Olathe Fire Department

Fire Station Location and Optimization Report

"We proudly exist to protect and preserve life and property through dynamic emergency response and excellence in training, preparedness and prevention."

Published: May 2014
Acknowledgement

This report was prepared at the request of Fire Chief Jeff DeGraffenreid by Battalion Chief Chuck Ozonoff and Captain Kevin Weyand with the assistance of Fire Analyst Kristine Martin.
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Executive Summary

The Olathe Fire Department exists for the primary purpose of providing dynamic emergency response to the community in their time of need. That response is time-critical, and in order to be effective, must arrive quickly and include the proper resources to mitigate the emergency. It is unequivocal that this is an ardent expectation of the community, and that is the passionate mission of the Olathe Fire Department to make it a reality.

An honest appraisal of the department’s capabilities in this regard is not only necessary, but should be seen as critical to fulfilling its ultimate mission. Therefore, this report itself springs from the expectation of the community that its emergency resources are kept at a constant state of readiness and have the capacity to meet the challenges set before them.

An effective emergency response network can be viewed principally as a time versus distance proposition, where one's proximity to a service delivery point (fire station) may determine the timeliness of critical, lifesaving intervention. Thus, fire apparatus travel time measures, which are fundamental in their relevance, became the underpinning approach for this report.

The City has provided an extensive emergency response network whereby resources are distributed and deployed systematically to provide optimum efficiency and effectiveness. Through careful analysis and based upon sound foundational principles, the City as a whole was viewed through the lens of equitable service delivery, and in so doing, several challenges were exactingly identified.

These challenges came in the form of geographical areas within Olathe that were found to be potentially under-protected due to their distance from the nearest emergency service delivery point. Within this context, current needs were studied by examining risk in terms of vulnerable people, homes, businesses, schools, etc. The higher the risk found in these particular areas of the City, the greater the concern and present need.

In order to take a complete look at community vulnerability, future needs were also studied and identified. Consistent with Olathe’s Comprehensive Plan, PlanOlathe, is the commitment to provide adequate public services to the community and to promote quality of life through well planned and thoughtful future land use and development. To that end, and using the time-tested principle of being prepared and planning for the future, this report establishes future needs that dovetail with the current needs assessment. Future population forecasts and projected development plans were used to determine future risk as well as anticipated increases in demand for emergency services.

The presence of this current and future risk, in areas of the City where credible emergency response coverage is lacking, constituted the findings which led to the recommendations within this report.

A crucial finding of this report is that the area within City limits but outside of the Olathe Fire Department’s credible emergency response coverage consists of 15.13 square miles, which is equal to over 25% of the City's overall land.
mass. While this finding is eye-opening, it is important to note that this model assumes a best-case scenario of coverage, where all resources are available, and awaiting the next emergency call. Of course, the reality is that the system is rarely, if ever, at rest. Units are busy responding to calls and moving about the City on many forms of business, and are not simply standing by, waiting for the next call to come in. This realization applies further emphasis to the needs analysis within this report.

The findings which led to the recommendations within this report have a justifiable focus on risk, in the form of adults and children, and homes and businesses. People and things that make up the heart of the City of Olathe – what really matters. Present and future needs are delineated and several prospective future fire station locations are presented along with compelling reasons for each.

The succinct point made in the recommendations within this report is that moving forward into the future, as these vulnerable areas continue to grow, the problems involving the lack of credible, equitable coverage will only compound with time.
Introduction

The Olathe Fire Department provides dynamic emergency services to the community through an "all-hazards" approach to emergency response. Therefore, the department's deployment strategy must carefully consider risk factors and service demand levels when determining the ideal number and locations of service delivery points in order to achieve the maximum effectiveness against the greatest number and types of risk.

Clearly, a modern analysis of fire station placement and optimization must include factors such as community risk, population growth, anticipated increases in calls for service and other changes in demographics within the community. The goal, of course, is to determine the optimal fire station locations and utilization to respond to emergency service demands within a reasonable time frame.

Dutiful attention to other important considerations beyond the distribution of fire department resources must also be a part of the discussion surrounding the overall safety and welfare of the community. These include elements such as building codes, public education programs, business inspections and pre-planning, fire alarm and notification systems, residential fire sprinklers, firefighter training and development, and so on.

This fire station location and optimization study is grounded in a fact-based analysis of existing conditions and future needs. Current conditions were assessed by studying community risk data such as call loads, population densities and existing home and business vulnerabilities. Future needs were determined through the examination of forecasted call volumes and population densities, and by studying future land use and growth area build-out projections. This comprehensive study should be seen as vital to creating a reliable picture of the credible coverage challenges faced today, as well as those that will be faced in the future.

Background

In 1991, the Olathe Fire Department conducted a Station Location Analysis prepared by Chief Patrick Coughlin and Battalion Chief Michael Penner. This study, which was updated in 1998, took a comprehensive look at deployment in a similar fashion to the way it is done today. It studied present (and future) service demand and community risk in making carefully considered recommendations for future fire station locations and utilisations.

Indeed, the 1991 Station Location Analysis correctly predicted the need for a fire station in the Cedar Creek area (Station 56 opened in 1999 at College Boulevard & Clare Road). The updated 1998 version of the report also identified several areas of need, with one such area being the south-central side of the City (Station 57 opened in 2007 at 161st Street & S. Mur-Len Road). These two studies have been included as appendices to this report.

Recently, two independent, external organizations completed comprehensive analyses of the Olathe Fire Department’s service delivery capabilities. Both organizations, known for their impartiality and neutrality, prepared and issued reports that may be seen as valuable tools for planning, budgeting and justifying fire protection improvements within the community.
In June of 2012, a peer assessment team from the Commission on Fire Accreditation International (CFAI) completed its onsite review and appraisal of the Olathe Fire Department. The 45-page report summarized key findings and made several recommendations for improving upon current facility, fleet and equipment resources. The report recommended that the department continue to refine its understanding of population growth and its impact on the delivery system, both now and in the future, as anticipated new development occurs. It further recommended that the department continue to pursue planned improvements in its service delivery network, particularly as it applies to new fire station construction and related staffing requirements.

In April of 2013, ISO (Insurance Services Organization), acting on behalf of the insurance policyholders within the community, completed its Public Protection Classification (PPC) analysis of the Olathe Fire Department’s delivery system and resources. In part, the 36-page summary report detailed Olathe’s “Fire Department” capacity in terms of equipment, staffing, training and geographic distribution of fire companies. In that specific area, only 68% of the possible total point value was achieved by the department, indicating significant opportunities for improvement in staffing and distribution.

These reports provided the department with a useful community protection baseline to aid in guiding future quality improvements to the Olathe Fire Department’s service delivery network.
Community Expectations

Community values and expectations play a key role in determining deployment objectives that assure citizen and responder safety while enhancing community service in a fiscally responsible way. Clearly, there is a cost associated with a planned level of service delivery. Arguably, a higher cost can be justified when it is offset by better service resulting in enhanced safety for the community.

Olathe’s Comprehensive Plan: PlanOlathe

The Comprehensive Plan, PlanOlathe, embodies the community’s vision by providing a roadmap relative to where and how Olathe will grow, with the understanding that what that growth looks like will affect the long-term quality of life and prosperity of the City.

PlanOlathe’s collective vision of the meaning of Quality of Life clearly states that Olathe is a place that provides quality public services and "values health, safety and well-being of all citizens." Feeling safe and secure within our homes and community is a basic human desire, and to that end, PlanOlathe's Community Services & Facilities Policy CF-3.2 (Fire Protection) provides the goal: "Continue to support fire protection services to ensure preservation of life and property."

One of PlanOlathe’s Guiding Principles (Principle CF-1) requires that new development “be located in areas where adequate public services and facilities presently exist or are planned to be provided.” Current development data and land use build-out projections indicate that in order to be consistent with this PlanOlathe principle, fire protection facilities are needed in the City today, as well as in the future.

Community-Driven Strategic Plan Priorities

In 2011, a facilitated community-driven strategic planning session was held to gather input regarding community service expectations and priorities for the Olathe Fire Department. Community stakeholders ranked “Quick response to emergency calls” as their number one expectation (out of a total of 51). In addition, when asked to prioritize the service delivery areas that the Olathe Fire Department provides, the top five areas identified involve emergency response activities, as shown in the table below:

<table>
<thead>
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<th>Rank</th>
<th>Program (Score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Rescue – Basic and Technical (216)</td>
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<tr>
<td>2.</td>
<td>Emergency Medical Services (213)</td>
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<tr>
<td>3.</td>
<td>Fire Suppression (211)</td>
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<td>4.</td>
<td>Hazardous Materials Mitigation (154)</td>
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<td>5.</td>
<td>Explosive Ordinance Response and Disposal (118)</td>
</tr>
<tr>
<td>6.</td>
<td>Fire Prevention/Life Safety (109)</td>
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<tr>
<td>7.</td>
<td>Fire Investigation (96)</td>
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<tr>
<td>8.</td>
<td>Public Fire/EMS Safety Education (80)</td>
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<tr>
<td>9.</td>
<td>Domestic Preparedness Planning and Response (79)</td>
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<td>10.</td>
<td>City Building Codes (27)</td>
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The Importance of Time

Time is a critical factor during fire and medical emergencies. A preponderance of scientific research conducted in the fields of fire science and emergency medicine has proven that from the moment an emergency transpires, the risk of mortality and property loss increases exponentially with each passing minute. Therefore, in the context of service delivery, time is the enemy, and utmost consideration must be given to the relationship between fire department intervention and public safety. The elapsed time to effective intervention has a direct impact on a fire department’s ability to mitigate both fire and medical emergencies with the highest percentage of positive outcomes.

In the sections to follow, information on the topics of fire propagation, changing fire dynamics and cardiac survivability will be presented to provide a deeper understanding of the importance of time as it directly relates to the delivery of fire department services.

Fire Propagation

Understanding the physics of fire propagation (the spread, growth and behavior of fire) as it directly correlates with time is crucial to providing the highest quality of fire protection and rescue capability to the community. In order to have the best chance of saving lives and minimizing property loss, fire suppression units must be able to arrive on scene of a fire before it reaches a critical point in its developmental stages known as flashover. A flashover is the point in the growth stage of fire at which all of the contents in an entire area simultaneously ignite resulting in conditions that are untenable for firefighters and potential survivors. According to the National Institute of Standards and Technology (NIST) along with the Underwriters Laboratory's Fire and Safety Research Institute (UL-FSRI), depending on the size, structure and contents of a fire room, studies have shown that a flashover can occur anywhere from less than 4 minutes to 10 minutes after ignition.
Fire Dynamics

Over the past decades there has been a very disturbing trend in the American fire service. Fire statistics show that despite a 53% decrease in the annual number of structure fires since the late 1970s, traumatic firefighter deaths (per 100,000 fires) has seen nearly a two-fold increase (Fahy, Rita, F., “U.S. Fire Service Fatalities in Structure Fires, 1977-2009”, NFPA, Quincy, MA., June 2010).

One significant contributing factor to this trend is the lack of understanding of fire behavior in residential structures resulting from the changing dynamics of residential fires. Changes in home size, geometry, contents and construction materials have added complexity to fire behavior, and over the last three decades, have negatively impacted escape times for occupants as well as firefighter safety.

The current building trend is towards larger homes with open floor plans, which are filled with plastics and other synthetic products that possess tremendous heat release rates. This, combined with present-day construction techniques utilizing engineered, light-weight components, has created a markedly different modern fire environment. Fires propagate faster and create more toxic and flammable products of combustion than in the past. This means shorter escape times for occupants, and shorter times to flashover and collapse for firefighters operating within this environment as seen in the UL-FSRI’s new fire formula shown below.
Cardiac Arrest Survivability

As with fire protection, *time* is also a critical factor for the delivery of effective emergency medical services. Life-threatening medical emergencies such as cardiac arrest, respiratory arrest, allergic reactions, trauma, stroke, etc. are extremely time sensitive and require the rapid response and intervention of trained fire/EMS professionals in order for there to be the best chance of survival. As the field of emergency medicine has become increasingly more research-driven and evidence-based, numerous studies have indicated that patients who have suffered from cardiac arrest, trauma, or respiratory arrest must receive emergency medical treatment within four to ten minutes of onset to prevent permanent damage to the brain or even death. The following diagram illustrates this relationship.

With cardiac arrest topping the charts as the leading cause of death in the United States according to the American Heart Association (AHA), it's no wonder why it is one of the most closely studied fields of medicine with regard to timely intervention. Also, various different techniques have evolved over time in order to best take care of a critically ill cardiac patient. Chest compression techniques, defibrillation, medications, airway management and even induced hypothermia have all aided in saving the lives of numerous patients that otherwise would have faced certain death. Although some of these techniques have changed over time, the constant variable to predicting positive outcomes has been the impact of time. Simply put, the faster the arrival of definitive Advance Cardiac Life Support (paramedic) care to a patient in cardiac arrest, the better the chance that the person will live.
Response Time Considerations

It is imperative that fire departments have the capability of delivering their resources within a reasonable timeframe to their communities. A rapid response is the best way to ensure the highest level of public safety. Since fire departments have no control over the amount of time that elapses between the start of an emergency and the activation of 9-1-1, it is critical that they endeavor to strategically manage the time they can control – their response time.

A fire department’s response time begins the moment firefighters are notified of an emergency (dispatched), and ends once they arrive on scene and begin crucial interventions. This timeframe consists of three main components – dispatch time, turnout time, and travel time.

**Dispatch time** is the time interval that begins when an alarm is acknowledged at a dispatching center and ends once firefighters are notified of an emergency.

**Turnout time** is the time interval that begins once firefighters are notified of an emergency and ends once they begin to travel.

**Travel time** is the time interval that begins when a fire unit is en route to an emergency and ends once they arrive on scene (drive time).

Ultimately, each community must decide what timeframes are acceptable and reasonable for their fire department’s response network.

Benchmarking

Many fire departments across the nation have begun benchmarking to help construct the necessary framework for determining reasonable response time parameters. Benchmarking is the practice of using industry standards or the best practices of other organizations as benchmarks to compare performance. These benchmarks function as comparison targets to measure against actual performance. This practice has been widely recognized as a proactive approach for achieving increased levels of service effectiveness within both the private and public sectors. Fire departments that have taken the time to evaluate various aspects of their service delivery and compare them to the best practices of other organizations have been able to gauge whether or not their performance is improving or declining year to year.

A small percentage of fire departments have even taken benchmarking a step further through the achievement of international accreditation. The accreditation process is a comprehensive self-assessment evaluation that promotes organizational and professional excellence through the utilization of well-defined internationally recognized best practice benchmarks. Administered by the Commission on Fire Accreditation (CFAI) through the Center for Public Safety Excellence (CPSE), accreditation utilizes tools such as strategic planning, community risk assessment, and emergency response analysis to assist fire departments in establishing a method to evaluate performance and achieve continuous quality improvements within their service programs. As of November 2013, there were 187 internationally
accredited fire/rescue agencies with the inclusion of the Olathe Fire Department as of 2012.

Performance Objectives and Measures

Within CFAI’s accreditation model, the Olathe Fire Department established response time performance objectives and measures using industry best practices as benchmarks. Specifically, the response time performance to code 1 emergency calls within the City limits were measured to 90th percentile compliance. These performance objectives and measures were outlined for each service delivery program (Fire, EMS, Rescue, and Haz-Mat) and varying levels of risk and population density. A complete view of these benchmark performance objectives and measures along with response time data can be found in their entirety in the department’s Community Risk and Emergency Service Analysis – Standard of Cover (CRESA-SOC) document.

For the purposes of this report, only the response time benchmarks for first due resources (closest fire station) will be used to help establish a methodology for determining the fire department’s network capabilities and limitations. These benchmarks consist of a one minute alarm processing time, a one minute turnout time (one minute and twenty seconds for fire, tech rescue & haz-mat), and a four minute travel time with a 90th percentile compliance. This means that according to industry best practices, the closest fire unit needs to arrive on scene approximately six minutes after being dispatched 90 percent of the time in order to be compliant with their performance objectives and measures.
The following charts illustrate the Department's first due apparatus response time benchmarks for fire suppression, EMS, technical rescue and haz-mat emergencies for Olathe’s most densely populated areas.

<table>
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<tr>
<th>First Due Apparatus Fire Suppression Benchmarks</th>
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<td>Population Density</td>
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<tr>
<td>Metropolitan</td>
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<td>Urban</td>
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<tr>
<th>First Due Apparatus EMS Benchmarks</th>
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<tr>
<td>Population Density</td>
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<td>Metropolitan</td>
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<tr>
<th>First Due Apparatus Technical Rescue Benchmarks</th>
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<tr>
<td>Population Density</td>
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<td>Metropolitan</td>
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<td>Urban</td>
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<tr>
<th>First Due Apparatus Haz-Mat Benchmarks</th>
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<tr>
<td>Population Density</td>
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<td>Metropolitan</td>
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<td>Urban</td>
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Methodology

Thus far, this report has been primarily descriptive in nature, identifying and outlining the underpinning values and quintessential considerations relating to the delivery of fire department services. Moving forward into the analysis portion of this report required the use of an appropriate methodology. Piggybacking on the Department’s performance-based approach to service delivery, a methodology was established based upon best practice benchmarks and travel time performance. This performance-based methodology will be further explained in the next two sections of this report.

First Due Travel Time Performance

Although each component of response time is vitally important to gauge the overall effectiveness and efficiency of service delivery, the best method for determining a fire department’s network capabilities and limitations is through the analysis of each fire station’s geographic position within the city and their respective travel time performance. The reasoning for this is because there is a direct relationship between the amount of time it takes to get to an emergency (travel time), and the proximity of the closest fire station (travel distance). Simply put, the further away a fire station is from an emergency incident, the more likely it will result in unfavorable outcomes and non-compliance with benchmark performance measures.

Understanding this relationship between time and distance and how it impacts the geographic equity and deployment performance of fire department resources was pivotal to establishing a performance methodology based upon the four minute travel time benchmarks of first due apparatus. By utilizing a four minute travel time methodology in this report as a lens for analyzing the current conditions and future needs of the City, the Olathe Fire Department was able to easily identify limitations of their current response network, and make informed planning decisions regarding the future need for additional investment in public safety infrastructure.

GIS-Based Four Minute Travel Time Polygons

Global information systems (GIS) technology played an important role in providing a method for integrating the four minute travel time methodology within different maps throughout the report. GIS technology is the process of displaying geographic data as different map layers. Being able to overlay different map layers greatly assisted in the analysis of the Olathe Fire Department’s response network. By utilizing fire station location data, street data (road type, actual speed limits, etc) and time data, a map could be created providing a visual representation of how effective each fire station would be in relation to time.

Utilizing four minute travel time data, resulted in a map displaying irregular shaped polygons around each fire station. These polygons represent where a fire apparatus could travel in any direction within four minutes. However, they do not factor in possible real-time delays due to traffic, weather conditions, etc Therefore, they should be seen as best-case scenarios, with actual performance being less effective than shown. The map below illustrates GIS-based four minute travel time polygons for each of Olathe’s seven fire stations represented by different colors.
On any given day of the year, the Olathe Fire Department’s (OFD) current response network consists of a minimum of 28 firefighters on duty 24 hours a day. Depending on the scale of the emergency, firefighters respond from one or more of the seven strategically located fire stations throughout the City. Below, is a table illustrating OFD’s current response network in terms of fire station locations, frontline apparatus locations and daily minimum staffing.

<table>
<thead>
<tr>
<th>Opened</th>
<th>Station Location</th>
<th>Frontline Apparatus</th>
<th>Daily Minimum Staffing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>Station #1 501 E. Old 56 HWY</td>
<td>Engine 51, Rescue 51, Truck 51, BC 51</td>
<td>3 Firefighters, 4 Firefighters, 0 Firefighters, 1 Firefighter</td>
</tr>
<tr>
<td>1989</td>
<td>Station #2 1725 N. Renner</td>
<td>Truck 52, BC 52</td>
<td>4 Firefighters, 1 Firefighter</td>
</tr>
<tr>
<td>1989</td>
<td>Station #3 14940 W. 143rd</td>
<td>Quint 53</td>
<td>3 Firefighters</td>
</tr>
<tr>
<td>1971*</td>
<td>Station #4 13301 S. Mur-Len</td>
<td>Engine 54</td>
<td>3 Firefighters</td>
</tr>
<tr>
<td>1992</td>
<td>Station #5 1128 W. Spruce</td>
<td>Engine 55</td>
<td>3 Firefighters</td>
</tr>
<tr>
<td>1999</td>
<td>Station #6 24200 W. College</td>
<td>Quint 56</td>
<td>3 Firefighters</td>
</tr>
<tr>
<td>2007</td>
<td>Station #7 16110 S. Mur-Len</td>
<td>Engine 57</td>
<td>3 Firefighters (28 Total)</td>
</tr>
</tbody>
</table>

*Originally station #2, re-opened as station #4

To better understand the overall effectiveness, efficiency and equity of the OFD’s response network, it must be analyzed in terms of the distribution, concentration and reliability of fire department resources within identified geographical planning areas throughout the City. These concepts will be further described in the sections to follow.

**Distribution**

Distribution is a term used to describe the geographic location of first arriving resources (e.g. fire stations, apparatus, and personnel) for an all-hazard and all-risk initial intervention. Basically, it describes the number of fire stations placed throughout neighborhoods and/or districts within the community.

The geographic positioning of these first arriving resources is critical in order to effectively meet the service demand throughout the City. Ideally, an optimized distribution network is able to deliver an equitable level of service to the community, while at the same time allowing each fire station to carry an equal amount of workload.
Currently, the OFD distributes resources from seven strategically located fire stations throughout the City of Olathe. Within this distribution network, one square mile geographic planning grids called emergency service zones (ESZs) are used to examine risk factors and help measure performance in each fire station’s response areas.

The geographic positioning of all seven fire stations within their respective ESZs is shown in the map below.

Concentration

Although the distribution of first due resources is vitally important for the successful mitigation of a large percentage of low risk fire and medical emergencies, the concentration of additional resources is equally if not more important due to the fact that higher risk emergencies (e.g. structure fires, technical rescues and haz-mat incidents) require a greater number of firefighters performing critical tasks in order to control the incident and
prevent its further escalation. Simply put, concentration implies that there are emergencies that will require resources beyond the capabilities of the closest first due fire station. Therefore, it is crucial that the concentration of fire department resources be arranged close enough in proximity with each other so that an effective response force (ERF) can be assembled to complete critical tasks at higher risk incidents. This means there is benefit to having overlapping coverage between fire stations.

Below is an example of the number of firefighters necessary to complete critical tasks at a structure fire.

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<thead>
<tr>
<th>Critical Tasks</th>
<th>Number of Firefighters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Command / Safety</td>
<td>1</td>
</tr>
<tr>
<td>Attack Line</td>
<td>2</td>
</tr>
<tr>
<td>Pump Operations</td>
<td>1</td>
</tr>
<tr>
<td>Back Up Line</td>
<td>2</td>
</tr>
<tr>
<td>Rapid Intervention</td>
<td>2</td>
</tr>
<tr>
<td>Search and Rescue</td>
<td>2</td>
</tr>
<tr>
<td>Ventilation</td>
<td>2</td>
</tr>
<tr>
<td>Water Supply</td>
<td>1</td>
</tr>
<tr>
<td>Utilities / Exposure Protection</td>
<td>2</td>
</tr>
<tr>
<td>Other / Aerial Operations</td>
<td>2</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>17</strong></td>
</tr>
</tbody>
</table>

**Reliability**

The reliability (dependability) of fire department resources is also an important part of the response network. Even though resources may be perfectly distributed and concentrated throughout the community, they must ultimately be reliable when called upon for an emergency. The reliability of a response network must be viewed in three ways:

1. The distribution and concentration of resources
2. The availability of resources
3. The performance of resources

The OFD's distribution network functions both statically and dynamically depending on the location of resources. If first due resources are in their respective fire stations, they are considered statically reliable. However, fire units are mobile at times (returning from calls, training, conducting business inspections, etc.) and frequently located outside their first due response areas causing potential unreliability. Still, if the next closest fire unit is able to respond to the emergency during these times, then ultimately the response network is still reliable. This is another reason why the proximity of additional resources is an important consideration.
Another factor affecting the reliability of resources is the availability of those resources. If fire units are unavailable to respond to an emergency due to high service demand in their response areas, then there is the potential for them to be unreliable when needed. This is one reason why it may be advantageous to co-locate resources within the distribution network.

Co-locating resources means placing additional fire units and personnel at an existing fire station to help alleviate workload and decrease unreliability. These resources could range from a fully staffed engine company to a 2-man squad company, each providing a distinctly different benefit to the response network based on their apparatus capabilities and staffing. For example, co-locating a fully staffed engine company in a high service demand area has the potential to greatly improve distribution reliability to all call types regardless of risk level, while at the same time helping provide a quicker concentration of resources to higher risk emergencies such as structure fires. On the other hand, a co-located 2-man squad company is limited by its apparatus capabilities and staffing, and thus mainly utilized for responding to low-risk fire/EMS calls. Additionally, a squad can help alleviate heavy workloads during high demand situations related to special events and severe weather so that frontline fully staffed units can be kept available for higher risk emergencies such as rescues and fires.

In either case, by having more resources available at one location, the chances for distribution and concentration unreliability decrease dramatically. The only caveat to co-locating resources is that even though it may help with distribution, concentration and availability in high service demand areas, it may not solve the issue of performance reliability if there are locations within the response area unable to be reached within established best practice benchmarks.

Performance reliability speaks to whether or not fire department resources are able to arrive on scene of an emergency within specified response time performance parameters (i.e. best practice benchmarks). It makes no difference whether or not more resources are added to the current distribution network if they too are unable to be reliable in their performance. This is another reason why the methodology of using the four minute travel time of first due resources is so important – because it paints the best overall picture of a fire department's response network in terms of the capabilities and limitations of the distribution, concentration and reliability of their resources.

In the end, there must be three things working in harmony to have an effective, efficient and equitable response network – the right amount of evenly distributed and concentrated resources that have the ability to respond when needed, and are able to arrive within predetermined best practice benchmarks.
Demographic Changes Impacting Service Delivery

In June of 2007, the Olathe Fire Department’s distribution network was augmented with the opening of Fire Station #57 at 16110 S. Mur-Len Road. Since then, there have been no significant upgrades to the City’s network of fire stations; however, much has changed with regard to community demographics and the demand for emergency services.

Population Growth

Population density is considered a unique risk factor in the prediction of emergency service demands. As a rule, greater population densities equate to greater call volume, which in turn requires more resources to achieve a credible level of service.

In general, the population of Johnson County, Kansas grew by 223,910 people from 1980 to 2010. More specifically, Olathe’s population increased from 92,962 in 2000 to 125,872 in 2010, for an increase of 32,910 or 35.4%. This data indicates that Olathe was the fastest growing city in the state of Kansas in absolute numbers during this time period. In comparison, the United States and Kansas saw a 9.7% and a 6.1% increase in population since 2000, respectively.

Nationally, Olathe was twice ranked as one of the 25 fastest growing cities above 100,000 from 2000 to 2010 by the United States Census Bureau. (In 2002, Olathe was ranked 8th nationally, and in 2007 the ranking was 24th). In terms of the greater Kansas City (metro) area, Olathe had the largest growth both in terms of total population added, as well as in percentage of growth.

Population estimates provided by the City’s Developmental Services Department show that between 2007 and 2013, Olathe’s population has grown by 6,691 (5.4%), from 123,364 to 130,055. This means that the City has added an average of 1,115 people per year, which is a sizable increase comparatively with other cities in the area. In addition, Olathe now ranks as
the fourth largest city in Kansas, behind only Wichita, Overland Park and Kansas City (KS).

