4.0	7.45		FAIL

MAP 715

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.04	1.2	2.68	3.03	PASS
STATION-2	3.29	3.8	7.08		FAIL
STATION-3	2.20	2.5	4.95		FAIL
STATION-4	2.38	2.7	5.30		FAIL
STATION-5	3.30	3.8	7.10		FAIL

MAP 725

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.20	1.4	3.00	2.92	PASS
STATION-2	3.22	3.7	6.95		FAIL
STATION-3	2.37	2.7	5.28		FAIL
STATION-4	2.24	2.6	5.03		FAIL
STATION-5	3.09	3.6	6.69		FAIL

MAP 731

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.50	1.7	3.58	4.00	PASS
STATION-2	3.90	4.5	8.27		FAIL
STATION-3	2.60	3.0	5.73		FAIL
STATION-4	2.96	3.4	6.44		FAIL
STATION-5	3.74	4.3	7.96		FAIL

MAP 733

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.32	1.5	3.23	3.13	PASS
STATION-2	3.74	4.3	7.96		FAIL
STATION-3	2.38	2.7	5.30		FAIL
STATION-4	2.85	3.3	6.22		FAIL
STATION-5	3.72	4.3	7.92		FAIL

MAP 735

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.01	1.2	2.62	2.98	PASS
STATION-2	3.44	4.0	7.38		FAIL
STATION-3	2.11	2.4	4.78		FAIL
STATION-4	2.63	3.0	5.79		FAIL
STATION-5	3.57	4.1	7.63		FAIL

MAP 755

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.14	1.3	2.88	3.69	PASS
STATION-2	3.80	4.4	8.08		FAIL
STATION-3	2.10	2.4	4.76		FAIL
STATION-4	3.08	3.5	6.67		FAIL
STATION-5	4.11	4.7	8.69		FAIL

MAP 775

	SL-DIST	ADJ-DIST	CALC-T	AVG-T	RESULT
STATION-1	1.27	1.5	3.13	4.05	PASS
STATION-2	3.97	4.6	8.41		FAIL
STATION-3	2.10	2.4	4.76		FAIL
STATION-4	3.31	3.8	7.12		FAIL
STATION-5	4.34	5.0	9.13		FAIL