The charts below illustrate the area’s steady population increase through the use of live birth data from the last 30 years. Of particular interest is fact that three of the four greatest years for live births since 1965 have occurred in 2006-2008.
Live birth data, showing Olathe as well as their neighbors, clearly illustrates the steady, upward trend of live births in three of the area’s largest cities.

When looking at the Olathe Public Schools’ upward trend in kindergarten enrollment history, the correlation with population growth is plainly evident.
Finally, without question, migration to Olathe due to its desirability as a community has also contributed to its compelling population growth. Such factors as the cost-of-living index, unemployment rate, crime rate and school quality contribute to a city’s desirability as a place to live. Olathe continues to score well in all these facets, and in fact was recently ranked as one of the ten best midsize cities in America to move to by the real estate website Movoto.

Population Shift: Age

The estimated median age in Olathe increased approximately 9.4% since 2000, indicating that the City’s population is growing older. Recent figures from the US Census Bureau’s American Community Survey show that Johnson County has experienced a prolific population shift upward regarding age between 2000 and 2011. Most notable are those 45 to 64 years of age, whose incidence has increased by 45.9%.
In addition to the aging population living in single-family homes, Olathe is home to many concentrated populations of older adults living in multi-family dwellings and so-called “retirement communities.” Further, the City has numerous facilities with an on-site skilled nursing component, which fall under the “Assisted Living” and “24-hour-care skilled nursing facility” designations.

According to the U.S. Fire Administration (USFA), these populations of older adults are considered at-risk for all hazards (fire, EMS, assists, etc.) due to their often less-ambulatory nature, chronic medical conditions, increased use of medications, and elevated likelihood of living in poverty-like or fixed income situations.

**Population Shift: Poverty**

Consistent with older adult populations, the USFA has demonstrated through exhaustive research that people in poverty-like or fixed income situations are more vulnerable to fire and other risks. The predictability of this impact on the community can be measured by quantifying the portion of the community living in poverty-like or fixed income situations.

The poverty rate is an economic indicator that measures the percentage of people with income below the poverty threshold. Nationally, between 2000 and 2012, the percentage of people in poverty increased from 12.2 percent to 15.9 percent, while the number of people in poverty increased from 33.3 million to 48.8 million. In Kansas, between 2000 and 2012, the percentage of people in poverty increased from 9.5% to 14.0%, while the number of people in poverty increased from 247,443 to 391,734, an addition of 144,291 people.

As evident from the map below, Olathe has several census tracts that are problematic in terms of poverty levels. 2010 Census Tract 535.56 (shown in red below) has greater than 20% of its residents falling below the poverty threshold. Also, Olathe has three other Census Tracts (535.02, 535.55 and 536.01) with population percentages that exceed Olathe’s poverty level average of 14.0%.
Another general indicator that is commonly used to determine a community’s economic wellbeing is the percentage of public school students that qualify for the free or reduced price lunch program. Olathe Public Schools USD 233 has noted a disturbing trend, in the fact that the percentage of their students that qualify for the free or reduced price lunch program has risen from 9.75% in 2000 to 28.41% in 2013. This is nearly a three-fold increase over the last 13 years.
Economic Development and Growth

Residential and commercial development in the community means the construction of buildings, with the structures themselves being vulnerable to all hazards, as well as the building’s occupants within. This risk creates the potential for major loss to the community in terms of life safety, economic impact and loss of tax revenue.

Although the entire country (including this area) has suffered through the greatest economic recession since World War II, a steady recovery has been underway since early 2010. After an unprecedented housing downturn, the numbers of new single-family home permits issued has increased steadily and are now approaching pre-recession levels. In fact, the Home Builder Association of Greater Kansas City reported 2013 to be the region’s best year for single-family home construction since 2007.

Comparatively throughout Johnson County, when “counting rooftops,” Olathe continues to lead all other cities in single-family home construction in absolute numbers.

*Source: Home Builders Association of Greater Kansas City*
In terms of a per-capita comparison metro-wide, Olathe demonstrates superior growth when set side-by-side with the most populous cities in the area.

![Per Capita Single-Family Building Permits](chart.png)

Sources: Home Builders Assoc. of Greater Kansas City/US Census 2010
The map below plots the locations of all of Olathe’s residential, commercial and industrial new construction permits from the past several years, which includes 2011, 2012, 2013 and 2014 (year-to-date).
Within Olathe, recent investment in the community has continued at a relatively steady pace as the economic recovery continues. Since 2007, investment in the City in the form of new residential, retail, office and industrial projects had a permit valuation figure of approximately $1.4 billion, according to Olathe’s Development Services Department.

Residential projects, which include single-family, duplexes and three- or four-family buildings, provided a $666.2 million investment in the City between 2008 and 2013, according to the permit valuation figures provided by Olathe’s Development Services Department.

Retail development is returning, with some major developments previously on hold breaking ground in 2013 and 2014. According to the Olathe Chamber of Commerce, in 2013 alone, Olathe added nearly 170,000 square feet of retail space with approximately $6.5 million in retail investment.

Recent industrial development within the City has predominantly taken the form of large warehouse and distribution facilities, with a major catalyst for this being the BNSF Railway Intermodal development just north of the City of Edgerton and just south of the New Century Airport. The table below highlights several warehouses built in Olathe in recent years, showing each of their large size as well as their significant monetary values.

<table>
<thead>
<tr>
<th>Name</th>
<th>Address</th>
<th>Size</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-35 Logistics Park</td>
<td>15220 Green Rd</td>
<td>821,663 sq. ft.</td>
<td>$ 20.0 million</td>
</tr>
<tr>
<td>Bushnell / FedEx</td>
<td>22101 W. 167th St</td>
<td>603,350 sq. ft.</td>
<td>$ 20.3 million</td>
</tr>
<tr>
<td>TVH Parts</td>
<td>16355 S. Lone Elm Rd</td>
<td>515,488 sq. ft.</td>
<td>$ 22.6 million</td>
</tr>
<tr>
<td>Pacific Sunwear</td>
<td>21800 W. 167th St</td>
<td>446,929 sq. ft.</td>
<td>$ 19.1 million</td>
</tr>
</tbody>
</table>
Recent economic development in the area has also impacted transportation. The BNSF Intermodal and Logistics Park KC, dubbed “the latest inland port,” provides logistics opportunities in the 18-county, bi-state Kansas City region. It is a direct connection to the global supply chain via the BNSF’s transcontinental railroad that begins in Long Beach, California and terminates in Chicago, Illinois.

This development resulted in numerous area transportation upgrades, including the addition of a new I-35 interchange just east of the City of Edgerton. The proximity of this facility to U.S. Highway 56 and I-35 furnishes a prime economic opportunity for businesses in adjacent cities such as Olathe.

Industrial and commercial projects provided a $324.8 million investment in Olathe between 2008 and 2013, according to the permit valuation figures provided by Olathe’s Development Services Department. The Olathe Chamber of Commerce reported that in 2013 alone, the City added 1.2 million square feet of industrial space with nearly $60 million in investment.

Geographically, the City has had nominal growth in terms of land area. At the end of 2007, Olathe was 59.89 square miles. Currently, the City is now 61.02 square miles, an increase of 1.13 square miles.

In an overall sense, the appraised value of Johnson County as well as Olathe has seen recent growth. The County Appraiser’s 2014 Revaluation Report showed the City of Olathe’s market value increased by 6.95% to an overall value of more than $11.4 billion. The City’s residential (single- and multi-family) appraised market values increased by 6.26%, while the commercial and industrial values increased by a mighty 11.98%.
**Olathe Public Schools USD 233**

A city's expansion or contraction and that of their respective public school district can be seen as closely linked and is typically proportionally similar.

Both entities provide vital service to the community, and both must change and evolve as the city's demographics and needs change.

The Olathe Public Schools has experienced continuous enrollment growth since its consolidation in 1965. As enrollment has grown, the district's systems for managing growth and facilities were required to keep pace. The district's planners have recognized that residential construction is an important factor that drives enrollment growth, so they work closely with their counterparts in city and county planning departments. This involves the analysis of monthly building permit and rezoning reports, as well as reviewing copies of city and county development proposals. When locating and buying future school sites, the district is not only looking at student locations and residential growth patterns, but also at local street and park plans.

The Olathe school district has grown from roughly 3,200 students in 1965 to 29,200 students in 2013. Between April 2000 and April 2010, Olathe, Lenexa, and Overland Park collectively grew by 23.1 percent, according to the United States Census Bureau. Over that same period of time, the Olathe Public Schools grew by 30.7 percent.

In terms of facility growth since 2007, USD 233 has built three elementary schools, one middle school, and one other educational facility, totaling 382,000 square feet of space. In addition to the new buildings, the district has built 17 additions to existing facilities totaling 360,000 square feet of new educational space.
The plans for the new high school (#5) are in place and the district is preparing to break ground soon. Due to community and student growth, the district needed room for approximately 2,200 students. The years of lead time required to build the new high school succinctly speaks to the need and value of good, proactive planning.

**Increase in Service Demand**

The Olathe Fire Department has seen a steady increase in emergency responses since 2007, when the City’s network of fire stations was last upgraded. As growth in population and investment in the community has taken place, there has been a corresponding increase in the community’s demands for emergency services. The graph below demonstrates a 15% expansion in service demand since 2007.

In 2013, these figures represented an average monthly demand of 807 calls for service, or about 27 calls every day.

From a broad historical perspective, when Chief Coughlin and Battalion Chief Penner issued their Station Location Analysis in 1991, the Olathe Fire Department had 1,954 emergency responses. Today, 22 years later, the fire department has experienced a whopping 500% increase in service demand.
The plot map below shows the distribution of calls throughout the community over the past three years. They are overlaid upon our Emergency Service Zones and each fire station's GIS-based four minute travel time polygon.

The majority of Johnson County fire departments operate within a cooperative deployment framework that essentially treats the entire county as one, seamless fire department when dealing with high priority emergency calls. Johnson County’s Mutual and Automatic Aid Inter-local Cooperation Agreement allows for the closest fire department resource to be sent, regardless of the jurisdiction.
Needs Analysis: Current Conditions

Clearly, development within the community over the past seven years has resulted in increased risk, vulnerability and emergency service demand city-wide. A central operational goal of the Olathe Fire Department is to provide rapid, uniform emergency response throughout the entire city. However, geographic equity of services naturally competes with demand and risk equity, meaning that geographic coverage must make sense, and be in balance with the locations where risk and service demand primarily exist.

Even so, there is a community expectation that the fire department and city leadership strive to keep pace with the existing and future service demands of the public. This means being proactive, as well a reactive, in ensuring that there is no disparity in the delivery system, and that it is consistently applied. In reality, this will likely require an investment in public safety infrastructure to maintain equal services, community-wide.

Vulnerability

A close examination of the areas of Olathe that lie beyond the nearest fire station’s GIS-based four minute travel time polygon reveals a significant and vulnerable group of people, homes and businesses. As the point was stressed earlier, the Olathe Fire Department’s responsiveness and service delivery effectiveness is ultimately defined by its capability of delivering resources to an emergency scene within a reasonable timeframe.

The map below shows each Olathe fire station’s GIS-based four minute travel time polygon. A separate color denotes each of the seven station’s respective travel time areas. As mentioned earlier, these illustrative polygons are derived using geospatial GIS technology based upon the existing road network and actual speed limits.
Scope
The white areas on the map above are locations that lie outside the nearest fire station's GIS-based four minute travel time range. Johnson County AIMS GIS 2011 data show that this area consists of 15.13 square miles, and is equal to over 25% of the City's current overall land mass.

In 2013, approximately 5% of the total fire calls and 4% of the total code 1 EMS calls took place within the white areas on the map above. Even more cause for concern is the fact that 7% of the total cardiac arrest emergencies in the City fell outside of the nearest fire station's GIS-based four minute travel time range. In fact, it can be stated with certainty that on none of those occasions was the closest fire resource able to arrive within the travel time benchmark of four minutes or less.

This area contains approximately 3,299 homes and an estimated 9,311 people. Rightly, this can be seen as potential community risk, and it is clear from the service demand data above that risk is the force that drives deployment of emergency resources. In short, this considerable number of people and homes can be deemed vulnerable due to their distance from emergency service delivery points (fire stations).

Risk can also be measured in terms of economic impact and loss. With regard to the residential property value within this potentially under-protected area, it contains homes with a 2011 assessed value close to $1 billion ($915,332,370). This figure represented 14% of the total assessed value of Olathe's single-family residential homes in 2011.
The previous information is based on 2011 data, which is the latest currently available in the Johnson County AIMS system. Without doubt, these values have increased over the past two and a half years. Indeed, the following plot map shows the locations of all of Olathe’s new construction permits from 2011 through 2014 (year to date). The majority of these are likely already built and occupied, adding weight and breadth to the 2011 data (regarding homes, population and valuation figures), as many are located in the areas outside the four minute distribution range.
Specifically, when considering homes and the safety of the people living within them, there are several locations of strong concern in these areas outside the four minute distribution ranges of first due fire apparatus. One prime example of this is ESZ 198, which is comprised almost entirely of the Forest View subdivision, and will soon contain as many as 725 homes. Another case is the Prairie Highlands area of Olathe (ESZ 269) where over 700 homes will eventually reside.

The table below lists the subdivisions, and their location by ESZ, that are vulnerable to all hazards due to their geographical position outside the nearest fire station’s GIS-based four minute travel time polygon.

<table>
<thead>
<tr>
<th>ESZ</th>
<th>NAME</th>
<th>ESZ</th>
<th>NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>124</td>
<td>North Shore Estates, Cedar Creek Village (30%)*</td>
<td>222</td>
<td>Persimmon Hills (20%)*</td>
</tr>
<tr>
<td>152</td>
<td>Mill Creek Farms, Woodland Manor</td>
<td>245</td>
<td>Whitetail, Lakeshore Meadows</td>
</tr>
<tr>
<td>153</td>
<td>Lakeridge South, Eagle Crest, Raven Crest, Fall Brook, Reuber Acres</td>
<td>268</td>
<td>Ascheman Farms</td>
</tr>
<tr>
<td>176</td>
<td>College Meadows, Mill Creek Grande, Terra Pine, Woodland Meadows North</td>
<td>269</td>
<td>Prairie Highlands, The Greens at Prairie Highlands, Reserve at Prairie Highlands, Oak Run, Huntsford</td>
</tr>
<tr>
<td>177</td>
<td>Woodland Hills Reserve</td>
<td>270</td>
<td>Wyckford Estates, Lakeshore Estates, Palmer View (75%)*</td>
</tr>
<tr>
<td>198</td>
<td>Estates of Forest View, Meadows of Forest View, Hills of Forest View (33%)*</td>
<td>319</td>
<td>Waterford Glen Estates</td>
</tr>
<tr>
<td>200</td>
<td>Woodland Estates, Woodland Meadows (25%)*</td>
<td>367</td>
<td>Nottingham Creek</td>
</tr>
</tbody>
</table>

*Percentage that is vulnerable
The mean parcel property value of the homes within the subdivisions in the table above is $316,087, or 61% higher than the mean residential parcel property value in Olathe city-wide (using Tax Year 2011 assessment values). This suggests even greater risk of economic loss in the event of a fire or other disaster.

In today’s world, children are seen as a priceless treasure, and represent the community’s future. With this in mind, credible coverage of schools in order to ensure reliable emergency response is essential because the potential for loss is so significant. The table below lists the three Olathe public schools that geographically fall outside of the closest fire station’s four minute distribution travel time range. The student population of these three schools numbers 1,543 children.

<table>
<thead>
<tr>
<th>ESZ</th>
<th>SCHOOL NAME</th>
<th># OF CHILDREN</th>
</tr>
</thead>
<tbody>
<tr>
<td>177</td>
<td>Woodland Elementary</td>
<td>363</td>
</tr>
<tr>
<td>198</td>
<td>Forest View Elementary</td>
<td>458</td>
</tr>
<tr>
<td>222</td>
<td>Mission Trail Middle School</td>
<td>722</td>
</tr>
</tbody>
</table>

Currently, there is a large amount of industrial property which has been built in the area beyond the credible distribution network of the Olathe Fire Department. This is especially true in the portion of the City’s southwest, in what PlanOlathe calls the “Industrial Employment District.” There are four new, very large warehouses of note, with a total assessed value of $82 million, and with 2.4 million square feet of available space.
I-35 Logistics Park at 15220 Green Road in Olathe (pictured above) is valued at $20 million and is close to 1 million square feet in size. This large warehouse, along with the other businesses shown in the table below, demonstrate significant community risk, as they all reside beyond the nearest fire station's GIS-based four minute travel time polygon.

<table>
<thead>
<tr>
<th>ESZ</th>
<th>BUSINESS NAME</th>
<th>ESZ</th>
<th>BUSINESS NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>Cedar Creek Plaza Shops</td>
<td>319</td>
<td>Pacific Sunwear</td>
</tr>
<tr>
<td></td>
<td>Cedar Creek Corporate Park</td>
<td></td>
<td></td>
</tr>
<tr>
<td>149</td>
<td>Shadow Glen Golf Club</td>
<td>320</td>
<td>TVH Parts Co.</td>
</tr>
<tr>
<td>153</td>
<td>Ridgeview Marketplace</td>
<td>343</td>
<td>Bushnell, FedEx</td>
</tr>
<tr>
<td>154</td>
<td>Corporate Ridge</td>
<td>344</td>
<td>Lone Elm Park</td>
</tr>
<tr>
<td>293</td>
<td>I-35 Logistics Park</td>
<td>393</td>
<td>Ensor Farm &amp; Museum</td>
</tr>
</tbody>
</table>
Forecasting Future Needs

As vitally important as it is to identify and address current needs, it is equally important to forecast the community's future needs regarding emergency service demand. This information becomes highly relevant when weighing the requirement for additional investment in Olathe's public safety infrastructure. Therefore, when evaluating the efficiency and effectiveness of a potential geographic location for the placement of a new fire station, current risk and service demands as well as anticipated future risk and service demand must be part of the equation.

Managing the growth of the community through effective planning is essential, and is an unambiguous expectation of the community. Through such vigilant and conscientious planning efforts, it has been clearly established that Olathe will continue its prodigious growth pattern well into the future. The purpose of the following information concerning anticipated City growth is to point out that community risk and increased emergency service demand will surely accompany such growth.

Population Density Projections

For decades, the Mid-America Regional Council (MARC) has garnered a well-deserved reputation for their reliability in forecasting population changes in the Greater Kansas City area. The map below depicts MARC’s Olathe planning zones, termed Transportation Analysis Zones (TAZs), along with the OFD’s ESZ identifier overlay. MARC has forecast Olathe’s population changes in raw numbers (not shown on the map) as well as by providing the corresponding percentage change within each TAZ. These population change forecasts (2010 to 2020) were color-coded on the map to aid with clarity of interpretation. It also has the current City boundary indicated by black lines.

The darker blue coloration indicates a significant 40.1% or greater population forecast increase. Unmistakable is the “C”-shaped, crescent moon pattern of growth which surrounds the City on three sides (north, west and south).
The map below, again based on MARC forecasts and vetted by City Planning staff, further makes the case for continued growth through the year 2040 on the same three sides of the City. These are the areas that the City's Long Range Planning group has termed Olathe's "Growth Areas."
Future Land Use and Growth Area Build-out Projections

Olathe’s Comprehensive Plan, PlanOlathe, has within it the Future Land Use Map (below), which is a tool used to develop geographically-based projections for the future growth of the City. This includes roads, transit, parks, utilities and community facilities. PlanOlathe states: “As illustrated in the Future Land Use Map, Olathe is poised to continue to be a strong economic force within the region. Innovation, technology, education, medical, office, science, distribution, industrial and downtown areas will provide an expansion of the job base, and enable Olathe to enhance its role as an employment center for the region.”
Also within PlanOlathe, there is a prediction that “more than 2/3 of Olathe’s ultimate population” will live within ½ mile of a commercial center. An analysis of this forecast, together with the map below, clearly shows the future growth potential of the City beyond its current development framework and 2014 geographic borders.

Another strong indicator of anticipated future growth in the area is the planned transportation upgrades to the interstate highways and major arterial roadways in and around Olathe. Indeed, the Kansas Department of Transportation (KDOT) concluded in their I-35 Moving Forward study that the interstate south of I-435 could go from 32% congested today, to an expected 61% congested in the future, with no improvements. In addition, predicted truck traffic could increase three-fold by 2040 along that same stretch of highway.

A big boost in economic development should result from the completion of KDOT’s Johnson County Gateway Project. The largest in the agency’s history, this $288 million project is expected to be completed by December of 2016. Along with the upgraded I-435/I-35/K-10 interchange, the project includes
upgrades in Olathe such as the widening of College Boulevard between Renner and Ridgeview, and the new interchange at K-10 and Ridgeview Road.

Olathe Public Schools: Forecasting for the Future

Public school expansion and growth can be seen as allegorical in nature to the expansion and growth of the city in which it resides. As well, the symbiotic relationship between the two is intuitive, and for that reason, the actions of the local public school district are seen as germane to this issue.

Along with migration to the City, which is expected to continue, residential construction drives area growth, and also that of the local public school district. Olathe school district staff estimates that the new residential housing market will continue to improve, eventually reaching 800 new single-family dwelling permits annually.

The National Center for Education Statistics projects steady Kansas enrollment growth resulting in a 5.3 percent increase from 2011-2021. Olathe Public Schools planners project an increase of 2,409 students over the next five years, from 2013 to 2019.

As the Olathe Public School district manages the probable increase in enrollment, they prepare for the future through the planned addition of facilities and through the functional capacity of existing infrastructure. In the next few years, USD 233 intends to build three new elementary schools and one new middle school, in addition to the new high school, upon which construction is ready to begin.
**Forecasted Increases in Service Demand**

Over time, the demand for emergency services escalates as community risk and vulnerability increases. It is indisputable that Olathe has experienced compelling growth during the recent past, and the Olathe Fire Department’s service demand, also known as “workload,” has increased commensurately.

This year, the call load is expected to top 10,000 emergency responses. The chart below shows the OFD’s forecasted call volume based on a very conservative 2% increase per year. Moving forward, there is a high probability that these numbers will be exceeded, as economic growth picks up to pre-recession levels and other demographic trends continue.
Needs Analysis: Future Planning

Through the examination of population density forecasts, demographic trends, growth-area build-out projections and anticipated future service demands, it is evident that Olathe will continue its pronounced and marked growth well into the future. Earlier in this report, a needs analysis for current conditions was conducted, and found vulnerabilities in terms of areas of the community residing outside of the nearest fire station’s GIS-based four minute travel time polygon. If there is no further investment in the City’s emergency response network, those current challenges faced today will only be compounded as the community moves into the future with regard to the anticipated growth and development.

Vulnerability

The following map depicts Olathe in its fully built-out state, consistent with PlanOlathe’s future land use vision. In this view, the potentially under-protected areas of the community (shown on the map below in white) are clearly evident, and present a chief concern related to equitable and credible emergency service coverage community-wide.
Scope

Using Johnson County AIMS population modeling and GIS data, in three to five years, the potentially under-protected area inside the current City limits (within the red outline in map above) is projected to contain 12,415 people and 4,356 homes.

Furthermore, when analyzing Olathe’s “growth area,” shown in the white portion on the map above, the land area within it is an appreciable 46.45 square miles. When considering the City’s full build-out area, this potentially under-protected area is projected to contain 14,510 people and 5,160 homes in three to five years. Ultimately, in years to come, when Olathe is fully developed, this area is projected to contain over 83,000 people. Therefore, if the City’s emergency response network is not augmented in a significant manner, those people, as well as the corresponding development within that growth area can be seen as under-protected and likely vulnerable.
The Paradoxical Nature of Automatic Aid

As stated earlier in this report, the “give and take” of automatic aid (often referred to as “mutual aid”) is not equal between the Olathe Fire Department and its neighboring regional partners. The OFD provided emergency services to areas outside of Olathe 350 times in 2013, but only received it from others 164 times. In short, other neighboring jurisdictions’ coverage gaps are being subsidized by the Olathe Fire Department.

With that said, when automatic aid is included in this analysis, Olathe’s current potentially under-protected area beyond the closest station’s four minute travel time range is still over 12 square miles (20% of the City’s overall land mass) and contains 2,441 homes with an estimated 6,971 people. In years to come, when Olathe is fully developed, well over 50,000 people are projected to reside beyond the four minute first due range of the closest fire station, regardless of its jurisdiction.

A crucial caveat regarding automatic aid is that the Olathe Fire Department possesses no control over the reliability and/or effectiveness of our neighboring jurisdictions’ distribution networks. The paradox of the term “automatic aid,” then, is that other jurisdictions’ properly placed emergency resources may not be there when you need them, and thus may not be much help at all. The map below graphically illustrates that our automatic aid partners (mainly the Lenexa Fire Department) actually cover only a small portion of Olathe within their four minute travel time polygons. So, in fact, the scope of the City’s current challenges regarding the considerable amount of Olathe’s people, homes, businesses and land area that lie outside the nearest fire station’s GIS-based four minute travel time range is not significantly impacted by our neighboring automatic aid partners.
Findings

In the previous sections of this report, community risk factors such as population demographics, property valuation, economic development and service demand were studied to determine potential increases in risk and identify vulnerabilities within the department’s response network. The analysis uncovered a number of significant findings relevant to these risk factors and their relationship to the current conditions and forecasted needs of the Olathe Fire Department’s response network.

1. Since the addition of Fire Station #57 in 2007, there has been a significant amount of demographic changes in the City of Olathe in terms of:

Population Growth:
- From 2000-2010, Olathe was the fastest growing city in the state of Kansas boasting a 35% increase in population.
- Since 2007, Olathe’s population has grown by 5.4% adding 1,115 people per year.
- Olathe continues to show a steady upward trend in live births and kindergarten enrollment.

Population Shift in Age:
- Since 2000, Olathe’s median age has increased 9.4% indicating that the population is growing older.
- From 2000-2011, Olathe’s 45-64 age range increased 46% and there was a 38% increase in the 65+ age range.

Population Shift in Poverty:
- Olathe has three census tracts that fall between 15-20% of the poverty level average and one that exceeds the 20% mark.
- From 2000-2013, Olathe Public Schools have had a three-fold increase (28.41%) in the percentage of students that qualify for free or reduced price lunch.

Economic Development & Growth:
- Olathe continues to lead all other cities in Johnson County and metro-wide in single-family home construction (528 new building permits in 2013).
- Since 2007, there has been a $1.4 billion permit valuation from new projects residential, retail, office and industrial.
- Olathe’s appraised market value has increased 7% to an overall value of $11.4 billion.

Olathe Public Schools:
- From 2000-2010, the enrollment in Olathe Public Schools grew by 31%.
- Since 2007, Olathe Public Schools has built three elementary schools, one middle school and 17 new additions to existing facilities.

Service Demand:
- Since 2007, emergency responses have risen in Olathe by 15% from approximately 8,200 total incidents to 9,700 incidents in 2013.
- In 2013, the OFD provided more than twice as much aid to other jurisdictions than it received.
2. The needs analysis of current conditions identified several under-protected geographical areas (25% of the City’s overall land mass) that fell outside of the department’s four minute travel time range of the closest fire station. Currently, within these areas, there is/are:

- An estimated 9,300 people.
- Approximately 3,300 homes valuing almost $1 billion.
- 33 vulnerable subdivisions with homes having a mean parcel property value of at $316,000.
- Three vulnerable public schools with approximately 1,500 children.
- 12 vulnerable businesses with assessed values totaling well over $100 million.
- A considerable number of fire and EMS calls (5% of the total fire calls and 4% of the total EMS calls were in these areas last year).