APPENDIX E

Thiessen Polygons - All Response Districts

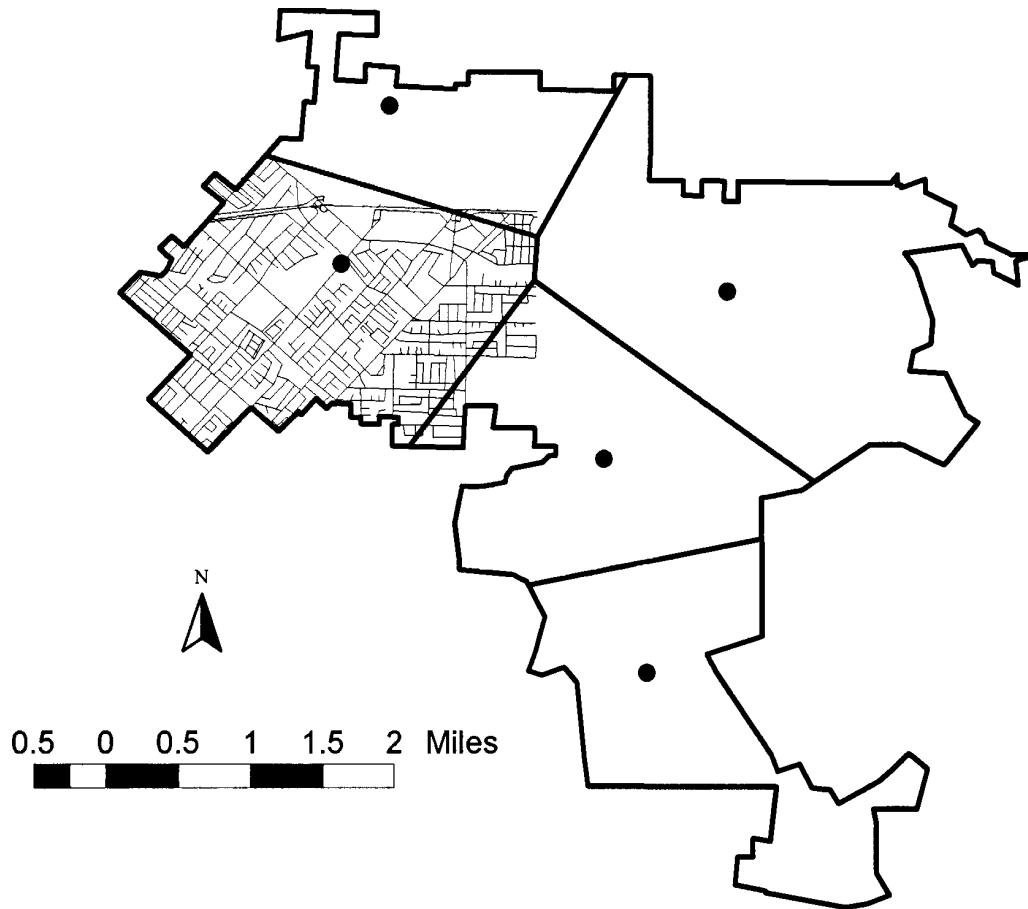


Figure E-1: Thiessen polygons calculated for all City of West Covina Fire Stations. Each station is represented by a point. Fire Station 1 first-due district streets are shown.

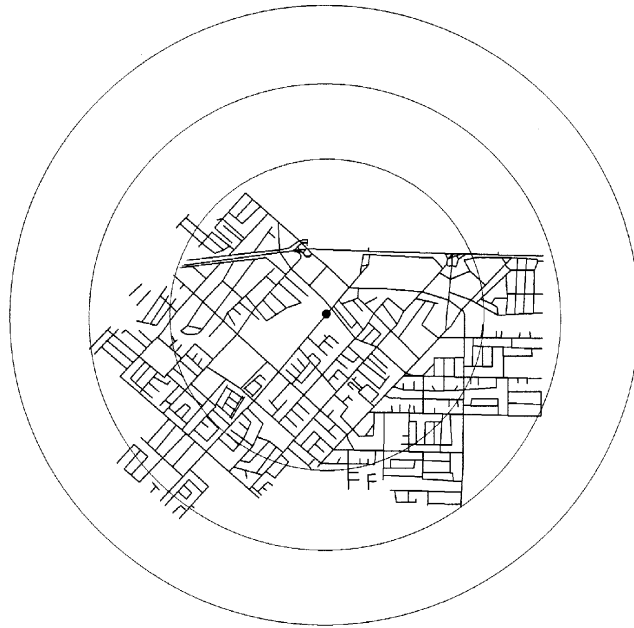
APPENDIX F**Circular and Diamond Shaped Response Areas**

Figure F-1: Circular response area - 2.0-mile, 3.0-mile and 4.0-mile diameter centered on Fire Station 1.

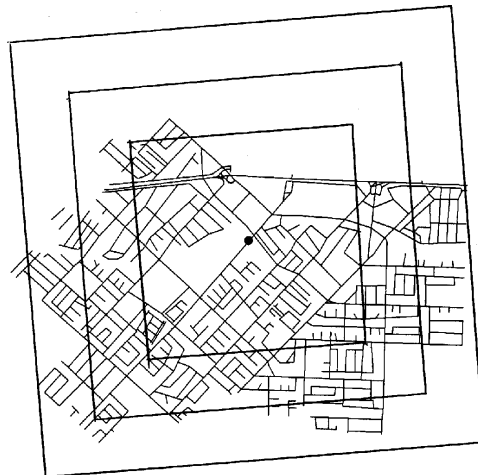


Figure F-2: Diamond response area – 2.0-mile, 3.0-mile and 4.0-mile diameter from corner to corner centered on Fire Station 1.

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