3. The analysis of the future needs of the community identified that there is a significant amount of projected demographic changes in terms of:

**Population Density Projections**
- From 2010-2020, Olathe is projected to increase in population anywhere from 40-500% to the north, west and south of its current borders.
- By 2040, Olathe is projected to increase in population from 130,000 to an estimated 197,000 people.

**Future Land Use & Growth Area Projections**
- Olathe’s boundaries are projected to increase by approximately 27 square miles when fully developed.

**Olathe Public School Projections**
- In the next 5 years (2013-2019), there is a projected increase in enrollment of 2,400 students.
- In the next few years, USD 233 intends to build three new elementary schools, one new middle school, and one new high school.

**Service Demand Projections**
- Responses for 2014 are on track to surpass the 10,000 mark.
- Service demand is conservatively forecasted to increase by 2% every year projecting 11,300 emergency responses by 2020.

4. The needs analysis of the future revealed that within the under-protected geographical areas, there is projected to be:

- In 3-5 years, an estimated 12,400 people and approximately 4,400 homes will lie within current City limits but beyond the four minute travel time range of the closest fire station.
- In 3-5 years, an estimated 14,500 people and approximately 5,200 homes will lie in the City’s projected “growth area” but beyond the four minute travel time range of the closest fire station.
- An estimated 83,000 people residing beyond the four minute travel time range of the closest fire station when Olathe is fully developed if no fire stations are added to the current response network.
Prospective Fire Station Location Modeling

The following maps were created through the use of specialized, map-based station and apparatus analysis software tools from Deccan International dubbed Cad Analyst and “ADAM” (Apparatus Deployment Analysis Module). This modeling software combination provides analysis for both strategic and real-time deployment planning. (“Cad” is an acronym for Computer Aided Dispatch – the overarching system used by the Johnson County Emergency Communication Center (ECC) to make resource recommendations and dispatch all calls for service in Johnson and Miami Counties).

The accuracy and reliability of this data is unparalleled, as all modeling is a result of assumptions compiled utilizing actual OFD call data from Cad Analyst, which resides in “real time” at the Johnson County Emergency Communication Center. Using this real data, ADAM predicts the workload of each unit in a particular area of the City and determines their probability of being available for any given call for service. Whereby, it builds a highly realistic “negative calculation” into each model, which reflects the reality that the system is rarely, if ever, at rest. Units are busy responding to calls and moving about the City on many forms of business, and are not simply standing by, waiting for the next call to come in.

Simply put, this modeling software produces as close to a real picture of system performance as is possible using the best of today’s modern technology. By applying actual system behavior (from the recent past) to predict system behavior today, the results that are generated are sound, reliable and extremely trustworthy for the purposes of this study. In fact, other users within our system have found that these analyses have an accuracy factor within 1%. 
Current Baseline Coverage

The map below represents the current Deccan baseline deployment analysis for Olathe, which is a very logical starting point – what the Olathe Fire Department does today. It is a graphic representation of the OFD emergency response network's percentage performance based on current map data and historical data (actual travel times) compiled by Deccan's Cad Analyst at the ECC. As the map legend shows, the darker green zones represent excellent arrival performance (at the 90 to 100 percent level) to high priority emergencies within four minutes or less.

The baseline system performance map also identifies zones shown in red that represent inferior arrival performance (at or below the 50 percent level) to high priority emergencies within four minutes or less. This is clearly indicative of zones with geographic and emergency service coverage inequities. Furthermore, those zones correspond with the areas within the City already identified as having the highest future growth potential, both in terms of people as well as vulnerable homes and businesses. Therefore, those zones were assigned the highest priority with regard to the specific fire station location modeling scenarios to come.
Future Location Models

The following maps use the ADAM modeling software’s precise and arduous calculations of predictive system performance based on current map data and historical data (actual travel times) compiled by Cad Analyst. Prospective fire station locations were entered into the ADAM software program in order to receive highly accurate predictive models of fire apparatus coverage from given geographic locations.

From that point, five prospective fire station locations were prioritized based on current and future needs. The first prioritized location modeled was in the area of 151st Street and Lakeshore Drive. The following map shows the predicted coverage with the addition of a fire apparatus at that location.

When compared to the baseline map, the effectiveness of the OFD’s emergency service coverage showed a major improvement in the western portion of the City with the addition of a fire station in the area of 151st Street and Lakeshore Drive. The map shows that all or part of 22 grid sections underwent a color change which graphically represents appreciable response network improvement.
The next prioritized location modeled was in the area of College Boulevard and Woodland Road. The following map shows the predicted coverage with the addition of a fire apparatus at that location.

When compared to the baseline map, the effectiveness of the OFD’s emergency service coverage showed a major improvement in the northern portion of the City with the addition of a fire station in the area of College Boulevard and Woodland Road. The map shows that all or part of 16 grid sections underwent a color change which graphically represents appreciable response network improvement.
The next prioritized location modeled was in the area of 167th Street and Lone Elm Road. The following map shows the predicted coverage with the addition of a fire apparatus at that location.

When compared to the baseline map, the effectiveness of the OFD's emergency service coverage showed considerable improvement in the southern portion of the City with the addition of a fire station in the area of 167th Street and Lone Elm Road. The map shows that all or part of 17 grid sections underwent a color change which graphically represents appreciable response network improvement.
The next prioritized location modeled was in the projected “growth area” in the southern portion of the City at 18700 S. Renner Road. The following map shows the predicted coverage with the addition of a fire apparatus at that location.

When compared to the baseline map, the effectiveness of the OFD’s emergency service coverage showed minimal improvement in the southern portion of the City with the addition of a fire station in the area of 18700 & Renner Road. This is largely due to the fact that the geographic position of this model is located outside of current City limits. With that said, the modeling map only showed slight appreciable impact on nearby grids within today’s response network.
The last prioritized location modeled was in the projected “growth area” in the western portion of the City at 135th Street and Cedar Niles Road. The following map shows the predicted coverage with the addition of a fire apparatus at that location.

![Map of Fire Station Location](image)

When compared to the baseline map, the effectiveness of the OFD's emergency service coverage showed minimal improvement in the western portion of the City with the addition of a fire station in the area of 135th and Cedar Niles Road. This is largely due to the fact that the geographic position of this model is located outside of current City limits. With that said, the modeling map showed appreciable impact on six of the nearby grids within today's response network.
Optimization Models

For the purposes of this report, the concept of optimization will be confined within the framework of the Olathe Fire Department’s response network. This limitation is necessary because of the wide expanse of elements that could potentially fall within this broad concept. Anecdotally, optimization speaks to achieving maximum efficiency while still being subjected to certain constraints. This section of the report will explore several optimization concepts within the realm of the efficiency and effectiveness of the OFD’s response network.

The idea of station movement (closing an existing fire station and rebuilding it at another location) has logical efficiency possibilities, with the idea that after the initial capital outlay for the new building, there would be no further costs for apparatus or staffing. The crucial question, however, is what affect does such an undertaking have on the effectiveness of the overall response network?

Earlier in this report, there were several areas of the City that were identified as potentially under-protected due to their location beyond the nearest fire station’s four minute travel time polygon. By reason, fire station movement (re-location) should address these vulnerabilities while not adversely affecting the response network as a whole.

The OFD’s 1991 Station Location Analysis (p. 71) succinctly points out Fire Station #52’s “travel barriers” which limit their response efficiency to the west. This is caused by the City’s road network arrangement; specifically, that 119th Street does not continue through to the west at Nelson Road. Rather, it turns to the north (becoming Northgate Street) prior to intersecting with Woodland Road. This geographic situation acts as a barrier preventing efficient movement of resources to the west of Nelson Road in that response area. This situation has created a clear “credible coverage island” in the area between Station #52 and Station #56.

Intuitively, using a broad overview of the OFD’s current baseline four minute travel time response areas (polygons) overlaid on the City map, the simultaneous re-location of Station #52 (to the west) and Station 54 (to the north) seems to make sense. Thus, seemingly solving a credible coverage issue without the additional capital outlay for staffing and apparatus.

A vital caution is that any re-location of Station #54 and #52 must occur simultaneously in order to avoid an inevitable magnification of coverage dilemmas in this area of the City.

This scenario was evaluated using Deccan’s ADAM modeling software, depicted on the map below. Station #52 was moved one mile to the west to 119th Street and Ridgeview Road, and Station #54 was moved one mile north to 127th Street and Mur-Len Road.
As seen on the map above, the effectiveness of the OFD's emergency service coverage did not show a major improvement in the northern portion of the City with the re-locations of these two fire stations. However, several meaningful results can be seen, most notably that the area between Station #52 and Station #56 showed no appreciable response network improvement. In fact, areas of the City that have the highest service demand actually showed a decline in coverage with these fire station moves.

In order to see a marked improvement in coverage in the College Boulevard and Woodland Road corridor (circled on the map above), Station #52 would have to be re-located fully to the west of the travel barrier created by 119th Street and Northgate Road. This, however, would have an extremely adverse effect on the reliable coverage in the busiest area of Olathe (in terms of emergency call volume). In 2013, ESZ 202, where Station #52 is located, and ESZ 250, which is the heart of Station #54’s district, above all others, were the two ESZs in the City with highest service demand. Therefore, it would not be possible for Station #54 alone to provide credible, efficient or reliable coverage to the busiest area of Olathe.
The idea of rebuilding and possibly relocating fire stations finds its origin in the well documented case of the condition (i.e. the deferred maintenance issue) of Station #52, as well as with the age and size of Station #54. Therefore, compelling assertions can be made for the replacement of both fire stations. However, what decisions are most appropriate for providing the optimum coverage to the City?

Among the relevant considerations are workload limitations, staffing and/or possible apparatus co-location options, and ultimately, the determination of the most effective position for resources within the response area. Because of these genuinely perplexing yet very real challenges, further study is needed to determine the most logical and efficient solutions for the City of Olathe.
Recommendations

This station location and optimization study revealed many compelling findings concerning community vulnerabilities and the challenges of achieving equitable coverage across the entirety of Olathe. The following recommendations are designed to meet those challenges in terms of both current and future needs.

In an effort to meet those needs, an expansion of Olathe's emergency response network is indicated through further investment in the community's public safety infrastructure. Again, based on specific needs related to potentially under-protected people, homes, schools and businesses, five prospective fire station locations were identified, prioritized and modeled to determine their geographic effectiveness.

The following five locations were selected as recommendations for the future placement of fire stations in the City of Olathe:

I. **151st Street and Lakeshore Drive Location**

The placement of a fire station at this location will address numerous current needs, including providing equitable, first due coverage to the Prairie Highlands area. This is one of the larger and more densely populated areas lacking credible, first due coverage, and includes 11 separate sub-divisions and many thousands of people. This location will also provide coverage to the 722 students of Mission Trail Middle School, as well as to the sizable I-35 Logistics Park warehouse complex.

This location also effectively addresses future needs, as projected population and economic development growth forecasts anticipate continued upward trending. Indeed, there is a significant 172% forecasted population increase by 2020 for the area west of the Prairie Highlands subdivision. There are also firm plans for a new elementary school in this area, as well as three additional large warehouses to be added to the I-35 Logistics Park complex.

The placement of a fire station at this location is considered an **immediate need** for the City. Moving forward into the future, as this vulnerable area continues its growth, the problems involving the lack of credible, equitable coverage will only compound with time.

II. **College Boulevard and Woodland Road Location**

The placement of a fire station in the College and Woodland corridor will address many current needs by providing equitable, first due coverage to the area. Additionally, due to travel barriers to the east of this area, this placement would improve performance when concentrating forces to handle a high risk event (e.g. structure fire, haz-mat event or technical rescue). First due coverage would also be provided to the 363 children of Woodland Elementary School, 11 separate sub-divisions, the Ridgeview Marketplace retail area and the Corporate Ridge business complex.

This location also effectively addresses future needs; specifically, by providing credible, first due coverage to Olathe’s new $51 million, 200-room
hotel and conference center that broke ground in March. Furthermore, 2020 population growth forecasts show a 130% expected increase in this area of the City.

The placement of a fire station at this location is considered an **immediate need** for the City. Moving forward into the future, as this vulnerable area continues its growth, the problems involving the lack of credible, equitable coverage will only compound with time.

III. **167th Street and Lone Elm Road Location**

The placement of a fire station at this location will address numerous current needs, as this area is already developing into the Industrial Employment District that *PlanOlathe* envisioned. Three major warehouse and distribution facilities (PacSun, TVH Parts Co., Bushnell/FedEx) valued at $62 million are lacking credible, first due coverage. In addition, this location would be first due to Cedar Lake Village, an expansive facility that is home to a large number of older adults. This ESZ (296) is the third busiest in the City in terms of call volume; therefore, the addition of resources here would relieve some burden from Station #51 units. Lastly, the location of the Nottingham Creek subdivision has been a concern for City and fire department leadership for a long time. A new fire station at 167th Street and Lone Elm would finally place these 1,400 people and 115 homes within credible, first due coverage limits.

This location also effectively addresses future needs, as this area is forecasted to see a sizable 286% increase in population by 2020. The Olathe Medical Center campus, home to Cedar Lake Village, and owned in partnership with the Olathe Health System and the Evangelical Lutheran Good Samaritan Society, plans to expand its senior living community greatly. This is compelling in that any such increase in older adults is known to have a heavy impact on emergency response resources. Finally, because of the growing significance of this area as a goods storage and transportation hub, substantial future growth is expected in this capacity as well.

The Lone Elm Vicinity Plan was originally prepared by the City in 1997 when the area was still part of unincorporated Johnson County. Updated and approved by the Planning Commission in 2007, it outlines infrastructure and service expansions needed in the area as it transitions from rural to urban use. A key conclusion within the plan was that two fire stations were needed in the area because of its expected growth and development.

The placement of a fire station at this location is considered an **immediate need** for the City. Moving forward into the future, as this vulnerable area continues its growth, the problems involving the lack of credible, equitable coverage will only compound with time.

IV. **18700 and Renner Road Location**

This area lies outside of Olathe’s current City limits, but is squarely placed within the projected growth area of the City. In fact, the south end of the planned Stonebridge project, which eventually will have 995 homes within
four subdivisions, falls within this station’s first due coverage area. This arrangement would help greatly to ensure performance when concentrating forces in the southern part of the City to handle high risk events such as structure fires.

The Coffee Creek Master Plan (2005) also identified infrastructure and development plans that strongly suggest growth and development in this area of the City. Consistent with these projections, 2020 population forecasts show a massive 510% expected growth within this prospective fire station's first due coverage area.

The placement of a fire station at this location is considered a future need for the City. As Olathe continues its steady growth to the south, as outlined within PlanOlathe, it is certain that this area will require public safety services in the form of fire protection in the future.

V. 135th Street and Cedar Niles Road Location

This area is located just a half mile outside of Olathe’s current City limits. The new Olathe public high school (#5) lies within this prospective fire station's first due coverage area. Just as housing growth drives the placement of new schools, the new schools themselves tend to drive housing growth in their direct vicinity. This pattern has repeated itself over the years and is expected to continue, putting this location at the heart of expected future growth. Consistently, 2020 population forecasts show a sizable 243% growth expected in the area surrounding this location.

Due to the geographic travel barrier created by Ernie Miller Park, this location will allow for credible, first due coverage to the Forrest View subdivisions in ESZ 198, to the northern portion of the Persimmon Hills subdivision, and to the 458 children of Forrest View Elementary School.

The placement of a fire station at this location is considered a future need for the City. With the westward expansion predictions that accompany the building of the new high school, it is certain that this area will require public safety services in the form of fire protection in the future.
Future Fire Station Placement

Station #8  151st Street and S. Lakeshore Drive
Station #9  College Boulevard and Woodland Road
Station #10 167th Street and S. Lone Elm Road
Station #11 18700 S. Renner Road
Station #12 135th Street and S. Cedar Niles Road
Appendix A

Station Location Analysis – 1991
Station Location Analysis

Olathe Fire Department
Station Location Analysis

for the

Olathe, KS Fire Department

September, 1991
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Acknowledgement

This study was prepared by Chief Patrick Coughlin and Battalion Chief Michael Penner, with the assistance of Ms. Sharon Schadowsky.

Captain Todd Hart conducted the fireground task time study which is discussed in Section Four and included as Attachment 3.
Overview

The central topic of this report is the fire station location study conducted by the Olathe fire department. But decisions on fire station location are tied to manpower and equipment issues, so the scope of the report includes them also.

The report is divided into four sections. The discussion in Section One shows why a poorly planned network of fire stations can be a financial burden to a community and how a well-planned network can provide financial benefits to the city and its citizens. The section introduces the issues related to measuring fire department capability and shows how station locations relate to that capability. Comparisons with surrounding cities are presented to give the reader an idea of how Olathe looks in relation to its neighbors.

Section Two describes the key aspects of fire behavior and fire department operations that must be considered when measuring fire department capability. The analysis methodology which is discussed in the next section rests on a set of assumptions about those two factors, and the background material in this section explains why the analysts made the particular assumptions for the Olathe study.

Section Three describes the analytical methodology used for the Olathe study. A comparison is made between two models, the Insurance Services Office rating and the Public Technology, Inc. street network/travel time analysis, to show why the latter method was selected for the Olathe study.

Section Four presents the study results in four parts. The data analysis in part I describes the risk in the city and the fire department's capability of handling those risks. Part 2 contains the analysis of the option of relocating Station 4. Part 3 compares eight potential sites for Station 6, and part 4 discusses the improvements that will be necessary if Olathe wants to improve its fire insurance rating. The last part also discusses the total number of new stations, manpower and equipment that will be needed to provide a reasonable level of fire safety in Olathe when the city is fully developed.
Definition of Terms

The definitions for technical terms used in the analysis are listed below in alphabetical order. The italicized text indicates terms which are defined elsewhere in the list. The definition for each term will be expanded upon in the section where it is used.

**DISPATCH TIME** - The portion of a fire department's *response time* that begins when the dispatcher receives a fire alarm and ends when the dispatcher assigns fire companies to the call.

**EFFECTIVE RESPONSE FORCE** - The minimum amount of manpower & equipment that must reach a *fire demand zone* within the *maximum prescribed travel time*.

**FIRE DEMAND ZONE (FDZ)** - A standard geographic area of the city identified by one of five *risk categories*. For the Olathe study, the FDZ's have a standard size of 1/8th sq. mile. The *risk category* assigned to each FDZ zone is determined by the highest risk structure in the FDZ.

**FIRE FLOW, AVAILABLE** - The amount of water that is available for firefighting. The highest domestic demand on the city water system is deducted from the flow test.

**FIRE FLOW, REQUIRED** - The quantity of water required to be available for a 2 or 3 hour period at a minimum pressure of 20 psi to extinguish a fire in a structure. The gallonage required is calculated for each structure, and is based on the structure size, compartmentation within the structure, construction material and exposure to other structures. The water must be available in addition to the highest domestic demand on the water system. This figure is a significant feature of the *Insurance Services Office* evaluation.

**FIRST-DUE AREA** - The portion of the city that each engine company has been assigned as the first to arrive at a fire. The engine company is also responsible for all single-engine fire calls and medical emergency calls in its first-due area.

**FIRST-DUE FIRE DEMAND ZONES** - The total number of *fire demand zones* within each engine company's *first-due area*. 
INSURANCE SERVICES OFFICE (ISO) - A national organization that evaluates each city's public fire protection and provides rating information to insurance companies. The insurers use the rating to set their basic premiums for fire insurance. The ISO inspects and tests each city's fire department and public water supply system about every 10 years.

MAXIMUM PRESCRIBED TRAVEL TIME - For each risk category, the maximum travel time to a fire demand zone that is deemed necessary for the responding fire department units to be considered an effective response force.

RESPONSE EFFECTIVENESS - A measure of the fire department's capability, expressed by the number of fire demand zones in the city that can be reached by an effective response force in the maximum prescribed travel time. It is expressed as a ratio of the fire demand zones within the time limit with the fire demand zones beyond the time limit.

RESPONSE EFFICIENCY - A measure of an individual fire station's productivity which grades the duplication of coverage within each engine company's first-due area. This measure has two components. The first is the number of fire demand zones that can be reached from the assigned fire station within the maximum prescribed travel time. The second component is a weight that is a function of the difference between the number of fire demand zones actually covered and the number of fire demand zones that the engine company would cover if it had an equal share of them.

For example, in a five-station arrangement, each station would ideally handle 20% of the fire demand zones that can be covered by the five stations. In reality, though, each district varies because the street layouts and street speeds vary in each district. The Response Efficiency measure takes this into account by giving a positive weight to stations that handle more than the equal share of fire demand zones and a negative weight to stations covering less than the equal share. In the five station illustration, a station which covers 25% of the fire demand zones would get a weight of 1.25, and a station which covers 15% would get a weight of .75.

RESPONSE RELIABILITY - The percentage of the time that all fire units are available for a call. This is a function of the average time that a fire unit is unavailable for a fire call because it is already at another call. Values for the formula for average time unavailable are taken from a Poisson distribution. Attachment 1 contains the source material for this subject.

When a station is unavailable, the response time will be longer because a more distant station will have to fill in for the unavailable station. Response Reliability is a statement of the probability that an effective response force cannot be provided when a fire call is received.
RESPONSE TIME - The total time that elapses from the time the fire dispatcher receives a fire alarm until the fire companies are prepared to fight the fire. Response time is composed of the following segments: dispatch time, turnout time, travel time, and setup time.

RISK CATEGORY - A rank assigned to each fire demand zone (FDZ) that reflects the degree of risk to life and property safety - and hence the demand upon the fire department - that exists in the FDZ. Five categories are used, ranging from maximum to minimum. A detailed discussion of each risk category and the related demand on fire department resources is included in Section Three.

STANDARD FIRE DEMAND ZONE AREA (SFDZ) - A uniform area used for comparison of future stations. The SFDZ includes some areas that aren't within Olathe's boundaries but will be in the future. The purpose of the SFDZ is to provide a common denominator for calculating the response efficiency and response effectiveness scores for stations that will cover those areas.

TRAVEL TIME - The portion of response time that fire companies are actually enroute to a fire call. The time begins when the assigned fire companies leave the station and ends when the companies arrive at the fire scene.

TURNOUT TIME - The portion of response time when the fire companies don their personal protective gear and go to their assigned apparatus. The time begins when the fire companies receive an assignment from the dispatcher and ends when the apparatus leaves the station.
Section One

Introduction

Good fire protection is vital to the safety and livelihood of Olathe’s residents and businesses. That protection comes at a cost, though, so economics is an important consideration in placing fire stations and adequately manning them. Everyone will agree that they want the highest level of fire protection possible, but every dollar devoted to fire protection is one less dollar that can be used for other city services such as street and park maintenance. Therefore, it is imperative that the most valid and reliable methods be used for planning station locations.

Good fire protection also saves money. Fire insurance companies base their premiums on the quality of public fire protection, and they assign every city an insurance rating that denotes that quality. Prospective business owners and homeowners check the rating to evaluate their insurance burden, and lower fire insurance premiums make Olathe more appealing to new businesses and residents.

A rationally planned fire department should be equipped and manned to gain the most effectiveness for the least cost, both to the tax base and the insurance burden. Station locations are critical to this effectiveness/efficiency balance. A station that is placed too close to the others will be inefficient, while a station that is placed too far from the others will render the fire unit less effective. Therefore, it is important that decision makers rigorously study all of the relevant factors in order to select a station site that is the best balance between effectiveness and efficiency. Then everyone can be confident that the money spent on fire protection was a wise investment.

That’s what this study is about. First, it evaluates the Olathe fire department’s capability to stop property loss and save lives. That capability is expressed in quantitative terms. The study then analyzes the impact of past decisions on station location which will augment or limit the productivity of future stations. The issue of what do with Station 4 is reviewed and data are provided for use in the pending decision to either close it, renovate it or build a new station.

The study then considers potential sites for Station 6 and their impact on the continuing need for an engine company at Station 2. The analysis predicts how the fire department’s capability will be helped, or hindered, by each potential station site.
The Olathe fire department station location study was a four-step process that involved months of manual preparation and an extensive computer analysis:

1. The fire department staff developed an evaluation procedure that can objectively and quantitatively measure department effectiveness, efficiency and reliability.

2. The staff selected an analytical method that is superior to methods traditionally employed by cities. The analytical package was modified to apply to Olathe.

3. Using the method selected in step 2, the analysts determined how Olathe's current fire station sites affect the fire department's effectiveness, efficiency and reliability.

4. The data was then used to find the best combination of existing stations, possible relocated stations and new stations that will provide an acceptable level of fire department effectiveness, efficiency and reliability as the city grows toward full development.

The data analysis also suggests options in lieu of additional stations that can make a smaller network of stations work better for the city. The resulting information from the entire set of data is designed to give the Olathe city council a comprehensive package of information about the city's fire protection system which can be used in planning Olathe's future.

Measuring Fire Department Capability

Three key terms will be used throughout this report: response effectiveness, response efficiency and response reliability. They are numerical measures that were created by the Olathe fire department staff to objectively and quantitatively analyze the relationship between Olathe's existing station locations and the fire department's capability.

The measures were then applied to the pending decision on Station 4, and were used to evaluate the impact of potential Station 6 sites. As street improvements and new land development take place, the data base can be revised to increase the accuracy of the data. Section Four, Analysis Results, will discuss the number of stations that will be needed when Olathe is fully developed.
Response Effectiveness

The percentage of Fire Demand Zones that can be reached by an Effective Response Force.

Response effectiveness measures the fire department's potential. Its potential is limited by the amount and type of equipment, the manpower available to operate the equipment, and how long it takes them to reach a fire scene. Once at the scene, the department's potential is limited by the degree of risk posed by the structure and the size of the fire. A fire that occurs in a small, uninhabited building usually requires fewer firefighters and equipment to stop than a fire in a crowded building or a building designed to let a fire spread very quickly. The size of the fire upon arrival also varies, and the stage of the fire is a very important factor in the outcome.

The Olathe study takes both of these factors of building risk potential and fire size potential into account in the response effectiveness equation. Using nationally recognized standards and data, specific assumptions were made about the combined effect of risk level and fire growth on the need to provide enough resources quickly enough to be successful. For the purpose of measuring risk potential, every structure in Olathe was assigned to one of five risk levels: maximum, high, moderate, low, and minimum. For the purpose of measuring fire potential based on the stage of fire growth, a specific stage of fire growth was selected for a common point of reference. The analysts then used nationally accepted fire department performance standards to predict the amount of manpower & equipment needed to stop a fire at that stage.

Once the minimum manpower & equipment needs were established for each level of risk, the analysts then determined how fast the entire force of manpower & equipment had to reach the fire scene in order to be effective. Data from fire growth experiments were used to determine the maximum travel time that would allow the manpower & equipment to get to a
fire scene while a fire was still in its early stages of growth. Section II discusses the data which were used to determine the risk categories, stages of fire growth, and the performance standards for fire operations.

It is important to keep in mind that these assumptions about risk level and fire growth place some conditions on the analysis model. Every statement about the fire department's effectiveness should include the caveat of under certain conditions. The assumed conditions for an effective response are optimum dispatch, travel, setup and suppression times, and that a fire will not be beyond the flashover stage of growth when all of the required forces arrive.

Response Efficiency

The percentage of a district's FDZ's that can be covered in the maximum prescribed travel time by another district.

The districts illustrated above have the same degree of overlap, and thus the same Response Efficiency.

Theoretically, stations would be 100% efficient if located such that their maximum "first due" travel times didn't overlap. Using a first-due travel time of 4 minutes, every station would be 8 minutes apart. But there is a negative correlation between efficiency and effectiveness, so perfect efficiency scores will lower the effectiveness score because the number of companies needed to make up an effective response force would be too far apart to meet the maximum prescribed travel times for the full assignment.

With the maximum prescribed travel times used in the Olathe study, the equilibrium point in the effectiveness/efficiency tradeoff is 67%. In a hypothetical city with 100% right-angle travel routes having uniform street speeds, a response effectiveness score of 100% would limit the station efficiency scores to 67%. Conversely, a uniform set of efficiency scores of 100% would limit the department's effectiveness to 67%. Some degree of overlap is desirable, however, to keep response reliability at a reasonable level. Areas which have a low response reliability score need more available engine companies to make up for busy engines.

Response efficiency is based upon the number of fire demand zones (FDZ's) that are within each fire apparatus' first-due district. Each district's boundary is drawn by mapping the maximum prescribed first-due travel time from each station and then counting the number of FDZ's in that area. The number of the district's FDZ's that are also in another dis-
District's boundary are divided by the total in the district, yielding a percentage. The percentage is weighted by the size of the district, so districts with more than their equal share of FDZ's get a positive weight and districts with less than their share of FDZ's get a negative weight. The response efficiency score, then, is the weighted ratio of each district's FDZ's that can be reached in the maximum first-due travel time over that district's total assigned FDZ's.

Where stations are located close to city limits, their response efficiency score will be arbitrarily lower. For example, Station 2 has only 329 FDZ's largely because it borders the north city limits. As Figure I - 1 shows, Station 2 would have 693 FDZ's if it were not limited by the city limits.

Response Reliability

The probability that a new call will be received while a fire company is already busy on another call.

Response Reliability is defined as the probability that the required amount of manpower & apparatus will be available when a fire call is received. If every piece of fire department apparatus were available every time a fire call was received, then the department's response reliability would be 100%. If, however, a call is received for a particular company but that company is busy at another call, a substitute company must be assigned from another station. If the substituting station is too far away, that company cannot respond in the maximum prescribed travel time.

As the number of emergency calls per day increases, the probability increases that a needed piece of apparatus will already be busy when a call is received. Consequently, the department's response reliability decreases.

To illustrate, consider a detached single-family home. It is in the moderate risk category, so the alarm assignment is two engines, one ladder truck, 12 firefighters and one battalion chief. The maximum prescribed travel time is 4 minutes for the first-due company and 6 minutes for the remainder of the assignment. If one of the engines is already busy at another call, the minimum amount of manpower & equipment cannot reach the scene in one or both of the maximum prescribed travel time. The probability of this unavailability is the measure of the fire department's reliability. Section Four contains data on Olathe's current and projected response reliability.
Station 2's FDZ's would increase from 329 to 500 without the city limits, an increase of 34.2%.

Figure 1 - Station 2 FDZ's Within and Without City Limits.
The formula for measuring this probability is based upon a statistical concept called queuing theory. The mathematical model used in this report has been tested in various departments around the country and has been found to be accurate. The theoretical basis for predicting fire apparatus availability is included in Attachment 1.

To summarize, the Olathe fire department's response effectiveness is the percentage of the FDZ's in the city where it can respond with the minimum-required amount of manpower & equipment within the maximum prescribed travel time. Its response efficiency is the weighted percentage of each first-due district that is overlapped by another district. Its response reliability is the percentage of the time that at least one company will be unavailable when a call is received.

The Fire Response Time Continuum

Travel time is only one of several variables related to an effective response. This point is usually overlooked and leads to overly optimistic - and very misleading - conclusions about how long it takes to respond to a fire. Figure I - 2 is a Fire Response Time Continuum which shows all of the variables in their time order. Time is critical because fires grow exponentially. They continue to grow until they either run out of fuel or the fire department intervenes and stops the burning. In an urban setting like Olathe, a structure fire has all the fuel it needs to continue destroying everything in its path, so the fire can only be stopped if enough firefighters arrive in time to stop it from taking lives and property. Everything the fire department does is time-critical.

Figure 1 - 2.
Fire Response Time Continuum
The location of stations impacts on one segment of the continuum, travel time. Figure I - 2 illustrates an important point that frequently gets overlooked - travel time and response time are not the same thing. When we say that a particular station has a four minute travel time to an address, it doesn't mean that a unit will arrive there in four minutes. Dispatch time can add up to two minutes and turnout time can add another two. Consequently, the unit's response time is eight minutes.

\[
\text{Fire Department Comparisons}
\]

The following tables have been included to give the reader some general comparisons between Olathe and surrounding cities. The data is included for informational purposes only, since most external comparisons aren't valid indicators of each department's capability. A fire department's capability can only be measured internally by assessing the specific risks that exist in each city and then evaluating that fire department's ability to handle those risks. Variations in such things as industrial base, hazardous materials storage and transportation, high-rise buildings, built-in fire protection, high-risk occupants, etc., can make the fire risk in cities of the same size vary widely.

The one external comparison that does approach validity is the Insurance Services Office (ISO) rating. The ISO is a service bureau that supplies rate data to member insurance companies. The ISO's fire insurance rating ranges from 1 to 10 and tells insurance agents what base rate to use in establishing insurance premiums for a building.

Lower numbers mean lower fire insurance premiums. The importance of this rating is discussed in detail in Section Three. The ISO rating is not a completely valid fire department comparison because half of the rating is based upon the quality of the water system. Table I - 1 compares Olathe's ISO rating with selected cities.
### Table I - 1
ISO Rates for Selected Cities

<table>
<thead>
<tr>
<th>City</th>
<th>Rate</th>
<th>City</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonner Springs</td>
<td>7</td>
<td>Mission</td>
<td>5</td>
</tr>
<tr>
<td>Blue Springs</td>
<td>4</td>
<td>Mission Hills</td>
<td>5</td>
</tr>
<tr>
<td>DeSoto</td>
<td>8</td>
<td>Olathe</td>
<td>5</td>
</tr>
<tr>
<td>Gardner (city)</td>
<td>6</td>
<td>Overland Park</td>
<td>4</td>
</tr>
<tr>
<td>Gardner (rural)</td>
<td>7</td>
<td>Prairie Village</td>
<td>5</td>
</tr>
<tr>
<td>Grandview</td>
<td>4</td>
<td>Raytown</td>
<td>4</td>
</tr>
<tr>
<td>Independence</td>
<td>4</td>
<td>Shawnee</td>
<td>5</td>
</tr>
<tr>
<td>Kansas City (K)</td>
<td>3</td>
<td>Spring Hill</td>
<td>8</td>
</tr>
<tr>
<td>Kansas City (M)</td>
<td>4</td>
<td>Stanley</td>
<td>8</td>
</tr>
<tr>
<td>Lawrence</td>
<td>2</td>
<td>Stilwell</td>
<td>8</td>
</tr>
<tr>
<td>Leawood</td>
<td>5</td>
<td>Topeka</td>
<td>3</td>
</tr>
<tr>
<td>Lee's Summit</td>
<td>4</td>
<td>Westwood</td>
<td>5</td>
</tr>
<tr>
<td>Lenexa</td>
<td>4</td>
<td>Westwood Hills</td>
<td>5</td>
</tr>
<tr>
<td>Merriam</td>
<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table I-2 compares Olathe's per capita manpower with selected cities. The addition of 12 personnel in 1992 will increase the ratio to about 1.13, depending upon the population increase.

### Table I - 2
Fire Department Employees Per Thousand Population

<table>
<thead>
<tr>
<th>City</th>
<th>Population</th>
<th>Employees</th>
<th>Per 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kansas City (K)</td>
<td>144,205</td>
<td>399</td>
<td>2.77</td>
</tr>
<tr>
<td>Lawrence</td>
<td>65,608</td>
<td>88</td>
<td>1.34</td>
</tr>
<tr>
<td>Lenexa</td>
<td>34,034</td>
<td>71</td>
<td>2.09</td>
</tr>
<tr>
<td>Olathe</td>
<td>64,900</td>
<td>65</td>
<td>1.00</td>
</tr>
<tr>
<td>Overland Park</td>
<td>111,970</td>
<td>127</td>
<td>1.13</td>
</tr>
</tbody>
</table>
Table I - 3 shows the per capita dollar loss for the years 1988-90 for Olathe and selected cities. Fire loss is a function of property value as well as fire department capability, so the types of risk that a city has must be considered when comparing these data.

<table>
<thead>
<tr>
<th>City</th>
<th>Year</th>
<th>Population</th>
<th>Dollar Loss</th>
<th>Per Capita</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kansas City(K)</td>
<td>88</td>
<td>144,205</td>
<td>$4,246,738</td>
<td>$29.45</td>
</tr>
<tr>
<td></td>
<td>89</td>
<td>144,205</td>
<td>4,883,295</td>
<td>33.86</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>144,205</td>
<td>8,530,311</td>
<td>59.15</td>
</tr>
<tr>
<td>Lawrence</td>
<td>88</td>
<td>59,460</td>
<td>512,270</td>
<td>8.62</td>
</tr>
<tr>
<td></td>
<td>89</td>
<td>62,534</td>
<td>965,212</td>
<td>15.44</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>65,608</td>
<td>949,383</td>
<td>14.47</td>
</tr>
<tr>
<td>Lenexa</td>
<td>88</td>
<td>32,533</td>
<td>923,725</td>
<td>28.39</td>
</tr>
<tr>
<td></td>
<td>89</td>
<td>33,563</td>
<td>2,680,450</td>
<td>79.86</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>34,034</td>
<td>619,200</td>
<td>18.19</td>
</tr>
<tr>
<td>Olathe</td>
<td>88</td>
<td>60,000</td>
<td>855,533</td>
<td>14.26</td>
</tr>
<tr>
<td></td>
<td>89</td>
<td>62,800</td>
<td>1,266,555</td>
<td>20.17</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>64,900</td>
<td>1,441,045</td>
<td>22.20</td>
</tr>
<tr>
<td>Overland Park</td>
<td>88</td>
<td>106,860</td>
<td>2,151,408</td>
<td>20.13</td>
</tr>
<tr>
<td></td>
<td>89</td>
<td>109,325</td>
<td>1,538,834</td>
<td>14.08</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>111,790</td>
<td>1,848,311</td>
<td>16.53</td>
</tr>
</tbody>
</table>

Figure I-3 shows the number of emergency calls for 1988-90. In this time period, about 30% of the emergency calls involved actual fires. The balance were either fire calls where there was no fire or emergency medical calls. The number of emergency calls is expected to double in 1992 because of the department's increased role in emergency medical responses.
Table I - 4 compares the Olathe fire department's per capita cost with selected cities.

<table>
<thead>
<tr>
<th>City</th>
<th>Budget</th>
<th>Population</th>
<th>Per Capita</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kansas City (KS)</td>
<td>$19,217,000</td>
<td>165,000</td>
<td>$116.47</td>
</tr>
<tr>
<td>Lawrence</td>
<td>3,415,000</td>
<td>65,608</td>
<td>52.05</td>
</tr>
<tr>
<td>Lee's Summit</td>
<td>3,808,442</td>
<td>44,700</td>
<td>85.20</td>
</tr>
<tr>
<td>Lenexa</td>
<td>3,697,446</td>
<td>34,034</td>
<td>108.75</td>
</tr>
<tr>
<td>Olathe</td>
<td>3,081,524</td>
<td>64,900</td>
<td>47.48</td>
</tr>
<tr>
<td>Overland Park</td>
<td>5,197,000</td>
<td>95,256</td>
<td>54.56</td>
</tr>
<tr>
<td>Shawnee</td>
<td>1,569,740</td>
<td>39,400</td>
<td>39.84</td>
</tr>
</tbody>
</table>
Firefighters meet a wide variety of fire conditions at each fire. Some fires will be at an early stage and others may already have spread throughout the entire building. This variation in conditions complicates attempts to compare fire department capability. A common reference point must be used so that the comparisons are made under equal conditions.

For the Olathe study, the analysts selected a particular point of a fire’s growth that marks a significant shift in its threat to life and property - the flashover point. The following discussion describes why flashover is such a significant fire event, and explains why this stage is appropriate for evaluating fire department capability.

Fire department performance capability is easy to measure, but at the same time difficult to interpret. Specific performances are not difficult to record. Travel time data will show how long it will take to get fire companies to a fire at point X. Likewise, fireground tasks like operating an attack line or raising ladders are easy to measure. But these measurements by themselves don’t say what can be accomplished in the time frames recorded. More needs to be known before concluding what the fire companies are capable of when they get to a fire. Two significant factors which must be known are:

- The threat of the fire - Is it small and isolated from other combustible material? Are occupants trapped by smoke or flames? How fast is it growing?

- The number of fire suppression tasks involved - A small fire with little smoke might require only a few firefighters to extinguish and remove from the building. A larger fire will require a greater number of firefighters, and a fire where lives are threatened will require still greater numbers of firefighters.

In order to make valid comparisons of fire department capability, the comparisons must control for the variation in the fire threat factor and the fireground task factor. Section Two describes the dynamics of fire growth in order to acquaint the reader with how the analysis
controls for the variation of fire growth. The section goes on to describe the fire suppression tasks that are required at a typical fire scene. This will introduce the reader to what the fire companies must do—simultaneously and quickly—if they are to save lives and limit property damage. The analysis controls for the variation in manpower needs by matching the manpower with a specific point of fire growth.

Dynamics of Fire Growth

The answer for controlling the variation in the fire dynamics lies in finding a common reference point, something that is common to all fires regardless of the risk-level of the structure, the material or the length of time the fire has burned. Such a reference point exists. Regardless of the speed of growth or length of burn time, all fires go through the same stages of growth. And, one particular stage emerges as a very significant one because it marks a critical change in conditions. It is called flashover.

The flashover stage of a fire marks a big turning point in fire conditions that escalates the challenge to a fire department's resources. How and why this is so is explained in the following descriptions of each stage of fire growth.

- **Smoldering Stage** - This is the first stage of any fire. When heat is applied to a combustible material, the heat oxidizes the material's surface into combustible gases. The oxidation process is exothermic, meaning that the oxidation process itself produces heat. The heat from oxidation raises the temperature of more material, which increases the rate of oxidation and begins a chemical chain reaction of heat release and burning.

  A fire can progress from the smoldering phase immediately or slowly, depending upon the fuel, nearby combustibles and the surrounding air. For example, a wad of newspapers will smolder only a few seconds before progressing to the next stage, but a couch with a burning cigarette may continue smoldering for over an hour.

- **Incipient Stage** - When the temperature gets high enough, visible flames can be seen. This stage is called incipient or open burning. The visible burning at this stage is still limited to the immediate area of origin. The combustion process continues to release more heat which heats nearby objects to their ignition temperature, and they begin burning.

- **Flashover** - Not all of the combustible gases are consumed in the incipient stage. They rise and form a superheated gas layer at the ceiling. As the volume of this gas layer increases, it begins to bank down to the floor, heating all combustible objects regardless of their proximity to the burning object.

  In a typical structure fire, the temperature of the gas layer at the ceiling can quickly reach 1500°F. As the gas layer moves down it begins heating combustible objects in the
room to their ignition temperature. The gas layer is mostly carbon monoxide, so the absence of oxygen prevents the heated objects from bursting into flame. Oxygen gets introduced in two ways. There is often enough available oxygen near floor level to start the open burning process when the gas layer reaches that level. Or, the high heat breaks a window and the incoming oxygen allows the burning to begin. It should be noted that the room becomes untenable long before flashover. Even though open flaming may not be present until everything reaches $500^\circ$ F and oxygen is introduced, the room becomes untenable for human survival at $212^\circ$ F.\(^2\)

When flashover occurs, everything in the room breaks into open flame at once. The instantaneous eruption into flame generates a tremendous amount of heat, smoke and pressure with enough force to push beyond the room of origin through doors and windows. The combustion process then speeds up because it has an even greater amount of heat to move to unburned objects.

**Figure 2 - 1. Time/Temperature Curve.**

![Time/Temperature Curve](image)

Flashover is a critical stage of fire growth for two reasons. First, no living thing in the room of origin will survive, so the chances of saving lives drops dramatically. Second, flashover creates a quantum jump in the rate of combustion, and a significantly greater amount of water is needed to reduce the burning material below its ignition temperature. A fire that has reached flashover means it is too late to save anyone in the room of origin, and a lot more manpower is required to handle the larger hose streams needed to extinguish the fire. A post-flashover fire burns hotter and moves faster, compounding the search and rescue problems in the remainder of the structure at the same time that more firefighters are needed for fire attack.
The Significance of Flashover

<table>
<thead>
<tr>
<th>Pre-Flashover</th>
<th>Post-Flashover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited to one room</td>
<td>• Has spread beyond one room</td>
</tr>
<tr>
<td>Requires smaller attack lines</td>
<td>• Requires larger, more attack lines</td>
</tr>
<tr>
<td>Search &amp; rescue is easier</td>
<td>• Compounds search &amp; rescue</td>
</tr>
<tr>
<td>Initial assignment can handle</td>
<td>• Requires additional companies</td>
</tr>
</tbody>
</table>

To summarize the above, it is clear that the stage of a fire affects manpower and equipment needs. Both of these needs can be reasonably predicted for different risk-levels and fire stages. This ability to correlate manpower & equipment needs with fires according to their stage of growth became the basis for the Olathe study. The analysts selected the following objective as the mark of effectiveness for the Olathe fire department: maintaining enough on-duty firefighters & equipment strategically located so that the minimum acceptable response force can reach a reasonable number of fire scenes before flashover is likely.

It is unreasonable to expect a fire department to reach all fires before flashover, even the most heavily manned and equipped department. As for the reasonable number of fires that an effective response force should reach before flashover, the following point must be kept in mind. Given that some fires will reach flashover before the fire department can respond - either because the materials involved are very volatile, because the fire was accelerated with flammable liquids, or because the fire went unreported - it is unreasonable to expect the fire department to save every life or stop all significant property loss. An effective response force should be able to handle fires that are reported shortly after they start and are within the maximum prescribed travel time for the full assignment of fire companies according to the risk level of the structure. In the Olathe study, the manpower, equipment and travel times that accompany each of the risk categories in Section Three are based upon that premise.

Considering that the fire department cannot hold fire risk to zero, the study's objective was to find a balance between effectiveness, efficiency and reliability that will keep fire risk in Olathe at a reasonable level, and at the same time yield the maximum insurance savings at the least cost. The maximum prescribed travel times act as the limit to efficiency - put stations too far apart and the minimum effective response force cannot get to a fire demand zone in time.

It is important to get all of the required firefighters to a fire scene quickly because fire suppression is a simultaneous and coordinated activity. The following discussion explains why this is so vital to safe and effective fire operations.
Fire Scene Operations

In the discussion above, it was shown that the variables of fire growth dynamics and property/life risk combine to determine the fireground tasks that must be accomplished to stop the loss. These tasks are interrelated but can be separated into two basic types, fire flow and life safety. Fire flow tasks are those related to getting water on the fire. Life safety tasks are those related to finding trapped victims and removing them from the building.

The required fire flow is based on the building - its size, structural material, distance from other buildings, horizontal and vertical openness (lack of partitions), and its contents - type, density, and combustibility (BTU's per pound). In fact, the ISO bases its rating on fire flow, and classifies areas of the city by its fire flow requirement, i.e., areas requiring up to 3000 gallons per minute (GPM) and those areas requiring over 3000 GPM.

Fire flow tasks can be accomplished with hand-held hoses or master streams (nozzles usually attached to the engine or ladder). Each 1-3/4" hose requires a minimum of two firefighters. The hose can flow 130 GPM, so when these lines are used the fire flow is 65 GPM per firefighter. The 2-1/2" hoses can flow 250 GPM and require a minimum of five firefighters, yielding a flow of 50 GPM per firefighter. Master streams can flow from 500 to 1000 GPM each. They take relatively fewer firefighters to operate because they are fixed to the apparatus.

The decision to use hand lines or master streams depends upon the stage of the fire and threat to life safety. If the fire is in a preflashover stage, the firefighters make an offensive attack into the building with hand lines. The lines are used to attack the fire and shield trapped victims until they can be removed from the building. If the fire is in its postflashover stage and the structural damage is a threat to the firefighters' life safety (e.g., weakened roof, stairs), then the structure is declared lost and master streams are employed to keep the fire from advancing to surrounding buildings.

As the number of larger commercial occupancies (>10,000 sq. feet), high rise buildings and occupancies with high value contents increase, the required fire flow increases. Areas with very large and very valuable buildings can require fire flows of 8-10,000 GPM. The manpower needed to generate these fire flows can also be calculated, and this is how the ISO determines the number and placement of engine and ladder companies. The ISO evaluation for cities with a lower fire flow (mostly residential, small low rise commercial buildings) will require fewer firefighters, engines and ladder trucks. As the required fire flow increases, the number of fire companies gets larger.

The life safety tasks are based upon the number of occupants, their location (e.g., a low rise vs. high rise), their status (awake vs. asleep), and their ability to take self-preservation action. For example, ambulatory adults need less assistance than non-ambulatory. The elderly and small children always require more assistance.
The key to a fire department's success at a fire is coordinated teamwork, regardless of whether the fireground tasks are all fire flow related or a combination of fire flow and life safety. At a fire in an occupied structure, a minimum of eight tasks (Table II - 1) must be simultaneously conducted in order to stop the loss of civilian lives, stop further property loss, and do so while keeping the risks to the firefighters' lives at a reasonable level. The number and type of tasks needing simultaneous action will dictate the minimum number of firefighters needed at the fire at the same time. The discussion following the table describes each of these tasks and shows why they must be performed simultaneously.

<table>
<thead>
<tr>
<th>Task</th>
<th>Number of Firefighters</th>
<th>Company Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attack Line</td>
<td>2</td>
<td>1st Engine</td>
</tr>
<tr>
<td>Search &amp; Rescue</td>
<td>2</td>
<td>Ladder Truck</td>
</tr>
<tr>
<td>Ventilation</td>
<td>2</td>
<td>1st/2nd Engine</td>
</tr>
<tr>
<td>Back-up Line</td>
<td>2</td>
<td>2nd Engine</td>
</tr>
<tr>
<td>Safety Crew</td>
<td>1</td>
<td>As assigned</td>
</tr>
<tr>
<td>Pump Operator</td>
<td>2</td>
<td>Each Engine</td>
</tr>
<tr>
<td>Water Supply</td>
<td>1</td>
<td>2nd Engine</td>
</tr>
<tr>
<td>Command</td>
<td>1</td>
<td>Battalion Chief</td>
</tr>
</tbody>
</table>

The two fire scenarios used here will illustrate the importance of simultaneous and coordinated action, and also demonstrate why different levels of fire risk require different amounts of manpower and equipment. The first example is a fire in a detached single-car garage, and the second is a house fire.
Several important factors make a house fire a higher risk than a burning garage. The first factor is size. Garages are much smaller than houses and thus require less water to extinguish than house fires. Another factor is life risk. A garage fire is not likely to be a threat to life. Exposure is another factor. A garage is usually separated far enough from other structures so it cannot spread to them. In addition to these factors, the combination of small size and access around all sides allows firefighters to extinguish the fire from the exterior, and this removes the need for a backup crew. All of these factors mean that a relatively smaller force of firefighters can handle the risks of a detached garage fire than is needed for other types of structures.

Compared to the garage example, a house fire poses a higher level of risk and requires a correspondingly larger force of firefighters. A house's larger area and contents generate hotter and faster-growing fires that require more water - and consequently more hose lines - for extinguishment. The threat to occupants requires search and rescue to be conducted simultaneously with fire suppression. And, the fire attack cannot be safely done without the simultaneous ventilation of rooftop or wall openings. A backup crew is necessary anytime the firefighters are inside the building, adding to the manpower need.

These two examples show that a significantly greater number of firefighters & equipment is needed for a house fire than for a detached garage. As the discussion below will show, the tasks must be performed simultaneously, so the necessary manpower must arrive in a minimum amount of time so the crews can coordinate their actions.

Other structures such as apartments, nursing homes or large warehouses pose still higher risks than house fires because they require greater levels of manpower and equipment to arrive in a reasonable time and work in a coordinated manner. The discussion of risk categories in Section Three includes details explaining why the higher risks increase the need for additional manpower and equipment.

The fire attack practices used by the Olathe fire department are similar to accepted practices throughout the country for urban fire departments. Our activities at fires conform to nationally recognized safety practices for structural firefighters, and they comply with federal Occupational Safety & Health Administration (OSHA) rules for the same. The following terms describe the work units and tasks that are routinely performed at a structure fire.

### Factors That Determine Manpower Needs

<table>
<thead>
<tr>
<th>Factors That Determine Manpower Needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Building area</td>
</tr>
<tr>
<td>- Building height</td>
</tr>
<tr>
<td>- Condition of occupants</td>
</tr>
<tr>
<td>- Access to building</td>
</tr>
<tr>
<td>- Time of day</td>
</tr>
<tr>
<td>- Exposures</td>
</tr>
<tr>
<td>- Weather conditions</td>
</tr>
<tr>
<td>- Contents</td>
</tr>
<tr>
<td>- Building design</td>
</tr>
<tr>
<td>- Stage of fire</td>
</tr>
</tbody>
</table>
• **Attack Line** - A 1-3/4" hose that produces 130 GPM and is handled by a minimum of two firefighters, or a 2-1/2" hose that produces 250 GPM and is handled by 5 firefighters. Each engine carries a set of attack lines that are either preconnected to the pump, are folded on the hosebed, or in a special pack for carrying into high-rise buildings.

The selection of which attack line to use depends on the type of structure, the distance to the seat of the fire, and the stage of the fire. The preconnected lines are the fastest to use but are limited to fires within 200' of the pumper. When attack lines are needed beyond this limit, the hosebed lines or high-rise lines are used.

A 2-1/2" attack line will be used when the fire is already beyond the flashover stage and threatens an unburned portion of a structure.

• **Search and Rescue** - A minimum of two firefighters assigned to search for living victims and remove them from danger while the attack crew moves between the victims and the fire to stop the fire from advancing to them. A two-man crew is normally sufficient for most moderate-risk structures, but more crews are required in multi-story buildings or structures with people who are not capable of self-preservation.

• **Ventilation Crew** - A minimum of two firefighters to open a horizontal or vertical ventilation channel when the attack crew is ready to enter the building. Vertical ventilation or ventilation of a multi-story building can require more than two firefighters. Ventilation removes superheated gases and obscuring smoke, preventing flashover and allowing attack crews to see and work closer to the seat of the fire. It also gives the fire an exit route so the attack crew can "push" the fire out the opening they choose and keep it away from endangered people or unburned property.

Ventilation must be closely timed with the fire attack. If it is performed too soon, the fire will get additional oxygen and grow. If performed too late, the attack crew cannot push the fire in the direction they want. Instead, the gases and smoke will be forced back toward the firefighters and their entry point, which endangers them, any victims they are protecting, and unburned property.

• **Back-up Line** - A 1-3/4" or 2-1/2" line that is taken in behind the attack crew to cover the attack crew in case the fire overwhelms them or a problem develops with the attack line. This needs a minimum of two firefighters if a 1-3/4" line is used.

A 2-1/2" line will be used for back-up instead of a 1-3/4" line where the type of fire is one that could grow rapidly if not stopped by the attack line.
• **Safety Crew** - A minimum of one firefighter equipped with self-contained breathing apparatus (SCBA) and available near the entry point to enter the structure and rescue the attack, S & R, or back-up crew if something goes wrong. This particular requirement is an OSHA rule.

• **Exposure Line** - A 1-3/4" attack line manned by two firefighters and taken above the fire in multi-story buildings to prevent fire expansion. Also used externally to protect nearby structures from igniting from the radiant heat. In situations where the heat release is great (flammable liquids), a 2-1/2" line or deluge gun would be used. If 2-1/2" lines are used it doubles the manpower requirement.

• **Pump Operator** - One firefighter assigned to deliver water under the right pressure to the attack, back-up and exposure lines, monitor the pressure changes caused by changing flows on each line, and ensure that water hammer doesn't endanger any of the hose line crews. This firefighter also completes the hose hookups to the correct discharges, and completes the water supply hookup to the correct intake. The Fire Apparatus Operator can sometimes make the hydrant hookup alone if the pumper is near a hydrant (50'), but the hydrant spacing for moderate risk fires normally precludes this.

• **Water Supply** - A crew of one or two firefighters who must pull the large diameter hose between the pumper and the nearest hydrant, hookup at the hydrant and deliver a water supply to the pumper before the pumper's water tank runs dry. A pumper has about four minutes of water if one 1-3/4" line is flowing.

• **Command** - An officer assigned to remain outside of the structure to coordinate the attack, evaluate results and redirect the attack, arrange for more resources, and monitor conditions that might jeopardize crew safety.

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**Fireground Tasks & Fire Department Capability**

When a fire starts, the fire risk factors for the structure, contents and occupants will control the fire growth dynamics. The rate of fire growth and its threat to life will determine the tasks that must be performed to stop the fire, save lives and minimize property loss.

The number of tasks and their need to be performed simultaneously determine the amount of manpower and equipment that must respond. The fire department’s effectiveness will be determined by its ability to get its resources to a fire early enough in the process so that its on-duty resources can adequately handle all of the needed tasks quickly and simultaneously.
For a fire in a moderate risk FDZ, the fire department should respond with 12 firefighters, two engines, a ladder truck and battalion chief. If the department is to be capable of doing this, then its fire stations must be located strategically so that the travel time to the FDZ's is short enough for all of the manpower and equipment to arrive before flashover occurs. This level of resources can set up the equipment and simultaneously handle the tasks of fire attack, search & rescue, ventilation, backup lines, pump operation, water supply and command, all within a few minutes. If fewer firefighters and equipment are available, or if they have longer travel distances to cover, then the department will not be successful.

Since the average time from a fire's incipient stage to flashover is five minutes, the travel times selected for Olathe should allow the fire department to arrive before flashover in the majority of cases (about 4 out of 5). The prescribed times are longer than the five minute flashover time, but this is compensated for by the fact that a portion of the fires will still be in the smoldering stage when reported, which will normally mean a longer time before flashover occurs. In the long run, then, the fire department will get to most fires before they reach flashover. The other one-in-five fires that are not reached before flashover are those cases noted earlier where the fire went to flashover rapidly because flammable accelerants were present or because the fire burned a long time before being reported.
Section Three

Measuring Community Fire Protection

A low fire insurance rating saves residents money and attracts commercial development. The insurance industry rating for municipal fire departments and water systems has become a de facto planning device for fire station locations, although it was never designed for that purpose. The Olathe analysts selected a street network model for the study, and made several alterations to replace qualitative judgements with quantitative data. This section compares the two models, explains why the street network model was selected, and discusses the modifications which were made.

Municipal Fire Protection Systems

Fire protection in a community is comprised of public and private components. The public component is provided by municipalities and consists of the fire department and municipal water supply. The private fire protection elements are the sprinkler and alarm systems that are installed by individual building owners.

Cities provide public fire protection for two basic purposes. The first is life safety. Because fires can grow quickly and cut off escape paths, fire departments should be capable of rescuing people who are caught in a burning building. A large portion of the population are not able-bodied and thus require help in exiting - such as the young, elderly, hospital patients, etc. These people rely heavily on the fire department to get there in time to remove them from harm.

The second purpose of public fire protection is property conservation. Fire departments should be equipped to prevent conflagrations, which are fires that involve multiple structures. The building density found in urban settings increases the risk that a fire will leap from one building to another if not stopped. Conflagrations have caused the loss of entire cities or major portions of them and are still a threat today.
Where fire departments are adequately equipped and manned, the citizenry receive a
double benefit. First, they have a reasonable chance that their places of work and residences
will be spared the threat of a fire and that they will survive a fire in their place of work or
residence. In addition, residents and business owners receive a proportionate reduction in
their fire insurance costs as the level of public protection increases.

The ISO Model

Historically, the insurance industry has been the only source for systematically measuring
the quality of public fire protection. A service organization for the insurance industry known
as the Insurance Services Office (ISO) grades public fire departments and water departments
on a variety of factors and then assigns a numerical rate to the city. The rating is used by
individual insurance companies to set their fire insurance premiums in a city.

The ISO rating has a range of 1 to 10. A rating of 1 is the best, and a rate of 10 is given
to areas with no public water supply and no fire department. The rate - and insurance premi­
ums - gets progressively lower as a city's fire protection and water supply improves. Only 10
cities in the U. S. have an ISO rating of 1.

Olathe's current ISO rate is 5. The fire department records don't indicate when Olathe
received its first rating, but in 1926 the rating changed from 7 to 6. A 1966 evaluation re­
duced the rating to 5. The last evaluation was conducted in 1976, but no change was made to
the rating.

Although it is designed for use by insurance companies, cities routinely use the ISO rat­
ing to gauge the quality of their fire protection. As part of its rating service, the ISO pro­
vides a "deficiency letter" to the city which outlines the steps needed to improve the rating.
Many cities have used the deficiency letter recommendations to plan for improving fire pro­
tection.

Limitations of the ISO Model

The ISO evaluation was developed for insurance purposes so agents could reasonably predict
the loss ratio in a particular jurisdiction. Also, the tool was designed for manual use and
oversimplifies its measurements to make them easier to be done by hand. These and the fol­
lowing factors restrict its validity for measuring fire department capability.

- The ISO rating focuses exclusively on property loss and does not consider the life loss
  potential. The number of firefighters and equipment called for by ISO are based on
  flowing the necessary amount of water to extinguish a fire. Consequently, a rating that
  yields an acceptable property loss record may not yield an acceptable life loss record.
The expense of getting a lower rating may be higher than the insurance savings.

The insurance savings aren’t uniformly distributed; once the rating goes below 5, businesses will receive further premium reductions but single-family homeowners won’t.

The ISO analysis applies a standard travel time to all areas regardless of local characteristics, and thus can underestimate or overestimate the actual travel time of fire department units. Figure III - 1 compares an ISO standard engine company response area with the PTI analysis for Station 1. The figure shows that the faster travel routes in Station 1’s area give it a longer reach than the ISO analysis credits it with.

### The PTI Model

In the late 1970’s, a computer program became available that could analyze large databases of street network information. Every intersection is called a node, and streets become segments between each node. Each segment is assigned a travel speed, which is a function of the posted speed limit. With this data, analysts can evaluate any combination of travel routes to find the best route for getting from point A to point B.

Since travel time is a critical element to a fire department’s response, the software developers expanded its application to fire station location analysis. This was accomplished by identifying pieces of property that lie along the travel routes as nodes, so travel routes could be evaluated for particular locations along segments as well as between intersections. A fire station would be the beginning node in the network and a selected site would be the destination.

This type of data base has a unique feature that applies specifically to fire departments. Fire departments deploy their equipment throughout the city to put as much of the city as possible within a short travel distance from

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### Features of the PTI Analysis

- Converts intersections to nodes.
- Converts streets to segments.
- Defines each fire station as a starting node.
- Defines each fire demand zone as a termination node.
- Can analyze multiple sets of start nodes at the same time.
- Allows an unlimited number of potential station sites to be added for planning.
- Ranks sets of fire stations according to the number of fire demand zones each set can reach.
a fire station. However, no one station has enough equipment to handle all of the tasks necessary at a structure fire, so several stations must respond in order to supply the required apparatus. The computer program is able to analyze countless variations of multiple stations to find the best combination for answering a fire call in a particular part of the city. This is invaluable because the possible variations make it impossible to perform this analysis by hand.

Some degree of uniformity is used to spare repeated computer runs for buildings on the same block, so each square mile section is broken into 1/16 sections, yielding 64 pieces per square mile. These 1/8 sq. mile sections become the destination nodes and represent all of the buildings within that area, about one square block. A risk level is assigned to each node, and is determined by the highest-risk building in the node. These sections are called fire demand zones (FDZ’s). The computer can be given a set of fire stations and it will find the fastest combined travel routes to each FDZ. It will then list a variety of station groups that are ranked according to the number of FDZ’s for each risk level that can be reached in the prescribed time.

Originally designed for mainframe computers, the program is able to perform a detailed analysis of the relative benefit of countless combinations of existing and potential fire stations. In order to make such a large number of comparisons, the computer program must make some assumptions about the travel routes (the particular assumptions that apply to Olathe will be discussed below). The assumptions used in the computer model were tested in various settings throughout the country, and a reliable method emerged for analyzing station location. The Overland Park fire department owns a version for smaller computer systems, and had already included parts of Olathe in their data base because the department’s have automatic aid agreements for their common borders. The Overland Park data base was updated and expanded to include the rest of Olathe, and the program was then able to analyze the Olathe region as well.

The analysts applied the PTI methodology in the following steps:

- Each structure in the city was surveyed, using the survey form in Attachment 2, and assigned to one of five risk categories listed below. The category assignments are based upon the number of firefighters and amount of equipment needed to effectively respond to a working fire in that type of structure.

- Each part of the city was assigned to an FDZ, and each FDZ was categorized according to the highest risk structure within it. For example, an FDZ comprised of all single-family homes would be classed as a moderate risk FDZ.

- Suggested station sites were evaluated based on their relative travel time to all FDZ’s in the station’s assigned area. The travel times were measured for each of the five risk levels.
The potential station sites were ranked according to the number of FDZ's that can be reached in the prescribed amount of time with the needed manpower and equipment.

Risk Categories & Travel Times

The Olathe study uses five levels of risk. The risk levels are defined by the following factors: the ability of occupants for taking self-preserving action, construction features such as building height, passive fire protection, built-in fire suppression, the required fire flow, exposure to other buildings and the nature of the contents. Each of these factors contributes a variable demand on fire department resources, and these demands are known. The relative demands are matched with the manpower & equipment which would be necessary to stop life and property loss if those resources can arrive before a fire reaches the flashover stage. This particular stage of a fire and its significance for fire analysis will be discussed below.

Each risk level is assigned two maximum prescribed travel times. The first travel time is for the first-due company, and the second time is for the remainder of the fire companies needed to make up an effective response force for that risk level. The travel times for each risk category are:

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>First Due</th>
<th>Other Assigned Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>3.0</td>
<td>5.0</td>
</tr>
<tr>
<td>High</td>
<td>3.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Moderate</td>
<td>4.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Low</td>
<td>5.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Minimum</td>
<td>6.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>

Like the manpower & equipment amount, the maximum prescribed travel times vary for each risk level. The shorter travel times are related to the same factors noted above that dictate higher numbers of manpower and equipment. The setup time is longer at the higher-risk levels, so travel time is shortened to compensate.
The following list of risk categories used in the Olathe analysis includes examples of the representative types of structures in each category and the minimum manpower & equipment needed for an effective response force for that risk level.

- **Maximum Risk** - High-rise & large-area buildings that lack built-in fire suppression and contain occupants who are not capable of self-preservation. Examples are Good Samaritan Towers and the Kansas State School for the Deaf.

  The effective response force for maximum-risk FDZ's is 24 firefighters, four engines, two ladders and two battalion chiefs. The maximum prescribed travel times are 3 minutes for the first-due and 5 minutes for the remainder of the assigned companies.

- **High Risk** - High-rise buildings with built-in fire suppression, commercial buildings over 10,000 square feet with occupants who would not normally need assistance, buildings with built-in fire suppression but with occupants who need assistance, apartment buildings over two stories or with areas beyond the reach of pre-connected attack lines, buildings with low occupancy but which use or store high-hazard material. Examples are the Olathe Medical Center and Witco Chemical.

  The effective response force for high-risk FDZ's is 16 firefighters, three engines, one ladder truck and one battalion chief. The maximum prescribed travel times are 3.5 minutes for the first-due company and 5.5 minutes for the remainder of the assigned companies.

- **Moderate Risk** - Commercial buildings under 10,000 square feet without high-hazard contents, detached 1 or 2 family homes, apartment buildings of two stories or less where all areas are accessible to pre-connected attack lines.

  The effective response force for moderate-risk FDZ's is 12 firefighters, two engines, one ladder truck and one battalion chief. The maximum prescribed travel times are 4.0 minutes for the first-due company and 6.0 minutes for the reminder of the assigned companies.

- **Low Risk** - Small commercial structures that are remote from other buildings, detached residential garages, out-buildings.

  The effective response force for low-risk FDZ's is eight firefighters, one engine, one ladder truck and one battalion chief. The maximum prescribed travel times are 5 minutes for the first-due company and 7 minutes for the remainder of the assigned companies.

- **Minimum Risk** - Rural land with no occupied structures, recreational areas. The effective response force for minimum-risk FDZ's is 4 firefighters and one engine. The maximum prescribed travel times are 6.0 minutes for the first-due company and 8.0 minutes for the remainder of the assigned companies.
Limitations of the PTI Model

The PTI model contains underlying assumptions about the street network data base that put conditions upon any conclusions drawn from the data. Thus, it is important to keep them in mind when interpreting the data.

- **Station Availability** - The model assumes that all stations are available. It assigns groups of stations to specific FDZ's, and it assumes that every station in the group always is free to respond. In reality, however, this is not the case. As a fire department's call load increases, the probability of unavailable units also increases.6

- **Travel Conditions** - The PTI model assumes that travel conditions are ideal. The travel time formula assumes that traffic loads are non-peak, road conditions are dry, and it is daylight. In reality, emergency responses are more likely to be made under less than optimum travel conditions, so decision makers must keep in mind that the theoretical results have a bias toward the best case scenario, not the normal scenario. In the case of travel times, the analysts already added one minute to the PTI times, and the difference between the theoretical results and actual conditions means that the results are somewhat liberal. Where a particular FDZ shows a travel time of 4 minutes, in reality it will likely be longer.

- **Intersection Traffic** - The PTI model assumes that all intersections are open, i.e., no stop signs or semaphores to slow the companies. In reality, most of the travel routes in Olathe do not have open intersections. In Olathe, about 85% of the traffic semaphores have Opticom traffic control units which minimize this limitation at signalled intersections. The Opticom control units are triggered by the fire apparatus. Each fire apparatus has a strobe light emitter which signals the control unit to turn its traffic signal to green so traffic will clear and allow the apparatus to proceed through the intersection. The intersection limitation still applies to intersections with stop signs and railroad crossings.

In summary, all of these assumptions and limitations must be kept in mind when interpreting the data. There is a systematic bias toward a liberal model in the analysis.

Modifications to the PTI Model

- **Response Reliability** - The analysts created the measure of response reliability to make decision makers aware of the difference between the theoretical results and what the department can actually produce. As will be discussed in Section Four, the measure shows that when a fire call is received, there is on average a 12.5% chance in 100 that one or more of the assigned companies will not be available. In these instances, a fire in an area that nor-
mally would be in the effective response area may not receive all of the resources that should respond. The measure also enables us to determine how the reliability will change as the number of alarms increases.

Response reliability is a function of the number of calls and the average time that a company is on a call. The formula for the response reliability score is based on a statistical measurement called a Poisson distribution.\(^7\)

Response reliability is calculated by finding the reciprocal of the probability:

\[
p(n) = \frac{(R^a)(D^a)^n}{n!} (R^a / D^a)
\]

where
- \(n\) = number of multiple alarms
- \(a\) = alarms
- \(R^a\) = Rate of alarms per time period
- \(D^a\) = Duration of alarms

For the Olathe study, the analysts assigned a duration time of .5 hours. Although the average fire call is longer, over half of the calls are emergency medical service (EMS) and they average relatively less time. The formula can be used to calculate the probability of a *double header* (a call already in progress when another is received), *triple headers* (two calls in progress when another is received), etc. by changing the value of \(n\). The value for \(R^a\) is found by dividing the alarm rate by the desired time period. A commonly-used time period is 24 hours.

- **Travel time Modifications** - The PTI model suggests the maximum prescribed travel times for each risk level, but users can modify the times if they think that it is justified because of local conditions that differ from the model's parameters. In the Olathe study, the analysts added one minute to each of the travel times. The analysts reasoned that the PTI's more restrictive travel times are more appropriate for jurisdictions such as densely populated areas where limited or zero property line setbacks increase the risk of exposure fires. Since a relatively smaller portion of Olathe resembles this scenario, the analysts felt justified in making the model more liberal for Olathe.

- **Travel route modifications** - The analysts modified the travel routes in three ways. First, travel barriers which will be improved were considered to be improved. For example, the 119th street bridge is going to improve Station 2's travel time to the east side of I-35. The computer runs assumed that the new bridge was already in place.

The other two modifications involved travel speeds and neighborhood access. The streets in some of the areas considered for potential fire stations are not improved yet, and that makes it difficult to predict street speeds. The problem is compounded in areas with no streets because the street layout isn't known either. For their projections, the analysts took
the best case scenario. Arterial streets were assigned speeds of 45 mph and collectors were
assigned 35 mph. It was assumed that land sections would have through streets to each eighth
section.

It is important to keep these assumptions in mind when considering the data on Station 6
and future fire stations, for these best case assumptions add a liberal bias to the results. If an
improved arterial ends up with a 35 mph limit instead of 45 mph, the projections overstate
the service area for a fire station using that street. If an area is designed to limit through
streets, travel speed to FDZ’s in that area will be
much longer than the projections show.

<table>
<thead>
<tr>
<th>Modifications to PTI Model</th>
</tr>
</thead>
</table>
| • All planned road improve-
  ments were assumed to exist. |
| • Where future street speeds
  were unknown, the most
  liberal anticipated speeds
  were assigned. |
| • Local neighborhoods were as-
  sumed to have liberal access, i.
  e., lots of through streets
  and no cul-de-sacs. |

• Risk category modifications - After the risk
categories were assigned to all structures in the city,
random structures in each category were selected for
review to check the model’s validity. The checks
revealed some factors that lead the analysts to
determine that some structures in the maximum risk
category could be treated differently.

Many churches in the city fell into the maximum
risk category. They can require a high fire flow
because they are large, open structures where fire
can move swiftly. The analysts noted that many of
the churches were set back on their property great
distances, which substantially reduces their threat to
adjoining property.

In the cases where the churches were set back on
their property so as to not pose a fire exposure risk
to other property, and where the structures were limited to worship services (i.
  e., not used
for day care, etc.), they were not considered as maximum risk structures for determining
response effectiveness. The FDZ’s, however, are still shown as maximum risk on the maps
in Section Four to denote the areas which require a high fire flow.
Section Four

Analysis Results

The results of the station location analysis are presented in four parts. Part 1 describes Olathe’s risk situation and shows how capable the department is of dealing with that risk.

Part 2 deals with the question of Station 4 and discusses the options of renovating, moving or closing the station.

Part 3 analyzes eight potential sites for a station in the Cedar Creek and north Olathe areas, which is expected to be the next priority for improving fire protection.

In Part 4, the analysts recommend the fire department improvements which will get Olathe’s ISO rating reduced from 5 to 3. A comparison is made between the ISO approach and the PTI model to show how the city can gain the maximum benefit from the most efficient and effective station layout.

☐ Olathe's Fire Risk

At present, Olathe has 2908 FDZ’s within the city limits. It is expected to have a total of 5634 FDZ’s when fully developed. Table IV - 1 shows the breakdown of FDZ’s by risk category and their percentage of the total.

Figure IV - 1 shows the distribution of FDZ’s by risk level. The moderate risk FDZ’s are uniformly distributed throughout the city. This is to be expected because most of the moderate risk FDZ’s are occupied by residential structures, and 52% of Olathe’s developed area is residential land use. The high risk FDZ’s have a heavy concentration along the I-35 corridor and US-169, although a moderate number are distributed among the moderate risk areas. The maximum risk FDZ’s are more concentrated in the older sections of Olathe, with a heavy concentration just east of I-35 between Santa Fe and 141st.
The majority of the minimum-risk FDZ's are on the perimeter of the city, but are gradually being converted to moderate or high-risk as undeveloped land changes to occupied land. Based on data from the Olathe planning department, the analysts project that moderate-risk FDZ's will comprise 60% of the total, high-risk about 25-30%, and the remaining 10-15% will remain minimum-risk.

Table IV - 1.
FDZ's Within City Limits

<table>
<thead>
<tr>
<th>Risk category</th>
<th>No.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>30</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>High</td>
<td>247</td>
<td>8.5</td>
</tr>
<tr>
<td>Moderate</td>
<td>802</td>
<td>27.8</td>
</tr>
<tr>
<td>Low</td>
<td>6</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Minimum</td>
<td>1823</td>
<td>63.2</td>
</tr>
<tr>
<td>Total</td>
<td>2908</td>
<td>100</td>
</tr>
</tbody>
</table>

Fire Department Manning

The Olathe fire department's on-duty strength is comprised of four engine companies and one ladder company that occupy four stations. Each engine company has an assigned manning of three firefighters. The minimum manning is also three firefighters, so the average manning on the engine companies never varies.

The ladder company is located at Station 1 and has an assigned manning of six firefighters. Three of the six assigned firefighters must be hazardous materials technicians. The ladder company's minimum manning is three and its average manning is also three. The additional assigned firefighters are used to replace engine company personnel who are absent for vacation, training or illness. The ladder company's minimum manning is three firefighters. If the manning falls below three the ladder is removed from service.
Figure IV - 2 shows the ladder company's manning frequency for the first six months of 1991. Budget constraints forced the department to reduce the minimum manning from four to three in 1991 and remove the company from service when the manning fell to less than three. The department plans to return to its normal minimum manning of four in 1992.

![Figure IV - 2. Ladder Company Average Manning](image)

**Projected Demand for Service**

The fire department has two major categories of alarms, fire and emergency medical service (EMS). The EMS calls accounted for about 50% of the total alarms until 1987, when a policy change cut the number of EMS calls by 75 percent. The EMS First Responder program which was initiated in July, 1991 essentially restores the pre-1987 response policy, so the annual alarms will increase significantly over the 1990 and 1991 rates. Figure IV - 3 shows the projected annual alarm rate based on a 1991 anticipated total of just under 2500 calls and a 1992 rate of 3000.

The annual alarm rate has been increasing at about 7 percent per year. Figure IV - 3 contains two projected growth curves, the top one with a 7 percent growth rate and the bottom with a more conservative 5 percent. If the alarms continue increasing at their historical rate, the department will experience a 120% increase in fire and EMS calls within 10 years. At the 5 percent rate, the total will increase by 88 percent.

The projected demand is important for two reasons. First, it helps decision makers in forecasting when additional stations will be needed. Second, it indicates how the additional workload will effect the department's response reliability.
With four stations and 3-man crews, no high risk FDZ's are in an effective response area.

Figure IV - 4. Coverage of High Risk FDZ's with four stations and 3-man companies.
Response Effectiveness

The Olathe fire department's response effectiveness was analyzed for each of the five risk levels, since the maximum prescribed travel time and effective response force vary for each level.

- Maximum Risk FDZ's

The effective response force requirements for maximum risk FDZ's are about double the fire department's on-duty strength, and a post-flashover fire in these structures will overwhelm the fire department's on-duty resources. Mutual aid is available to make up the manpower and equipment deficiency, but the longer travel time puts them out of reach for an effective response area. With its present manning and equipment levels, the fire department will only be successful at this risk level when fires have not reached flashover.

- High Risk FDZ's

Figure IV - 4 shows the distribution of high risk FDZ's relative to the four existing fire stations. With this station arrangement and three-man fire companies, none of the high risk FDZ's are in an effective response area.
Figure IV - 5 shows the effective response area for three-man companies with the addition of Station 5. The fifth station will provide enough on-duty strength to cover some high risk FDZ's, but their number is minimal.

--- Moderate Risk FDZ's

Table IV - 2 shows the fire department's response effectiveness for moderate risk FDZ's in three different time periods. The first column shows the department's effectiveness before December, 1990 when it had three stations. The second column is the current situation with four stations, and the third column shows the impact of adding Station 5 in 1992.

<table>
<thead>
<tr>
<th>Table IV - 2.</th>
<th>Response Effectiveness for Moderate Risk FDZ's, with 3, 4, &amp; 5 Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(based on 2908 FDZ's)</td>
</tr>
<tr>
<td>Stations</td>
<td>3</td>
</tr>
<tr>
<td>No.</td>
<td>%</td>
</tr>
<tr>
<td>FDZ's</td>
<td>83</td>
</tr>
</tbody>
</table>

Figures IV - 6, 7, and 8 show the change in response effectiveness for moderate risk FDZ's with the former three-station arrangement, the current four-stations, and the addition of Station 5.

Table IV - 2 and Figure IV - 7 show that reopening the former Station 2 as Station 4 has made a significant impact on the department's response effectiveness. Although the department's manning did not increase, redeploying the firefighters with one additional engine company put an additional 635 FDZ's within reach of an effective response force. Figure IV - 7 also compares the effective response areas for the three and four-station arrangement. In the four-station arrangement, the south perimeter is expanded because Station 4 is providing the third engine instead of Station 2. In the three-station arrangement, effective coverage of the south perimeter was limited by Station 2's six minute travel time.

The small improvement in the northeast area illustrates the limitation that one available ladder company puts on response effectiveness. Even though Station 4 is closer to that area, the full assignment for a moderate-risk FDZ includes the ladder company. Response effectiveness for the northeast area is limited by the six minute travel distance of the ladder company.
With 3-man companies, .5% of the high risk FDZ's are in an effective response area.

Figure IV - 5. Effective Response Area for High Risk FDZ's, five stations, 3-man companies.
With three stations and 3-man crews, the effective response area covers 83 moderate risk FDZ's & 3% of the total FDZ's.

Figure IV - 6. Effective Response Area for stations 1, 2, 3 with three-man companies.
With four stations and 3-man crews, the effective response area covers 718 moderate risk FDZ's & 24.7% of the total FDZ's.

Figure IV - 7. Effective response area for stations 1, 2, 3, & 4 with 3-man companies.
With five stations and 3-man crews, the effective response area covers 817 moderate risk FDZ’s & 28.1% of the total FDZ’s.

Figure IV-8. Effective response area for stations 1, 2, 3, 4, & 5 with 3-man companies.
Table IV-2 and Figure IV-8 show that the addition of Station 5 will net a marginal increase in response effectiveness. Only 99 additional FDZ's are covered by an effective response force. Again, the ladder company's travel time is a significant limiting factor because any FDZ's over six minutes from Station 1 are essentially out of the moderate risk effective response area.

Taken by itself, Station 5's contribution to response effectiveness is questionable. But, considering that the ladder company's travel time limit and other factors, the particular site that was chosen may have been the best option. When the decision was made to build a fire station on the west side, the primary objective was to reduce response time to the Persimmon Hill subdivision. The site at Spruce & K-7 will reduce the first-due engine's travel time from nine minutes to about six, a significant improvement but still short of the maximum prescribed first-due travel time of four minutes. But, the Spruce/K-7 site (and other prospective sites which would have yielded an even lower first-due travel time) was handicapped by several factors.

An overriding factor that limits Station 5's contribution is that prior decisions on siting Olathe's fire stations always considered each station as an independent unit, not as part of a system. Rather, the stations were distributed in terms of geographical equity (an engine company for every part of the city). Spreading stations out like they have been is equitable on the surface, but apparently the impact on the department's effectiveness was never considered. Consequently, geographic equity was gained at the expense of demand and risk equity - the stations weren't placed strategically to help where the fires occur and where the residents are at more risk.

In fact, the case can be made that the decisions to close the downtown station and former Station 2 actually worsened the fire risk. Station 5, then, was handicapped from the start because its ability to improve the department's effectiveness score is limited by where the existing stations are.

The second factor is the limited access to Persimmon Hill. In a preliminary report to the city council in 1990, the analysts confirmed that a station site north of Spruce/K-7 would have improved the department's response effectiveness and Stations 5's efficiency. However, the site would have had a marginal impact on first-due travel time to Persimmon Hill because the subdivision has no access from the north. The situation would have been quite different if 127th linked Persimmon Hill to highway K-7. With access to Persimmon Hill from the north, an alternate Station 5 site north of the Spruce/K-7 area would have reduced the first-due travel time to the subdivision, while at the same time improving Station 5's efficiency and the department's effectiveness.

The Spruce/K-7 site does, however, yield an important benefit that shouldn't be overlooked. In spite of its limited impact on response effectiveness and efficiency, the Station 5 site will make a significant difference in response reliability for the older parts of Olathe and the downtown business district.
— Low and Minimum Risk FDZ's

The fire department can cover all of the low and minimum risk FDZ's in the city with the exception of the Cedar Creek area, as shown in Figure IV - 9. The low/minimum area coverage is what most people equate with good fire protection, i.e., a single fire engine arriving within a few minutes. The single engine response is adequate for vehicle fires, outside fires and medical emergency calls. Figure IV - 9 shows that, with the exception of the Cedar Creek subdivision and five smaller subdivisions on the periphery of the city, there is an equitable distribution of service for small fires and medical emergencies.

— Summary of Response Effectiveness

In summary, the data point out that the Olathe fire department is essentially equipped and organized to respond to emergencies in moderate, low and minimum risk FDZ's. The department's coverage of low/minimum risk FDZ's is adequate, but most moderate, high and maximum risk FDZ's are not covered by an effective response force. Pre-flashover fires that involve both life risk and property risk will exceed the fire department's resources because the department doesn't have enough on-duty firefighters who can arrive at such a fire in an adequate time. Post-flashover fires in these FDZ's will continue to overwhelm the fire department's on-duty resources, and the fire department action in these cases will be primarily defensive operations. This means that the department will essentially declare the structure as lost and set up their equipment to prevent fires from extending to other properties.

The results are consistent with the ISO rating of 5. As noted above, the maps point out that the department's response effectiveness is limited by the six minute travel time of the ladder company, which is needed to fill the assignment for a moderate-risk FDZ. Consequently, the department's response effectiveness cannot improve until a second ladder company is added. The department is recommending that a second ladder company be added when Station 6 is built. Part 3 of this section discusses alternative sites for Station 6 and compares the improvement in response effectiveness for each site.

Response Reliability

The Olathe fire department's response reliability varies throughout the day because the call load isn't uniformly distributed over the 24 hour period. As shown in Figure IV - 10, the score averages about 88% from 8 AM to 12 PM, a time period which comprises 66% of the day but when 80% of the daily calls are received.

The response reliability increases to 94% during the midnight to 8 AM period, when the calls drop off considerably. The time period between 3 PM and 7 PM is the peak demand time, and here the response reliability drops to 75%. This means in the peak demand period, all of the companies needed for an alarm will only be available 75% of the time when a call
is received. Consequently, 25% of the calls in that period will require that a substitute company replace the busy one. Using a substitute company will mean that the normally expected response time for a particular FDZ cannot be met.

Figure IV - 10. Response Reliability by Hour.

Using the 1991 fire reports, the analysts validated the response reliability formula by counting the double headers (a call that is received while one is already in progress). The monthly totals of double headers ranged from 10-17%, which matches the average predicted by the formula. Based on the annual expected alarm increases shown on Figure IV - 1, within 10 years the department's response reliability could reduce to about 60%. That means that the reliability will be even lower during peak demand times of the day.

Just as response reliability is not uniform throughout the day, it isn't uniform throughout the city. The roughly four sq. mile area that is old Olathe makes up about 8 percent of the city but generates over one third of the fire calls. Consequently, the probability of an unavailable fire company is much higher for this area than the rest of the city. Engines 1 and 4 share the first-due duties for most of the area in question.

An additional point that must be kept in mind when interpreting the scores is that the number of fire companies assigned per call is not uniform. Depending upon the risk level of the FDZ where a call is received, as many as three engines and the ladder truck might be dispatched. Thus, the probabilities discussed here reflect the unavailability of at least one engine company, but any particular call could remove up to three engines and the ladder from availability.
While the Station 5 location does not add a lot to the department's effectiveness and is fairly inefficient relative to Station 1, its presence on the west edge of Olathe's high-demand area is a solid margin of safety for the area of the city which is most likely to have fires. Given the higher probability that one of the first-due engines will be busy when a fire call is received, Station 5 gives the department a third engine to fill in for the missing company. This will make a marked improvement in the department's reliability in the very area that needs it. Taken in context, then, the siting decision for Station 5 can be seen as a sound one.

Response Efficiency

The response efficiency formula created by the Olathe analysts measures each station's productivity. A station's response efficiency depends upon two factors: how many FDZ's it covers in its maximum prescribed first-due travel time, and how many of those FDZ's get duplicate coverage by other companies in their maximum prescribed first-due travel time. Figure IV - 11 illustrates the overlapping FDZ's for Stations 3 and 4.

Each station's response efficiency score is a weighted average of its station-to-station efficiency scores. Those scores are added and divided by the number of stations. That average is then multiplied by a weight of $< > 1$ which is derived from each station's actual share of FDZ's vs. its ideal share. For example, if a city had four stations that covered 2000 FDZ's in their first-due travel times, each station's ideal share would be 25% of the FDZ's, or 500. A station that actually covered 350 of the 2000 FDZ's would get a weight of .7. The weight for a station that covered 600 FDZ's would be 1.2.

Table IV - 3 shows the response efficiency scores for the four Olathe fire stations. Table IV - 4 shows the change to response efficiency that results from adding Station 5. Its four minute first-due area will add 457 more FDZ's for a total of 2435.

The response efficiency scores point out some interesting facts about the existing station locations, with Station 2 in particular. Station 2's relatively low score indicates that its value to the department's effectiveness is questionable. There are three reasons for the station's low efficiency, the first being its proximity to the north city limits. Because most of its north area is cut off by the city limits, the station's 329 FDZ's are the smallest of the five stations. As Figure I - 1 showed, the station could actually cover 500 FDZ's if it were not limited by the city limits.

The two other factors contributing to Station 2's low efficiency are the street layout of the Olathe Trails subdivision just east of I-35 and the street layout just west of the station. The street network in the Olathe Hills subdivision is dominated by cul-de-sacs and has few through streets. This layout was an intentional planning decision. It is preferable for residential areas because it reduces vehicle speed and increases safety to pedestrians. However, the increased safety comes at the cost of longer travel times for emergency vehicles.
Station 4 FDZ's = 507
FDZ's common to Station 3 = 259
Station 4/3 Efficiency = 49%

Figure IV - 11. Station Efficiency for Station 4 vs. Station 3.
### Table IV - 3.
Response Efficiency
(Based on four stations with 1978 FDZ's)

<table>
<thead>
<tr>
<th>Station No.</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>FDZ's</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With Station:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>*</td>
<td>92</td>
<td>80</td>
</tr>
<tr>
<td>2</td>
<td>96</td>
<td>*</td>
<td>99</td>
</tr>
<tr>
<td>3</td>
<td>86</td>
<td>98</td>
<td>*</td>
</tr>
<tr>
<td>4</td>
<td>68</td>
<td>73</td>
<td>33</td>
</tr>
<tr>
<td>Average</td>
<td>83.3</td>
<td>87.7</td>
<td>70.7</td>
</tr>
<tr>
<td>FDZ %</td>
<td>34.3</td>
<td>16.6</td>
<td>23.4</td>
</tr>
<tr>
<td>Weight¹</td>
<td>1.37</td>
<td>.66</td>
<td>.94</td>
</tr>
<tr>
<td>Response Efficiency</td>
<td>114.1</td>
<td>57.9</td>
<td>66.5</td>
</tr>
</tbody>
</table>

Notes:
1. The weight value is the percentage over/under the station's equal share of FDZ's. For example, the equal share of FDZ's for four stations is 494, or 25% of the 1978 shared FDZ's. Station 1 has 679 FDZ's, which is 34.3% of the total FDZ's. That figure is 137% of the 25% figure. Therefore, the weight for Station 1 is 1.37.

The street layout west of Station 2 also causes longer travel times. Because 119th street doesn't connect Nelson and Woodland, Engine 522 must travel four miles to reach 119th and Woodland rather than the two mile distance if 119th went through. If this barrier were not present, a much larger area west of Station 2 would have been within its four minute first-due travel time and its response efficiency score would have been larger.
### Table IV - 4.
Response Efficiency
(Based on five stations with 2435 FDZ's)

<table>
<thead>
<tr>
<th>No. FDZ's</th>
<th>Station No.</th>
<th>1 (679)</th>
<th>2 (329)</th>
<th>3 (463)</th>
<th>4 (507)</th>
<th>5 (457)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stations:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>*</td>
<td>92</td>
<td>80</td>
<td>55</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>96</td>
<td>*</td>
<td>99</td>
<td>83</td>
<td>91</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>86</td>
<td>98</td>
<td>*</td>
<td>49</td>
<td>N²</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>68</td>
<td>73</td>
<td>33</td>
<td>*</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>68</td>
<td>88</td>
<td>N²</td>
<td>95</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>79.5</td>
<td>87.8</td>
<td>70.7</td>
<td>70.5</td>
<td>79.7</td>
</tr>
<tr>
<td>FDZ %</td>
<td></td>
<td>27.89</td>
<td>13.51</td>
<td>19.01</td>
<td>20.82</td>
<td>18.77</td>
</tr>
<tr>
<td>Weight¹</td>
<td></td>
<td>1.39</td>
<td>.675</td>
<td>.950</td>
<td>1.04</td>
<td>.938</td>
</tr>
<tr>
<td>Response Efficiency</td>
<td></td>
<td>110.5</td>
<td>59.3</td>
<td>67.2</td>
<td>73.3</td>
<td>74.9</td>
</tr>
</tbody>
</table>

**Notes:**

1. The weight value is the percentage over/under the station's equal share of FDZ's. For example, the equal share of FDZ's for five stations is 487, or 20% of 2435. Station 1 has 679 FDZ's, which is 27.89% of the total FDZ's. That figure is 139.4% of the 20% figure. Therefore, the weight for Station 1 is 1.39.

2. N = no contiguous FDZ's.
Station 4 Decision

The former Station 2 was closed in July, 1989 when Stations 2 and 3 were opened. Shortly after the station location study was initiated in mid-1990, preliminary data showed a serious gap in coverage on the northeast area. The data showed that the response time to that area would get much longer when the 119th street bridge was closed, but also that the response times would still be poor when the new 119th street bridge opened. After reviewing the data, the city council ordered that the former station be reopened on a temporary basis pending a decision to either renovate it for permanent use or relocate it to a more effective location.

The station location analysis was used to evaluate an alternate location for Station 4 at the intersection of 127th and Blackbob, 1.8 miles from Station 4. The capability measures are compared to show the impact on the department's capability of relocating the station vs. renovating the existing one.

— Response Effectiveness.

The alternate site won't improve the department's response effectiveness because the ladder truck's six minute travel time only goes partially into the Station 4 district. The ladder company limitation can be seen on figures IV - 7 & 8. The north and east limits around Station 4 remain the same for the four-station and five-station arrangements because those lines are set by ladder company's six minute travel distance.

— Response Efficiency.

The alternate site would significantly improve Station 4's efficiency. Table IV - 5 compares the station:station efficiency and response efficiency scores for Station 4 and the alternate site.

The table shows that the biggest contributor to the alternate site's efficiency improvement is the better Station 4:Station 1 ratio. A net increase in FDZ's also helps by giving the alternate site a higher weight. The 16% improvement could have been higher if some of the gain from reducing the Station 1 overlap weren't offset by the increased Station 2 overlap.

— Response Reliability.

At its present location, Station 4's first-due travel time extends west of I-35. This is what contributes to the low Station 4:Station 1 efficiency ratio, but it also provides more redundancy to the area with more fire calls. Consequently, relocating Station 4 will improve the Station 4:Station 1 efficiency at the expense of lowering the department's response reliability in the downtown area.
Table IV-5.
Response Efficiency for Station 4 & Station 4 Alternate

<table>
<thead>
<tr>
<th>No. FDZ's</th>
<th>Station 4</th>
<th>Alternate 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(507)</td>
<td>(574)</td>
</tr>
<tr>
<td>With Station:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>55</td>
<td>94.7</td>
</tr>
<tr>
<td>2</td>
<td>83</td>
<td>74.9</td>
</tr>
<tr>
<td>3</td>
<td>49</td>
<td>54.5</td>
</tr>
<tr>
<td>5</td>
<td>95</td>
<td></td>
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<tr>
<td>Average</td>
<td>70.5</td>
<td>75.7</td>
</tr>
<tr>
<td>Weight¹</td>
<td>1.04</td>
<td>1.15</td>
</tr>
<tr>
<td>Response Efficiency</td>
<td>73.3</td>
<td>87.0</td>
</tr>
</tbody>
</table>

Notes:
1. The weight value is the percentage over/under the station's equal share of FDZ's. For example, the equal share of FDZ's for five stations is 487, or 20% of 2435. Station 4 has 507 FDZ's, which is 20.8% of the total FDZ's. That figure is 104% of the 20% share. Therefore, the weight for Station 4 is 1.04.

— Construction vs. Renovation costs.

Preliminary cost estimates in 1990 for renovating Station 4 were $150,000-200,000.00. The station was designed for a 20-year life span and hasn't received any substantial maintenance since it was built in 1971. The renovation would add 500 square feet to expand the dormitory and construct bathroom facilities for female employees.

The preliminary cost estimate for a new station at 127th and Blackbob is estimated at $600-700,000.00 (assuming a one-engine station similar to Station 5). The cost difference will obviously be a significant question in the decision on whether to relocate or renovate.
— Relationship to Station 6 Decision.

The decision on Station 4 should not be made independently of the Station 6 decision because that decision could involve removing the engine company from Station 2. The data for the potential Station 6 sites indicate that it could be more cost effective to move the Station 2 engine to the Station 6 site, thus requiring 12 new firefighters for the ladder company instead of 24 new personnel to man both a second ladder and a sixth engine. If this were done, the efficiency of the alternate Station 4 site would improve even more. The alternate site's efficiency would increase beyond the 87% score because the gain in the Station 4:Station 1 ratio would not be picked up by the Station 4:Station 2 overlap. Most of the Station 6 sites could still provide the backup coverage for the downtown area and would restore the redundancy that Station 4 currently provides downtown.

The alternate Station 4 location, coupled with the location of a second ladder company along the north area of Olathe, would also increase the department's response effectiveness. When the overall costs are tabulated, the construction cost of the alternate Station 4 site would be paid for in two years of operations with five engine companies instead of six.

Station 6 Planning

The northwest area of Olathe is the next priority for improving fire protection. The Cedar Creek subdivision already has a significant number of moderate risk FDZ's as well as two high risk FDZ's with high fire flow and life safety factors. Opening Station 5 will improve the first-due travel time to the subdivision, but both the first-due and full assignment travel times will still be well beyond the maximum prescribed travel times for moderate and higher risk FDZ's.

Station 2 currently has a 12 minute travel time to Cedar Creek. Station 5 will reduce it to nine minutes. The first-due travel time will still be twice the maximum prescribed travel time for moderate-risk FDZ's, and the still greater distance of the subdivision from the other stations will keep Cedar Creek out of an effective response area until another station is built. Also, the ISO rating for commercial structures in the Cedar Creek area will likely be higher than 5 unless a second ladder company is added to the new station along with its engine company.

The station location analysis compared the efficiency and effectiveness of eight potential sites to find the best combination of improving fire protection on the northwest side, improving the department's response effectiveness and reducing the city's ISO rating. As was noted in Section Three, the analysis of this region was based upon the best case assumptions that all planned arterial and collector streets were available, street speeds were the highest that could be anticipated, and that street layouts enhanced access from any direction.
These are important points to keep in mind because the few existing streets in that area have low travel speeds, and the existing residential streets restrict through travel. Consequently, the analysis of the Station 6 alternative sites is really measuring future effectiveness and efficiency, and with a very liberal bias. To wit, the first-due FDZ's for the potential Station 6 sites average 959 FDZ's as opposed to the 487 FDZ average for Stations 1-5.

Placing a station in that area today with the existing street network will yield lesser effectiveness and efficiency scores than the study shows. And assuming that the present residential street layout continues to be employed as new plats are developed, then the FDZ's in the Cedar Creek area that will actually be within an effective response area will reduce in number from the projected numbers.

This fact is not a criticism of the present development policy of favoring cul-de-sacs and few through streets. The point is being made to explain why the existing response effectiveness and efficiency scores are lower than the ones projected for the Station 6 sites, and to make the reader aware of how decisions like these impact on the city's ability to provide equitable levels of fire protection for areas of the city that may be dissimilar.

The potential sites were designated as 6A through 6H, and the locations were chosen to yield a range of values for effectiveness and efficiency on both the north/south and east/west axes in the north part of the city. The sites which were evaluated are located at the following intersections:

<table>
<thead>
<tr>
<th>Station</th>
<th>Intersection</th>
</tr>
</thead>
<tbody>
<tr>
<td>6A</td>
<td>College &amp; Lone Elm Road.</td>
</tr>
<tr>
<td>6B</td>
<td>College &amp; Woodland.</td>
</tr>
<tr>
<td>6C</td>
<td>119th &amp; Lone Elm Road.</td>
</tr>
<tr>
<td>6D</td>
<td>119th &amp; Woodland.</td>
</tr>
<tr>
<td>6E</td>
<td>123rd &amp; Ridgeview.</td>
</tr>
<tr>
<td>6F</td>
<td>College &amp; K-7.</td>
</tr>
<tr>
<td>6G</td>
<td>College &amp; Clare Road.</td>
</tr>
<tr>
<td>6H</td>
<td>College &amp; Cedar Niles Bled.</td>
</tr>
</tbody>
</table>

Response Efficiency.

Table IV - 6 compares the response efficiency of the eight selected sites for Station 6.
Table IV - 6
Efficiency of Potential Station 6 Sites

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDZ's</td>
<td>(905)</td>
<td>(802)</td>
<td>(921)</td>
<td>(944)</td>
<td>(918)</td>
<td>(1075)</td>
<td>(1135)</td>
<td>(973)</td>
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<tr>
<td>1</td>
<td>96.6</td>
<td>88.8</td>
<td>84.7</td>
<td>85.7</td>
<td>76.6</td>
<td>91.5</td>
<td>98.2</td>
<td>N²</td>
</tr>
<tr>
<td>2</td>
<td>73.2</td>
<td>38.5</td>
<td>91.4</td>
<td>63.4</td>
<td>36.9</td>
<td>90.8</td>
<td>78.9</td>
<td>N²</td>
</tr>
<tr>
<td>3</td>
<td>N²</td>
<td>N²</td>
<td>N²</td>
<td>N²</td>
<td>N²</td>
<td>N²</td>
<td>N²</td>
<td>N²</td>
</tr>
<tr>
<td>4</td>
<td>N²</td>
<td>N²</td>
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<td>N²</td>
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<tr>
<td>5</td>
<td>58.1</td>
<td>84.4</td>
<td>60.8</td>
<td>64.2</td>
<td>74.9</td>
<td>85.9</td>
<td>75.1</td>
<td>83.0</td>
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<td>62.8</td>
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<td>84.1</td>
<td>83.0</td>
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<tr>
<td>Weight¹</td>
<td>1.62</td>
<td>1.48</td>
<td>1.65</td>
<td>1.68</td>
<td>1.64</td>
<td>1.84</td>
<td>1.91</td>
<td>1.71</td>
</tr>
<tr>
<td>Response Efficiency</td>
<td>123.1</td>
<td>113.8</td>
<td>132</td>
<td>119.4</td>
<td>103.0</td>
<td>164.5</td>
<td>160.6</td>
<td>141.9</td>
</tr>
</tbody>
</table>

Note: 1. The weight value is the percentage over/under the station's equal share of FDZ's. For example, the equal share of FDZ's for Station 6A and the other five stations is 557, or 17% of 3340. Station 6A has 905 FDZ's, which is 27.1% of the total FDZ's. That figure is 162% of the 17% share. Therefore, the weight for Station 6A is 1.62.

2. N = noncontiguous first-due areas.

Response Effectiveness.

For the evaluation of potential response effectiveness, the analysts made two changes to procedure. First, the number of potential FDZ's was based on a Standardized FDZ Area. Second, the FDZ's were not categorized by hazard category.

The Standard FDZ Area was set for uniformity. All of the potential sites cover areas that are not now within the city limits but will be in the future. Each site has a different ratio of in/out FDZ's. In order to make uniform comparisons for the six sites, the analysts selected a standard FDZ limit as shown in Figure IV - 12. The south limit doesn't cover all of the incorporated area, but the line disregards the unincorporated areas within the existing city limits, making an even trade. The specific line isn't important, though, since it is only being used to get a common denominator for the effectiveness calculations.

Table IV - 7 and Figures IV - 13-20 show the response effectiveness scores and the distribution of each site's FDZ coverage.
Figure IV - 12. Comparison of Standard FDZ Area and existing city limits.
The effective response area covers 1341 FDZ's, 35.2% of the Standard FDZ Area.

Figure IV - 13. Effective response area for moderate risk FDZ's using six stations with 3-man companies, Station 6A at College & Lone Elm.
The effective response area covers 1329 FDZ's, 34.9% of the standard FDZ Area.

Figure IV - 14. Effective response area for moderate risk FDZ's using six stations with 3-man companies, Station 6B at College & Woodland.
The effective response area covers 1556 FDZ's, 40.9% of the Standard FDZ Area.

Figure IV-15. Effective response area for moderate risk FDZ's using six stations with 3-man companies, Station 6C at 119th & Lone Elm.
The effective response area covers 1417 FDZ’s, 37.2% of the Standard FDZ Area.

Figure IV - 16. Effective response area for moderate risk FDZ’s using six stations with 3-man companies, Station 6D at 119th & Woodland.
Figure IV - 17. Effective Response Area for moderate risk FDZ's using 3-man company's station 6E at 123rd & Ridgeview.

The effective response area covers 1212 FDZ's, 31.8% of the standard FDZ Area.
The effective response area covers 1527 FDZ's, 40.1% of the Standard FDZ Area.

Figure IV - 18. Effective response area for moderate risk FDZ's using six stations with 3-man companies, Station 6F at College & K-7.
The effective response area covers 1095 FDZ's, 28.8% of the Standard FDZ Area.

Figure IV - 19. Effective response area for moderate risk FDZ's using six stations with 3-man companies, Station 6G at College & Clare.
The effective response area covers 960 FDZ's, 25.2% of the Standard FDZ Area.

Figure IV - 20. Effective response area for moderate risk FDZ's using six stations with 3-man companies, Station 6H at College & Cedar Niles Blvd.
Table IV - 7
Response Effectiveness
of Station 6 Sites
(with 3806 FDZ/s)

<table>
<thead>
<tr>
<th>Site No.</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. FDZ's</td>
<td>1341</td>
<td>1329</td>
<td>1556</td>
<td>1417</td>
<td>1212</td>
<td>1527</td>
<td>1095</td>
<td>960</td>
</tr>
<tr>
<td>Response Effectiveness</td>
<td>35.2</td>
<td>34.9</td>
<td>40.9</td>
<td>37.2</td>
<td>31.8</td>
<td>40.1</td>
<td>28.8</td>
<td>25.2</td>
</tr>
</tbody>
</table>

Notes:
1. The number of FDZ's is from the Standard FDZ Area, which covers area outside of the existing city limits.

When comparing the data in Table IV - 7, it is important to note that the calculations were based on the Standard FDZ Area and not the FDZ's in the existing city limits. This changes the denominator for the efficiency and effectiveness calculations to 3806, as opposed to the denominator of 2908 that was used for Table IV -2. To make the data comparable, the FDZ's on Table IV -2 must be divided by 3806 instead of 2908. For example, the entry on Table IV - 7 for the Station 6H site is 25.2% and the entry on Table IV -2 for 5 stations is 28.1%. To make the data comparable, they both must be divided by 3806, which would change the Table IV - 2 entry from 28.1% to 21.5%.

The response efficiency and effectiveness scores for the eight potential sites illustrate the dilemma between efficiency and effectiveness. If efficiency were the only criterion, the obvious selection would be the 6H site at College and Cedar Niles Boulevard. It is closest to the center of the Cedar Creek development and has the second-highest efficiency score. Its efficiency score is arbitrarily lower because it is close to the eventual west city limit, and if this were disregarded it would be the highest score.

If the selection of the Station 6 site is made similar to past decisions on station locations, 6H would appear to be the best site. However, the data on response effectiveness show that 6H provides the least improvement in department capability. For the Cedar Creek area, the station could provide six firefighters, one engine and one ladder within the maximum prescribed travel time. But the minimum manpower for moderate risk FDZ's is 12 firefighters, two engines and one ladder. While the station site appears to add a lot, in reality it adds little to the overall cost effectiveness of the Olathe fire department.
Improving Response Effectiveness

The data show that the fire department's manning & equipment level is adequate for moderate risk structures in a limited part of the city, but that a sizable portion of the moderate risk FDZ's will remain beyond the effective area until a second ladder company is added on the north side. The data also show that the department is getting closer to meeting the response criteria for high risk FDZ's in a small portion of the city. The addition of Station 5 will yield enough personnel to meet the manning need for some high-risk FDZ's, but only in a small area around Santa Fe and I-35 (Figure IV - 4).

The current response effectiveness scores point up the fact that the ISO rating isn't likely to change unless the department's capability is improved. The data show that the department is capable of handling a single-family house fire in the center of the city, and only one at a time. Part of the reason is that the stations were sited to maximize efficiency, but the decisions ignored the impact on overall effectiveness.

The other reason for the low effectiveness scores is manpower, which leaves the city with two options. First, it can locate stations closer together. The increased density of three-man companies will then allow the required minimum manpower to reach a larger part of the city within the maximum prescribed travel times. The second option is to keep the stations spread to maximum efficiency but add a fourth firefighter to each company. This arrangement requires fewer companies to make up an effective response and would significantly increase the department's response effectiveness.

The data also point to another deficiency in the relationship between the 6H site and Station 2 regarding the coverage of the north Olathe area between I-35 and Cedar Creek. Station 2's travel barriers limit the station's efficiency for the area in question, and that restricts Station 2's contribution to the department's response effectiveness. If the decision is made to place Station 6 relatively closer to Cedar Creek, then the city must either accept deficient coverage of the area between Station 2 and station 6 or add a seventh fire station to serve that area.

Adding a fourth firefighter would also allow the city to exploit a cost saving advantage pointed out in the data on the Station 6 sites. The response effectiveness scores for four-man companies indicate a potential for a more cost-effective alternative than adding a sixth engine company. The alternative could also remove the need for a seventh fire station in the north region. Using the 6F site as an example, the 6F site is far enough east of Cedar Creek to increase the response effectiveness for the north area and yet still place the high risk FDZ's that are planned along K-10 west of K-7 in an effective response area. The residential part of Cedar Creek would be just outside the moderate risk effective response area, but the solution
to this would occur when enough development takes place to warrant a fire station south of the subdivision.

This arrangement would benefit the commercial development in the K-10/K-7 area because it would be within the two-mile ISO standard response zone for ladders, so the ISO rate would be lower for that region. The position of the site in question, when coupled with a relocated Station 4, would serve both Cedar Creek and the north region of Olathe without the need for Station 2. Thus the net number of engines would remain at five instead of six. The annual cost savings of about $500,000.00 is significant.

The four-man option gives the city more flexibility in the long run. The fire service is constantly seeking methods to extend the time to flashover, such as higher standards in the building codes for padded furniture and wall finishes. If this were to occur in the future and the time to flashover lengthens, then the city could reduce the manning to three firefighters per company without any loss in response effectiveness.

An addition of a fourth firefighter to each engine company would, all things considered, lower Olathe's ISO rating. The additional firefighter per unit would increase each engine company's pumping capacity, which is a significant factor in the ISO rating. The lower ISO rating would mean lower insurance premiums for businesses, which would increase Olathe's attractiveness for business.

As noted earlier, a lower ISO rating would yield a double benefit to Olathe residents. Their tax burden would decrease as more businesses pay a bigger share of the taxes. And, their life safety would increase because more firefighters would be available to perform rescues. The fire department's per capita manning would increase to 1.26 per thousand, slightly less than Lawrence, which has 1.34 personnel per thousand and an ISO rating of 2.

Figure IV - 21 compares the department's current response effectiveness with the potential response effectiveness if each fire company had four firefighters. Figure IV - 22 makes the same comparison for the addition of Station 5.

All of the Station 6 analysis assumed that a ladder company would be added along with an engine company. If this improvement isn't made, then Station 6 will not increase the department's response effectiveness at all. As was noted earlier in the report, the six minute travel time of the ladder limits the effective range of surrounding engine companies for moderate risk FDZ's.

The addition of a second ladder company at Station 6 will significantly improve the department's response effectiveness. Table IV - 8 shows the relative improvement that would occur for each of the Station 6 alternative sites. Figures IV - 23-30 show the distribution of the areas in question.
3-man crews cover 24.7% of the total FDZ's.

4-man crews cover 32.6% of the total FDZ's.

Figure IV - 21. Comparison of effective response area for four stations, 3-man vs. 4-man companies.
3-man crews cover 28.1% of total FDZ's.

4-man crews cover 55.7% of total FDZ's.

Figure IV - 22. Comparison of effective response area for five stations, 3-man vs. 4-man companies.
Figure IV - 23. Comparison of effective response area for six stations, 3-man vs 4-man companies, Station 6A at College & Lone Elm.

3-man crews cover 35.2% of Standard FDZ Area.

4-man crews cover 66.4% of Standard FDZ Area.
3-man vs. 4-man companies, Station 6b at College & Woodland.

Figure IV - 24. Comparison of effective response area for six stations.

- City limits
- Four-man
- Three-man

FDZ Area
4-man crews cover 63.7%
3-man crews cover 34.9%

FDZ Area
4-man crews
Figure IV - 25. Comparison of effective response area for six stations, 3-man vs. 4-man companies, Station 6C at 119th & Lone Elm.

3-man crews cover 40.9% of Standard FDZ Area.

4-man crews cover 64.2% of Standard FDZ Area.
3-man crews cover 37.2% of Standard FDZ Area.
4-man crews cover 67.4% of Standard FDZ area.

Figure IV - 26. Comparison of effective response area for six stations, 3-man vs. 4-man companies, Station 6D at 119th & Woodland.
Three-man crews cover 31.8% of Standard FDZ Area.

4-man crews cover 66.7% of Standard FDZ Area.

Figure IV - 27. Comparison of effective response area for five stations,*
3-man vs. 4-man companies, Station 6E at 123rd & Ridgeview.
*Station 2 engine would move to 6E station.
Three-man crews cover 40.1% of the Standard FDZ Area.

4-man crews cover 71.4% of the Standard FDZ Area.

Figure IV - 28. Comparison of effective response area for six stations, 3-man vs. 4-man crews, Station 6F at College & K-7.
Figure IV - 29. Comparison of effective response area for six stations, 3-man vs. 4-man crews, Station 6G at College & Clare.
Figure IV - 30. Comparison of effective response area for six stations.
3-man vs. 4-man crews, Station 6 at College & Cedar Niles Boulevard.

City Limits

4-man crews cover 88.1% of the Standard PDZ Area.
3-man crews cover 25.2% of the Standard PDZ Area.

FIGURE IV - 30
Table IV - 8.
Response Effectiveness\(^1\) for Six Stations
Three vs. Four-man Companies

<table>
<thead>
<tr>
<th>Site</th>
<th>3-man crew</th>
<th>4-man crew</th>
</tr>
</thead>
<tbody>
<tr>
<td>6A</td>
<td>35.2</td>
<td>66.4</td>
</tr>
<tr>
<td>6B</td>
<td>34.9</td>
<td>63.7</td>
</tr>
<tr>
<td>6C</td>
<td>40.9</td>
<td>64.2</td>
</tr>
<tr>
<td>6D</td>
<td>37.2</td>
<td>67.4</td>
</tr>
<tr>
<td>6E</td>
<td>31.8</td>
<td>66.7(^2)</td>
</tr>
<tr>
<td>6F</td>
<td>40.1</td>
<td>71.4</td>
</tr>
<tr>
<td>6G</td>
<td>28.8</td>
<td>69.3</td>
</tr>
<tr>
<td>6H</td>
<td>25.2</td>
<td>68.1</td>
</tr>
</tbody>
</table>

Notes:
1. The response criteria used for these scores are for moderate risk FDZ’s.
2. The scores for 6E do not count Station 2 because of their close proximity.

In addition to its impact on response effectiveness, the crew size significantly affects setup time and suppression time at a fire scene. A minimum of four firefighters per unit is recommended by nationally recognized standards for safe and effective operations.\(^9\) The recommendation is supported by research on the relationship between crew size, effectiveness and fatigue.\(^10\) The Dallas (TX) fire department conducted two major research projects on the relationship between manpower and fireground task performance, and the Olathe fire department has replicated the Dallas study to verify its results. The replication results support the validity of the Dallas study, and are included as Attachment 3 to this report.

— Option for Manpower Increase.

The recommendation to staff each apparatus with a minimum of four firefighters would require a 25% increase in fire department manning. Since personnel costs comprise the majority of the fire department's budget, the cost of this option is significant. The analysts have created a manning plan that would provide the manpower increase for less money than hiring additional career firefighters.

The recommended option is to create a firefighter apprenticeship program and assign a firefighter apprentice to each apparatus so that each engine would be staffed with three career firefighters and one apprentice. The apprentices would be counted by ISO as regular firefighters, thus helping the city to get an improved rating but at a lower cost.
The apprenticeship program would differ from traditional apprenticeships in that the apprentices would not be guaranteed jobs with the Olathe fire department when they complete their apprenticeships. The Olathe fire department would be their training ground, but when an apprentice completes his three-year program he would be replaced with another apprentice. It would then be each apprentice's responsibility to gain employment as a journeyman firefighter.

This model is a significant cost benefit to the city because one fourth of the fire department would be paid apprentice wages, and those wages would never grow to journeyman wages. In addition, the city would not accrue higher fringe benefit costs such as vacation and sick leave because each apprentice would leave the program after three years.

Obviously, four career firefighters would be the best method for increasing manpower. But when one considers the fireground tasks described in Section Two, it can be seen that relatively inexperienced apprentices can fulfill the less demanding tasks and free the experienced firefighters for the more demanding tasks.

The tasks can be categorized into two levels of difficulty. Compared to the tasks of fire attack and rescue, tasks like pulling hoselines, making hydrant hookups and placing ladders can be performed by less experienced personnel. In fact, these tasks are already divided this way in every fire department. New firefighters are always assigned to the less risky tasks until they have enough training to be used in selected incidents. As they prove themselves to their supervisors, they are assimilated into the more risk-laden fireground tasks. The apprentice program would systematically provide each crew with a less experienced firefighter who would always perform the less-demanding but just-as-necessary support functions.

The Olathe apprenticeship program would have a unique feature which answers the question of what happens to the apprentices when they qualify as firefighters. The Olathe program would act as an affirmative action program by selecting recruits who normally could not pass typical fire department exams. The apprentices would be required to perform remedial work to address their deficiencies as they progress through the normal firefighter training.

To illustrate, the typical firefighter selection process can be seen as a three skill-track approach. Firefighters must be mentally and physically capable, and must have a certain level of firefighting training. Historically, fire departments have filled their ranks by selecting individuals who are qualified mentally and physically but who are deficient in the firefighting skills area. They then put the recruits through a rookie school to bring their firefighting skills up to standard.

The Olathe program would test each individual's abilities in the three skill-tracks just like typical fire departments, but would select individuals who might have educational or physical deficiencies as well. The apprentice training would address these deficiencies just as typical apprentice programs address a recruit's firefighting skill deficiency. This program becomes
an affirmative action program because those individuals who historically fail to meet fire department standards in education and physical strength are overrepresented by members of minorities and protected classes.

The issue of physical strength is a case in point. Females typically do not possess the amount of upper body strength that males do, and this one attribute can single them out in firefighter physical ability tests. Fire suppression tasks emphasize stamina of the upper body muscles, so females consistently fail to measure up to the test criteria. However, these tests can be revised to identify those females who are capable of increasing their upper body strength through a remedial program. The Olathe apprenticeship program would design a physical training program for each individual, and that person would be required to meet physical improvement milestones during their apprenticeship in addition to meeting their firefighter training milestones.

The educational skill track would work in the same manner. An individual who is not educationally skilled enough to pass the firefighter entry exam but has at least an eighth grade reading ability could complete the apprentice program by meeting remedial reading, writing and math milestones in addition to the firefighter training milestones.

The apprenticeship program that would serve as an affirmative action program benefits everyone. The city can improve its ISO rating and attract more commercial development. Olathe residents get a reduced tax burden and better life safety. The firefighters life safety improves because they have enough support personnel at fires to allow more of the experienced firefighters to work on the fire.

The apprentices benefit by becoming qualified for a job that they normally could not attain. They would be in demand from fire departments both locally and across the country because those departments need more qualified minorities to balance their ranks.

Many issues need to be addressed to identify the program's total costs. For example, it must be decided if community resources are available (or can be developed) to supply the remedial training, or if the training must come from department personnel. Some issues cannot be resolved until the program is actually implemented. For example, other fire departments have indicated a need for qualified minority applicants, but the successful placement of Olathe apprentices wouldn't be known until they graduate and apply at other departments. The fire department would address this issue by requesting a pilot program with a smaller number of apprentices. A full-scale program would not be requested until the pilot program demonstrates that the apprenticeship program works as anticipated.
Additional Steps for Improving Response Effectiveness.

In addition to the manpower issue, several additional items can help improve the department's capability. Some of them are non-cost items.

Automatic Aid Agreements — Expanding Olathe's existing automatic aid agreements can improve the department's response effectiveness for moderate risk FDZ's in selected parts of the city. For example, the ladder company at Overland Park Station 4 (at 119th and Lowell) can reach the northeast corner of Olathe within the six minute maximum prescribed travel time. Figure IV - 31 shows the portion of Olathe in question. The agreement has been discussed and tentatively agreed on, and could add up to 76 moderate risk FDZ's to the Olathe effective response area. It is important to note that the ISO rating will count the automatic aid as if it were an Olathe ladder company. This further enhances the likelihood of a rate improvement, not to mention the improved life safety for the area in question.

The inclusion of Lenexa's Station 4 (at 108th & Renner) in the alarm assignment for a part of the north side can increase Olathe's response effectiveness, but the specific degree of improvement depends upon the addition of a second ladder company and its location. The two departments have initiated discussion of an automatic aid agreement, and Figure IV - 31 shows the area that Lenexa is willing to consider for a response area. Lenexa has expressed the willingness to enter into such an agreement but the matter is complicated by the fact that Rural Fire District 3 has territory in the same area.

Dispatch Policy — The fire department has also requested changes to dispatch policies which can reduce dispatch time. The county has reviewed its dispatch needs and has prepared a request for proposals to improve the fire dispatch computer system. The county has also increased taxes so additional fire dispatchers can be hired.

Turnout Time Reduction — The fire department is currently evaluating fire company turnout times in hopes of reducing the time it takes to leave the fire stations. Olathe's mix of address numbering systems and street naming adds to turnout time because the firefighters often have to stop and consult detailed maps to make sure they know where a call is located. This can add up to a minute to turnout time. Short of revamping the Olathe address system, the only viable solution is to install a computer data base that will produce routing information to every address in the system. The address could be automatically downloaded from the county fire dispatchers system as they take the call, and the routing could be printed in every fire station and fire vehicle as the firefighters don their protective clothing.

Fireground Setup Time — Setup time is another potential area for improvement. The firefighters can reduce this time by practicing their fire suppression tasks, but Olathe doesn’t have a training facility for this purpose. This will continue to limit the scope and quality of the firefighters training until a training facility is available.
Long Range Planning

Olathe will have 5634 FDZ's when fully developed, about double the existing number. As new areas are added to the city, the station location data base should be revised to forecast the timing and location of new fire stations. The current data, when coupled with the planning department data, indicate the need for seven to nine fire stations with 7-9 engine companies and three ladder companies. This number is the most cost-effective method for gaining and keeping a lower ISO rate (2 or 3). This assumes that the department has four-man companies, since three-man companies would require several more stations to yield the same level of effectiveness. It also assumes that the water system will be improved to a higher level so its deficiencies don't prevent the city from getting a more favorable ISO rating.

In comparison with the PTI analysis, the ISO method projects that up to 13 engine companies and six ladder companies would be needed for the same area. The manpower needs for the nine-station PTI projection, assuming four-man companies, are 192 firefighters vs. the ISO projection of 304.

Olathe's Options

In summary, the city of Olathe has several options ranging from remaining with the status quo to going for the best level of fire protection in the area. All of the options in this range do not necessarily involve additional public expenditures. The final decision on what to do or not to do will have to consider the value vs. cost for Olathe's residents and business owners, and the decision must also consider the safety of Olathe's firefighters.

— The Status Quo Option.

The city can opt to take no action to improve Olathe's ISO rating. As was pointed out earlier, the improvement comes at a cost, and the decision makers must determine if the benefits are worth the cost. There is no definitive benchmark or yardstick for making this decision. Rather, it will depend upon each individual's values and how he or she perceives the fire risk in Olathe.

This option has several consequences. The city will have to accept the higher risk of property loss and life safety that is indicated by the low response effectiveness scores for all but the low/minimum risk FDZ's. It will have to accept the current ISO rating and the accompanying higher insurance costs to residents and business owners than in neighboring communities. Also, this option will not address the firefighter safety issue that is raised by sending too few firefighters to post-flashover fires in high risk structures.
— Balance with Built-in Fire Protection.

A second option is to not increase manpower but require more built-in fire protection. This shifts more of the cost of fire protection from the general public to the building owners who build the risk. For example, a requirement to install sprinkler systems in buildings that are in the maximum and high risk categories would reduce their risk levels to the moderate and high categories, respectively. As the study points out, the fire department is currently organized and equipped for moderate risk FDZ's, so as additional stations are built the effective response area for moderate and high risk FDZ's will expand. A policy to require more built-in fire protection could allow the department to remain at its present level of organization as long as new stations kept up with development. This option is being adopted more frequently across the country, and cost-effectiveness data is available to assist in exploring this alternative.

— Replace Engines with Combination Apparatus.

A third option would reduce the need for separate ladder companies by equipping every station with a combination apparatus called a quint, which is essentially a larger pumper equipped with a hydraulic ladder. With the current station arrangement, the pumpers could be replaced with quints and the closest stations to a fire would respond. The second-in company would act as the ladder truck, thus removing the need to have the ladder company from Station 1 respond on all structure fires. This can increase the effective response areas for moderate risk FDZ's because the area's size is then limited by proximity of the closest stations instead of the ladder company's six minute travel time. The city of St. Louis (MO) took this alternative a few years ago when they replaced their entire fleet of aging fire apparatus.

This option is costly, and the quints cannot get full ISO credit as engines or ladders. A quint can get full ISO credit as a ladder company if it has a full complement of ground ladders in addition to a hydraulic ladder that is at least 75 ft. long. The ground ladders leave less space for the minimum complement of pumper equipment. Deleting the necessary ground ladders to carry the necessary pumper equipment will qualify the apparatus for ISO pumper credit but not ladder credit. Whether equipped primarily as a ladder or pumper, quints cost $400,000.00 as opposed to $250,000.00 for a pumper.

The St. Louis fire department kept several full ladder companies in service in addition to converting its engines to quints in order to keep its ISO rating lower, so the full cost savings of this option must be carefully weighed. If this option were discussed for Olathe, street width and design become important considerations. The wheelbase of quints is 50" longer than pumpers, and they could not turn onto many of Olathe's narrow streets, nor could they negotiate cul-de-sacs.
— Three-man Companies, Closer Stations.

Another option is to stay at 3-man crews but add more stations that are closer together. The ISO rating would go down and the effective response area would increase for moderate, high, and maximum risks. This would come at the expense of station efficiency but would increase the department’s response reliability.

— Four-man Companies, Efficient Station Locations.

This option was discussed in the last part of this report, and that is to keep stations spaced at their maximum efficiency/effectiveness ratio, add a fourth firefighter to each fire company and add a second ladder company. As the earlier discussion noted, this option would qualify Olathe for a lower ISO if the water department improvements match the city's growth. In addition, the effective response area would increase for all risk categories, and this option is the best method for bringing firefighter safety to an adequate level. Placing a firefighter apprentice on each company in lieu of a journeyman firefighter would appear to make this option a cost-effective solution for reducing Olathe’s fire insurance rating, while at the same time improving the fire department’s capability to respond to Olathe’s present and future fire risks.

1 Audit of Johnson County Fire Dispatch activity conducted by the Olathe fire department, 1990.
2 Fire growth tests conducted by Armstrong Industries, Inc.
5 Ibid.
7 See Attachment 3.
8 Olathe Comprehensive Plan, 1990, p. 36.
10 Fireground task time and manpower analysis conducted by the Dallas (TX) fire department, 1985.
Chapter 7
Probabilistic Models of Fire Company Availability and Dispatching

Synopsis

The availability of fire companies to be dispatched to alarms changes from time to time as incidents occur, and as companies are released from the scene of incidents. To estimate performance characteristics such as workloads of companies and travel times to incidents, it is sometimes necessary to know how often each company will be unavailable, or how often a given number of companies will be unavailable.

Among the methods that can be used to make such estimates, the ones described in this chapter are the least complicated. By making simplifying assumptions that are approximately correct, principles of queuing theory and Markov decision theory can be applied to problems concerning unavailabilities and dispatching policy. While the results from such models are necessarily no more than rough approximations of the real world, they can be useful in several ways:

1. In some cases, a rough calculation is sufficiently accurate for choosing among alternative policies.

2. In other cases, rough calculations indicate the type of model needed for more detailed analysis. For example, the firehouse siting models described in Chapter 10 are based on the assumption that all companies are always available. Calculations based on queuing theory can indicate whether or not this is a reasonable assumption.

3. The insights derived from using simplified models often suggest how to design more complex models, or what policy options to try in more complex models.

Queuing models show how to estimate the average number of companies busy in each region of a city. This information is important not only for travel time calculations, as described in Chapter 6, but also for other aspects of deployment analysis. In addition, since the actual number of busy companies fluctuates around the average, the analyst some-
times needs to know how large the variations might be. For example, how often will it happen that all the companies in a region will be busy? The answer to this question, also provided by queuing models, helps to determine whether a region is self-sufficient in terms of fire protection.

When companies are frequently unavailable, a dispatcher's decisions about what companies to dispatch to an incoming alarm will affect not only the response times of companies sent to the current alarms, but also the response times to future alarms that occur while some of these companies are still busy. Although the dispatcher cannot know exactly when and where the future alarms will occur, probabilistic information about them can help improve his decisions. This chapter presents several simplified models of the dispatching decision; these motivate the complete treatment presented in Chapter 11.

One key finding is that dispatchers need not always send the closest available companies to every incoming alarm. Indeed, if the dispatcher has a choice between two companies that are "almost" equally close to an alarm, and the incident is unlikely to be affected by a delay of a fraction of a minute in-response time, the dispatcher should, in some circumstances, choose the farther company. By sending the farther company, the dispatcher leaves the closer one available to respond to the next alarm, and this is desirable if future alarms are likely to be near the closer company.

When deciding the number of companies to send to an incoming alarm, fire department dispatchers generally take into account the reported nature of the incident. However, when no information about the incident is obtained (as with an alarm from an alarm box), models show that the past history of alarms from the same location can help determine how many companies to dispatch. If past data show that alarms from the location in question are unlikely to be serious, fewer companies should be dispatched than if the alarms often signal serious fires.

This chapter describes the characteristics of fire alarms and fire company unavailabilities that are central to many of the models presented in later chapters. Terms that will be used repeatedly, such as Poisson process and service time distribution, are defined and illustrated by examples in this chapter. In addition, principles of queuing theory and Markov decision theory are applied to several problems concerning the unavailabilities of fire companies and policies for dispatching companies.

The models described in this chapter are fairly elementary and, in many cases, are based on unrealistically simplified assumptions. However, there are several benefits to be gained from studying simplified models. First, they give a clear indication of the types of data that must
be collected to analyze fire deployment options. This topic is discussed in detail in Chapter 8, so for now we shall proceed as if any needed data can be somehow collected. Second, simple models often lead to general conclusions that are true, no matter how complicated a model is used. Finally, some of the conclusions derived from simple models are useful for the insights they lend, although they are not correct except under the restrictive assumptions made in this chapter. Such conclusions motivate more detailed models or policy options that are worth trying out in other models.

The chapter begins with an introduction to queuing theory. Readers who are familiar with this subject, including the use of bubble diagrams to solve for steady-state probabilities, can skip Section 7.1 or skim it briefly to determine the terminology being used in this book.

7.1 BASIC ELEMENTS OF QUEUING THEORY

Queuing theory is a collection of mathematical techniques that apply to situations where customers arrive at some kind of service facility and may have to wait for service. A typical example would be a bank where customers may have to wait for a teller to be free. Airplanes waiting to land at an airport also constitute a queuing system: here the "customers" are the airplanes and the "servers" are the runways on which they can land.

In most applications of queuing theory to problems of the fire service, the "customers" are fire alarms (or any type of incidents requiring a response from the department), and the "servers" are dispatchers or fire companies. Some of the earliest uses of queuing theory involved telephone calls, and fire alarms have many properties in common with telephone calls (indeed, many of them are telephone calls). Thus, some of the important facts in this chapter were known long before anybody began to use queuing theory to analyze fire service problems.¹

While the word "queuing" brings to mind customers waiting in a line, queuing theory can be very useful in analyzing situations where no one actually has to wait for service. For example, in most medium- and large-sized cities it has never happened that a fire alarm occurred when all the fire companies in the city were busy at previous fires, so that the new fire had to wait for a company to become available. Or, if it did happen, mutual aid agreements provided for a response from a neighboring department, in which case the new fire did not wait for a response anyway.

¹ Many excellent textbooks on queuing theory are available. The reader interested in an introductory approach might consult Kleinrock (1975), Lindgren and McElrath (1967), or Morse (1967). Kleinrock uses bubble diagrams.
Nevertheless, queuing theory can be used to calculate important information about fire companies.

7.1.1 Describing a Queuing System

When considering a real-world problem in terms of queuing theory, some characteristics are irrelevant, while others are important. For example, the color of an airplane has no influence on whether it will be delayed in landing or not, while the time of its arrival in the vicinity of the airport is important. If it arrives when no other aircraft are nearby, it will be able to land without delay (assuming that the runways are open). But if several planes arrive at nearly the same time, some or all of them will have to wait before landing. Similarly, the length of time from the landing of an airplane until the runway is free for another landing is an important descriptor of the system. In this section, five descriptors of a queuing system are defined.

Arrival Process. The times at which airplanes will arrive in the vicinity of an airport can be predicted with reasonable accuracy, especially after they are all airborne. Not so with fire alarms. A fire department cannot state with assurance that the next fire alarm will occur between 10 and 11 minutes from now, but it can compare the relative chances of various events. For example, based on past experience it might be possible to say that the next fire alarm is more likely to occur within the next 10 minutes than it is to occur after 10 minutes have passed.

Whatever is known about the times at which future arrivals will occur is an important characteristic of a queuing system. It can be expressed mathematically in terms of the cumulative distribution of interarrival times at time \( t \), which is defined as the function\(^2\)

\[
A(t,T) = \text{probability (no arrival will occur between } t \text{ and } (t + T)).
\]

(7.1)

For example, if it is now 12:00 noon, and the next arrival will definitely occur between 12:10 and 12:11, then \( A(12:00,7) \) will equal 1 for \( T \) less than 10 minutes and will equal 0 for \( T \) greater than 11 minutes. For values of \( T \) between 10 and 11 minutes, \( A(12:00,7) \) decreases from 1 to 0. Such a distribution of interarrival times might apply to airplanes but not to fire alarms. Typical distributions for fire alarms will be discussed in Section 7.1.3.

\(^2\) In most textbooks the cumulative distribution is defined as \( 1 - A \), but defining the cumulative distribution as \( A \) is more convenient for the particular distribution to be discussed in this chapter.
If the cumulative distribution is known, then other probabilities can be calculated from it. For example, the probability that the next arrival will occur between 5 and 6 minutes from \( t \) is \( A(t,5) - A(t,6) \).

**Service Time.** A second important characteristic of a queuing system is the length of time during which a server will be handling a customer. This is called the "service time." If fire companies are considered the servers, the service time is the number of minutes from the moment the company is dispatched until the moment it is released and available to be dispatched to a new incident. If dispatchers are the servers, the service time might be the length of time spent determining which companies to dispatch, or the length of time they speak to the caller on the telephone, or both of these together, depending on the questions to be answered by the queuing analysis.

The service time ordinarily varies according to the nature of the incident (false alarms have shorter service times than three-alarm fires), the particular server in question (distant companies have a longer service time because their travel time is longer), the tasks assigned to the server (first-due companies may work longer than third-due companies), and perhaps other characteristics. Even when all these characteristics are known, the service time still cannot be specified exactly in advance, so it is necessary to consider a probability distribution as in the case of arrivals. The cumulative distribution of service times is

\[
S(T) = \text{probability}(\text{service takes at least time } T \text{ to complete}).
\]  

(7.2)

Although it is possible to specify one distribution of service time that applies to the totality of alarms, for many purposes it is preferable to have several distribution functions, one for each combination of characteristics, such as incident type, server, and so forth.

**Number of Servers.** This is an important descriptor that is readily understood. An airport with two runways has two servers from the point of view of the landing aircraft. A bank with seven tellers has seven servers. A dispatch center with five dispatchers has five servers and will perform differently from the same center with only three dispatchers on duty.

**Maximum Number of Customers Who Can Wait for Service.** Some systems do not permit any customers to wait; these are called loss systems. For example, a business firm might have 12 incoming telephone lines. When all the lines are in use, a caller gets a busy signal. He cannot wait on his telephone until one of the firm's lines is free, but must hang up and try later. This constitutes a 12-server loss system. By contrast,
another firm, such as an airline company, might have a device to hold callers in queue until one of the reservation clerks is free. Such devices are also installed in many “911” systems. They have a limited capacity, so that, for example, at most 30 callers can wait in queue. The thirty-first caller will get a busy signal. In this system, the maximum number of customers who can wait is 30.

In some circumstances there is practically no limit on the number of waiting customers. For example, a dispatcher of ambulances could keep a stack of cards, each indicating a person who is waiting for an ambulance to be dispatched. There is no reason why he would have to stop accepting cards after five were in his stack, or ten, or more. In this case we say that an infinite number of customers can wait. This does not mean that an enormous number of customers do wait, simply that there is no identifiable limit on the possible number of waiting customers.

**States of the System.** To complete the description of a queuing system, the analyst must specify what conditions or states of the system are of interest. For example, in a telephone system one might like to know the number of lines in use at any time, the particular lines being of no importance. If there are \( N \) lines, this system has \( N + 1 \) states: no lines in use, 1 line in use, 2 lines in use, and so forth up to \( N \) lines in use.

If the servers are fire companies, one might like to know whether Company 1 is busy, rather than simply that some company is busy. One might also need to know when both Company 1 and Company 2 are busy simultaneously. To add to the complexity, one might like to know whether Company 1 is busy at an incident in its own first-due area or in some other company’s first-due area. As the number of descriptions for each state increases, the total number of possible states for the system can become so enormous that even high-speed computers would require years to calculate the probability of each state occurring. For example, with only nine fire companies, if one is interested in knowing the first-due area in which each company is working (i.e., it is either available or working in one of nine first-due areas), the system has a billion states (all companies available, Company 1 busy in its own first-due area with all the others available, etc.). Thus, it is a challenge to formulate a queuing problem in such a way that the results tell the analyst what he needs to know, without overwhelming him with computational problems.

7.1.2 How Queuing Theory is Related to the Fire Service

The most common uses of queuing theory for problems related to the fire service tell the analyst *how often* a particular state of the system will occur and *how long* it will last. This information can be used in many ways: to calculate travel times, workloads, and various other perform-
ance statistics corresponding to the current operations of the department: to devise better locations for fire companies, or improved dispatching practices; and others that will be illustrated in this and subsequent chapters.

Each of the applications will be described at the appropriate place in terms of the characteristics just mentioned: interarrival time distribution, service time distribution(s), number of servers, maximum number of waiting customers, and states of the system. However, before getting into the details, we can indicate roughly the types of queuing systems that have been applied to fire deployment analysis.

Several models consider the fire companies to be the servers. In some cases the system includes all the engine companies (or ladder companies) in the city or in a large region of the city, and no distinction is made among the various engine companies. These models are used to calculate the probability that any specified number of companies are busy at once. Since the chance that all companies will be busy is typically very small, in which case it is of little value for answering policy questions, the number of servers can often be assumed to be infinite. While this results in an infinite number of states for the system, the calculations focus on the first ten, twenty, or thirty states (whatever number is relevant). The calculations are actually simplified somewhat by assuming an infinite number of servers, without any significant loss of accuracy.

In other cases, such as in considering the design of first-due areas, only two companies are of interest, or perhaps a single company plus the four or so others whose first-due areas are adjacent. For such analyses, the system of two companies, or five, or whatever, may be considered a loss system because any alarms that arrive when all of these companies are busy will be handled by some other companies. These other companies are not included in the queuing system, and so, from the point of view of the system, the extra alarms are "lost."

An example of a queuing system in which the fire companies are not the servers is given by a bank of operators who answer the emergency telephones. While few fire departments that have their own telephone numbers experience problems where callers get a busy signal or have to wait before talking to an operator, this problem can arise with centralized police-fire-ambulance numbers (such as 911). Calculating the number of telephone operators needed at different times of the day is quite easily accomplished using queuing theory. Here the telephone calls are the customers, the servers are the telephone operators, and the service time is the length of time needed to complete the conversation. The method for performing the necessary calculations has been described by Larson (1972) and will not be repeated in this book. One has to consider not only the probability that a caller will get a busy signal but also the length of time he will have to wait until his call is answered. In an emergency
situation, a delay of twenty seconds can seem like many minutes to a caller.

In Section 14.5 we discuss a queuing system in which the servers are the dispatchers who must decide which companies to send to each incoming alarm. When several fires are in progress at once, the dispatcher may not be certain about the availability of particular companies, and any of the available companies may be the best choice for two or more different alarms waiting to be dispatched. This constitutes a particularly complicated queuing system, since the service time (length of time needed to make a decision) can vary according to the number of incidents in progress at the moment of dispatch. In our previous discussion, and for the remainder of this chapter, the service time has been assumed to be unrelated to the state of the system.

7.1.3 The Poisson Process

The distribution of the arrival times of fire alarms is central to any queuing analysis of the fire service. Fortunately, one family of distributions has been found to apply in every fire department that has been studied, no matter what region of the city is considered or what time of day it is. These are the time-dependent Poisson processes, which will be described in this section.

The Poisson process is a mathematical formulation of the observation that fire alarms are completely unpredictable, or totally random. In fact, in order to derive all the properties of time-dependent Poisson processes, it is necessary to make only two assumptions: (1) in very short intervals of time, fires or other emergency incidents occur singly, rather than in pairs or triplets: that is, two alarms do not arrive simultaneously; (2) the arrival of one alarm does not affect the probability of another alarm in either the future or in other locations. In order for the second assumption to be correct, the term "alarm" must be properly defined to exclude multiple reports of the same event. Each incident requiring a response from the department (whether it is a fire, a medical emergency, or even a false alarm) corresponds to just one alarm. In the case of large fires, several telephone calls and signals from alarm boxes may be received at the dispatch center. Only one of these should be considered the alarm.

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3 In rare disasters, such as aircraft collisions, several fires may start simultaneously, but otherwise this assumption is valid.

4 The arrival times of telephone calls at a fire department dispatch center may not constitute a Poisson process because of this "bunching" phenomenon. However, any delays experienced by the second or third caller are unimportant, since the fire companies will have been dispatched upon first notification. For this reason, it is possible to perform many analyses of telephone calls by assuming that they constitute a Poisson process, even though this is not precisely true.
When interpreting the term alarm in this fashion, it is intuitively reasonable that fire alarms do obey the two assumptions stated, and therefore constitute a time-dependent Poisson process. However, it is not necessary to accept this conclusion on faith. We indicate here some properties of Poisson processes that can be tested for validity by statistical techniques. Then, in Chapters 8 and 14, examples will show how well actual data concerning fire alarms match the Poisson assumption.

Interarrival Time Distribution for a Poisson Process. The only characteristic of the arrival times that must be specified to describe a particular Poisson process is the average number of fire alarms per hour. This is called the alarm rate and is denoted by \( \lambda \). The term time-dependent means that the alarm rate can vary over the course of the day, week, or year, in which case its value at time \( t \) is denoted \( \lambda(t) \). For example, if an average of two alarms per hour occur at 3 a.m., and an average of nine at 6 p.m., we have \( \lambda(0300) = 2 \) per hour and \( \lambda(1800) = 9 \) per hour.

As defined in Section 7.1.1, the interarrival time distribution, \( A(t,T) \), is the probability that no alarm will occur between \( t \) and \( (t + T) \). To calculate the interarrival time distribution for a Poisson process, one must find the average alarm rate \( \bar{\lambda} \) between \( t \) and \( (t + T) \), which is denoted \( \bar{\lambda} \). Then

\[
A(t,T) = e^{-\bar{\lambda}T}.
\]

For short periods of time, it may be assumed that the alarm rate is a constant \( \lambda \). In this case we have an ordinary (not time dependent) Poisson process with interarrival time distribution

\[
A(t,T) = e^{-\lambda T}, \tag{7.3}
\]

which does not depend on \( T \). This interarrival time distribution is called an exponential distribution and completely characterizes an ordinary Poisson process with alarm rate \( \lambda \). An example is graphed in Figure 7.1. In most types of analyses it is mathematically much more complicated to assume time-dependent Poisson arrivals than to assume a constant alarm rate \( \lambda \). For this reason, the analysis is performed separately for short time intervals, such as an hour.

Memoryless Property. For a Poisson process with constant rate \( \lambda \), the average time until the next fire alarm is \( \frac{1}{\lambda} \). Thus, if there are two fire alarms per hour (on the average), then the average time to the next fire alarm is \( \frac{1}{2} \) hour. Remarkably enough, it does not matter when you start

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\(^5\) The average alarm rate is mathematically defined as \( \bar{\lambda} = \int \frac{1}{T} (f^{T+T} \lambda(u)du) \).

\(^6\) Or, more precisely, it is called a negative exponential distribution.
FIGURE 7.1. The exponential function. The curve shows the probability of waiting more than \( t \) hours for the next alarm when the alarm rate is one per hour.

counting the time to the next arrival; the answer is always the same. This means that you could begin at 2:00 p.m. or at the last fire alarm, and the distribution of the time until the next alarm will be the same as Equation (7.3). Stated another way, knowing when the last fire alarm occurred does not help predict when the next fire alarm will occur.

**Number of Alarms in a Time Interval.** If \( \lambda \) is the average alarm rate over any time interval of length \( T \), say 15 minutes, then the average number of alarms that will occur is \( \lambda T \). For example, for a constant \( \lambda = 4/\text{hour} \), if you average the number of alarms that occur in many different 15-minute periods, the result will be that, on the average, one call occurs in 15 minutes. However, some 15-minute periods will have no alarms, others will have one alarm, others will have two, and so forth. (In principle, a 15-minute period could have 10,000 alarms, but the probability of this is so small that it can be ignored.)

In a Poisson process with average alarm rate \( \lambda \) over an interval of
length $T$, the probability that $n$ alarms will occur is
\[ p(n, T) = \frac{\lambda^n T^n}{n!} e^{-\lambda T}, \quad n = 0, 1, 2, \ldots \] (7.4)

For fixed values of $T$, this is called a Poisson distribution with mean $\lambda T$. (The Poisson process refers to the arrival pattern of alarms; the Poisson distribution refers to counting the number of alarms that occur in some period of time.) An example of a Poisson distribution is given in Figure 7.2.

**Interpretation of Randomness.** An interpretation of the randomness of the Poisson process with constant alarm rate $\lambda$ can be obtained by considering a long time interval of length $K$ hours. This interval may be divided into consecutive subintervals of length $T$, as shown in Figure 7.3. (We assume that $K$ is some integer times $T$.) Suppose that we know exactly how many alarms occurred in the whole interval of length $K$. Call this $N$. If the precise arrival time of each of these $N$ alarms is determined completely randomly (for example, by throwing darts at the line without favoring one location over another), the number of alarms falling in the various intervals of length $T$ will be distributed approxi-

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**FIGURE 7.2.** The Poisson distribution, with mean 6.2.
mately as in Equation (7.4).\footnote{More precisely, each of the $N$ alarms is assumed to be uniformly distributed over the interval $(0,K)$, independent of the other alarms. Calculate the probability that $n$ alarms fall in any specified subinterval, $n = 0, 1, \ldots, N$. This is a binomial distribution. Take the limit as $N$ and $K$ go to infinity in such a way that $N/K$ approaches $\lambda$. The result is Equation (7.4), with $\lambda$ replaced by $\lambda$.} This fact corresponds to our intuitive feeling about the unpredictability of fire alarms, and adds strength to our assumption that the Poisson process is a good mathematical representation of the arrival times of fire alarms.

*Additive Property.* When you add together two or more Poisson processes, the result is a Poisson process where the alarm rate is the sum of the two original rates. For example, suppose a city is divided into two regions. If the alarms coming from Region 1 constitute a Poisson process with alarm rate $\lambda_1(t)$, and the alarms from Region 2 constitute a Poisson process with alarm rate $\lambda_2(t)$, then the alarms from the whole city constitute a Poisson process with alarm rate $\lambda(t) = \lambda_1(t) + \lambda_2(t)$. This mathematical property makes Poisson processes easy to work with.

### 7.1.4 Service Times

Some types of queuing systems, such as those involving telephone calls, have an exponential service time distribution, exactly like the distribution of interarrival times for the ordinary Poisson process. This means that there is a number $\mu$ (called the service rate), such that the cumulative distribution of service times is

$$S(T) = e^{-\mu T}.$$ 

In this case the average service time is $1/\mu$.

The service times for fire companies do not match an exponential distribution. In fact, for a small fire, the distribution is likely to look something like Figure 7.4. This shows that the probability of the service time lasting more than 10 minutes is nearly 1. We are assuming that the company must travel to the scene of the fire, connect a hose, extinguish a fire, and return the hose to the apparatus before its service time is completed. Accomplishing all these tasks in less than 10 minutes is nearly impossible, while in half of all fires of this type it can be accomplished.
within 20 minutes. The distribution in Figure 7.4 does not look at all like Figure 7.1, which is an exponential distribution.

Despite the failure of the exponential service time distribution to match reality, it is often used in queuing analyses related to the fire service. The analyst assumes an exponential service time because it simplifies his calculations, not because it is correct. When his findings are obtained, he may be able to prove that they are correct for any service time distribution, even though he began with the assumption of exponential service times. More commonly, he will be able to show that his calculations are approximately correct for several examples of "real" service time distributions. For example, the calculation using exponential service times may show that Company 1 is busy 17.7 percent of the time, when the true value is 17.1 percent. These numbers are sufficiently close that ordinarily either one could be used for policy decisions.

7.1.5 Steady-State Solutions

Suppose that, on the average, two fire companies are busy in a city. At a particular moment, however, it could happen that ten fire companies are busy at fires. If a calculation is made for the number of companies expected to be busy, starting at that moment, it will show that this expected number of busy companies gradually decreases from 10 to 2 over the course of several hours. The formula that expresses the number of busy companies as a function of time is called a transient solution to the queuing problem. The transient solution depends on the state of the system at the initial moment.

No matter how many companies are present at the start, all calculations
will show that after many hours have passed, two companies are expected to be busy. This part of the solution, which is independent of the situation at the start and does not vary with time, is called the *steady-state* solution.

In many types of analyses, such as planning the locations of fire stations, the situation at the time of analysis is considered unimportant, so steady-state solutions are used. In other cases, such as deciding the number of companies to dispatch to incoming alarms, the transient solution may be needed.

### 7.1.6 A Graphical Method for Performing Queuing Calculations

An extraordinarily useful graphical method can be used to perform queuing calculations when three assumptions are made: (1) arrivals constitute a Poisson process with constant alarm rate; (2) service times have an exponential distribution; and (3) steady-state solutions are desired. This method consists of drawing a "bubble" for each state of the system and showing by arrows the states that will be reached if a single alarm arrives or a single service is completed. On each arrow, one writes the rate at which the arrivals or service-completions occur.

Figure 7.5 shows a "bubble diagram" (also called a state diagram) for a simple example with three states. It describes a small city with two engine companies. The bubble with "0" in it represents the state with no busy engine companies. The bubble with "1" means one company is busy, and the bubble with "2" means two companies are busy. If an alarm arrives when both companies are busy, it is handled by another department under mutual aid.

We assume (for this example) that alarms arrive according to a Poisson process with rate \( \lambda \), that each has an exponential service time with mean \( 1/\mu \), and that one engine company responds to each alarm. Therefore, there is an arrow from state 0 to state 1 with a \( \lambda \) written on it, and an arrow from state 1 to state 2 with a \( \lambda \) written on it. These mean that if an alarm arrives when no company is busy, immediately afterward one will be busy, and if an alarm arrives when one company is busy, immediately afterward two will be busy. Similarly, if a service is completed when one company is busy, immediately afterward no companies will be

![Figure 7.5: Example of a bubble diagram: alarms require one engine company.](attachment)
busy; and if one service time is completed when two companies are busy, immediately afterward one company will be busy. The arrow from state 2 to state 1 has \( 2\mu \) written on it because either one of two companies could finish service at rate \( \mu \). In other words, the rate at which state 2 converts to state 1 is twice as fast as the rate at which state 1 converts to state 0.

The diagram is used to calculate the steady-state probability that each state occurs. We use the symbol \( p(0) \) to represent the probability of state 0, \( p(1) \) the probability of state 1, and \( p(2) \) the probability of state 2. The meaning of these probabilities is that if every minute (or second) you wrote down what state the system was in at that point, then in the long run a fraction of \( p(0) \) of all the observations would find the system with no companies busy, and so forth.

To convert the bubble diagram into equations, one considers the diagram as if it represented a flow of water through pipes. The probability of state 0 can be thought of as the amount of water in bubble 0. The diagram shows that a fraction \( \lambda \) flows out of state 0, so we have

\[
\text{flow out of state 0} = \lambda p(0).
\]

Similarly, the arrow from state 1 to state 0 shows that

\[
\text{flow into state 0} = \mu p(1),
\]

since \( p(1) \) is the probability of state 1.

In the steady state the flow out must equal the flow in, so we have

\[
\lambda p(0) = \mu p(1).
\]

Similarly, by considering the flows in and out of state 1 we find

\[
\lambda p(1) + \mu p(1) = \lambda p(0) + 2\mu p(2),
\]

and by considering state 2 we have

\[
\lambda p(1) = 2\mu p(2).
\]

It turns out that any two of these equations tell us as much as all three of them, so we solve the first and third to get

\[
p(1) = \frac{\lambda}{\mu} p(0)
\]

\[
p(2) = \frac{1}{2} \frac{\lambda}{\mu} p(1) = \frac{1}{2} \left( \frac{\lambda}{\mu} \right)^2 p(0).
\]

To find \( p(0) \) we have to realize that the sum of all probabilities equals 1, thus

\[
p(0) + p(1) + p(2) = 1.
\]
or

\[ p(0) + \frac{\lambda}{\mu} p(0) + \frac{1}{2} \left( \frac{\lambda}{\mu} \right)^2 p(0) = 1 \]

or

\[ p(0) \left[ 1 + \frac{\lambda}{\mu} + \frac{1}{2} \left( \frac{\lambda}{\mu} \right)^2 \right] = 1 \]

or

\[ p(0) = \frac{1}{\left[ 1 + \frac{\lambda}{\mu} + \frac{1}{2} \left( \frac{\lambda}{\mu} \right)^2 \right]} \]

Thus we have expressed \( p(0) \) in terms of \( \lambda \) and \( \mu \), and so we also know \( p(1) \) and \( p(2) \) in terms of \( \lambda \) and \( \mu \). This is the solution to the problem, because the probabilities of each state can be determined for any given \( \lambda \) and \( \mu \), and once the probability of each state is known, any other numbers that could be calculated for this system are also known.

To summarize the method:

1. Draw the states as a bubble diagram.
2. Show changes of states by arrows with rates.
3. Set flow out = flow in for every state.
4. Solve the equations.

Another example is given in Figure 7.6. Here some alarms arrive at rate \( \lambda_1 \) and require one engine company. Others arrive at rate \( \lambda_2 \) and require two companies. All companies have the same exponentially distributed service time, namely the one with mean \( 1/\mu \), regardless of whether they have responded to a one-company fire or a two-company fire. (When one company is busy, and a two-engine alarm is received, the available company responds, along with a mutual aid company that is not being considered as part of the system.) The reader who was not previously familiar with bubble diagrams should find for himself the probabilities of each state in Figure 7.6, using the method illustrated above. The results are given in the Appendix to this chapter (Section A7.1).

**FIGURE 7.6.** Example of a bubble diagram: some alarms require two engines.

\[\begin{array}{c}
0 \\
\lambda_1 \\
\mu \\
1 \\
\lambda_1 + \lambda_2 \\
\lambda_2 \\
2\mu \\
2 \\
\end{array}\]
7.2 NUMBER OF COMPANIES BUSY IN A REGION

Here we apply the queuing techniques described in Section 7.1 to determine the number of fire companies busy in any region of a city. The fire alarms arising from the region are assumed to constitute a Poisson process with constant rate \( \lambda \). As we have noted, this is a correct assumption for short periods of time. To apply the results of this section for policy analysis, it would be necessary to find the correct values of \( \lambda \) for various times of the day or week, and calculate numerical results separately for each time period of interest. Methods for estimating the alarm rate are discussed in Chapter 8.

Since ordinarily the number of companies in a region of a city is substantially less than the total number of companies in the city (although it may sometimes be greater than the number of companies stationed in the region), it is convenient to consider the system as having an infinite number of servers. This assumption avoids some mathematical complications that arise when the maximum number of servers is specified, without affecting the accuracy of the results substantially.

The results to be derived in this section include formulas for calculating the distribution of the number of busy companies (that is, the probability that no companies are busy, the probability that one company is busy, and so forth) and the average number of companies busy. The most important result is that the average number of busy companies is \( \lambda \) times the average number of company-hours per alarm. Numerical examples are given to illustrate how these calculations are performed. For example, the number of company-hours at an alarm is obtained by adding together all the service times (in hours) of all the companies that work at the alarm. Applications are given in this section, as well as in later chapters.

We begin with a calculation of the number of incidents in progress (or the number of alarms in progress). This is identical to the number of companies busy if only one company responds to each alarm, which might be the case for emergency medical services. If several companies respond to an alarm, then for purposes of calculating the number of alarms in progress, the service time is defined to be the length of time from the dispatch of the first company until the last company is released from the incident. Considering this special case permits us to ignore some of the complexities at the start.

7.2.1 Number of Alarms in Progress

We consider an infinite-server system in which state "0" is the situation in which no alarms are in progress (i.e., all companies are available), state "1" means that one alarm is in progress, and so forth. If we assume that alarms arrive according to a Poisson process with rate \( \lambda \) and have
n exponential service time with mean $\tau = 1/\mu$, the graphical method of section 7.1.6 can be used, with Figure 7.7 representing the queuing system. In this case, the average service time ($\tau$) is the duration of an average alarm, from the dispatch of the first company until the last company leaves the scene.

This approach provides an example of the value of the graphical method, because it can be proved (Khintchine, 1960) that the equations we will derive under the assumption of exponential service times are correct, no matter what the service-time distribution is. In fact, a single service-time distribution can represent a mixture of different types of alarms, each with its own service-time distribution, so the model is a very realistic representation of the real world. The only feature of the real world that is ignored in Figure 7.7 is the possibility that alarm durations will increase as the number of alarms in progress increases. This can happen because travel times increase as the number of available companies decreases, as explained in Chapter 6. Travel time is part of service time, and, in addition, a long travel time may permit the fire to escalate, resulting in a long on-scene service time for extinguishment and overhaul.)

The steady-state queuing equations corresponding to Figure 7.7 are

$$\lambda p(0) = \mu p(1),$$

$$ (\lambda + \mu)p(1) = \lambda p(0) + 2\mu p(2),$$

$$ (\lambda + 2\mu)p(2) = \lambda p(1) + 3\mu p(3),$$

and so forth. Here $p(n)$ is the probability that $n$ alarms are in progress. These equations can be expressed in general form as

$$ (\lambda + n\mu)p(n) = \lambda p(n - 1) + (n + 1)\mu p(n + 1), \quad n = 0, 1, 2, \ldots ,$$

if we interpret $p(-1)$ as zero.

The equations are solved by expressing $p(1)$ in terms of $p(0)$ from the first equation, $p(2)$ in terms of $p(0)$ from the second equation, and so

---

* The service times may be assumed to be independently identically distributed, with a finite mean.
forth. The result is
\[ p(n) = \frac{(\lambda/\mu)^n}{n!} p(0), \quad n = 1, 2, 3, \ldots \]

Using the fact that \( \tau = 1/\mu \), the equation stating that the sum of all probabilities equals 1 is as follows:
\[ \left(1 + \lambda \tau + \frac{(\lambda \tau)^2}{2!} + \frac{(\lambda \tau)^3}{3!} + \cdots\right) p(0) = 1. \]

The sum multiplying \( p(0) \) can be written as \( \Sigma_{n=0}^{\infty} (\lambda \tau)^n / n! \), which equals \( e^{\lambda \tau} \). Since \( 1/e^{\lambda \tau} = e^{-\lambda \tau} \), we know that \( p(0) = e^{-\lambda \tau} \). Therefore, the final result for the probability that \( n \) alarms are in progress is
\[ p(n) = \frac{(\lambda \tau)^n}{n!} e^{-\lambda \tau} \quad n = 0, 1, 2, \ldots \quad (7.5) \]

This equation is identical to Equation (7.4), except that \( T \) has been replaced by \( \tau \). Therefore, the number of alarms in progress has a Poisson distribution with mean \( \lambda \tau \), where \( \lambda \) is the arrival rate and \( \tau \) is the average duration of an alarm. To say that the mean of this distribution is \( \lambda \tau \) is the same as saying that the average number of alarms in progress is \( \lambda \tau \).

**Example.** Suppose that in some city the alarm rate is 4 per hour (\( \lambda = 4 \)) and the average duration of an alarm is 45 minutes (\( \tau = \frac{3}{4} \) hour). If the dispatcher on duty wrote down every 15 minutes (1) the number of alarms that occurred in the past 15 minutes, and (2) the number of alarms in progress, he might get a table like Table 7.1. (Note that \( T = 15 \) minutes = \( \frac{1}{4} \) hour.) We will imagine that the dispatchers collect data for 250 hours, or one thousand 15-minute periods.\(^*\)

Equation (7.4) states that a fraction \( e^{-\lambda} = 0.368 \) of the entries should have no alarms occurring in the past 15 minutes (because \( \lambda = 4 \) and \( T = \frac{1}{4} \)). Thus, approximately 368 of the lines on the table will show no alarms having occurred. Similarly, Equation (7.5) states that a fraction \( e^{-\tau} = 0.050 \) of the entries should have no alarms in progress (because \( \lambda = 4 \) and \( \tau = \frac{3}{4} \)). Thus, approximately 50 of the lines in the table will show no alarms in progress.

Continuing, approximately \( 1000 \times 1 \times e^{-1} = 368 \) lines will show that one alarm occurred in the past 15 minutes (this is the same as the number of lines where no alarms occurred), and approximately \( 1000 \times 3 \times e^{-3} = 149 \) lines will show 1 alarm in progress.

\(^*\) This example ignores the fact that alarm rates vary by the time of day. The purpose of the example is to illustrate the equations.
If the dispatcher averaged all 1000 numbers in the column labeled "number of alarms in the past 15 minutes," he should get approximately 1.0 (= \lambda \tau). If he averaged all the numbers in the next column, he should get approximately 3.0 (= \lambda \tau).

In the example, dispatchers have spent time writing down data that they do not need for their own work. An analyst who needed to know the number of alarms that might be in progress simultaneously could reconstruct Table 7.1 if the dispatcher simply recorded the time at which each alarm arrived, and the time at which the last company at the incident became available. But the analyst does not have to reconstruct the table from the data. He can simply calculate the average duration of an incident, which is \tau, and use Equation (7.5).

Why would he need to know the distribution of the number of alarms in progress? One possible application might be for designing a computer-assisted dispatch (CAD) system. Suppose that the information to be stored in the CAD system concerning each alarm in progress requires a certain amount of computer memory space. The analyst wants to be sure that the CAD will not fail at a critical moment when there are many fires. He might feel that allowing enough space to have one alarm in progress for every company in the city, plus perhaps 10 more for mutual aid companies, gives a satisfactory safety margin. But such a specification might lead to an unnecessarily expensive CAD system.

To determine whether a less expensive system might be adequate, the analyst could ask, "How much memory space is needed so that the probability of running out of space is less than 1 in 10,000?" In other words, he wants to find a number of alarms, \( M \), such that \( p(0) + p(1) + p(2) + \cdots + p(M) \) is greater than 0.99999. This can be accomplished
by calculating the value of \( p(n) \) from Equation (7.5) for \( n = 0, 1, 2, \ldots \) and stopping when the sum exceeds 0.99999.

The analyst will want to allow for the possibility that alarm rates will increase in the future. So, if a "busy night" currently has about 4 alarms per hour, the analyst might use \( \lambda = 8 \) per hour in Equation (7.5). The result of his calculations, with \( \tau = 45 \) minutes, is shown in Table 7.2. From this table, it can be seen that the CAD needs enough space for 19 alarms to meet the standard set by the analyst.

7.2.2 Number of Busy Companies

Calculating the distribution of the number of busy companies is similar to calculating the number of alarms in progress, except that the description of the queuing system must account for the fact that several companies may respond to a single alarm. The method applies to engine companies, to ladder companies, or to all companies together, but we illustrate it by discussing engine companies. One possible approach is to

<table>
<thead>
<tr>
<th>( n ) = Number of Alarms</th>
<th>( p(n) = ) Probability that ( n ) Alarms are in Progress</th>
<th>Probability that ( n ) or Fewer Alarms are in Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>.00248</td>
<td>.00248</td>
</tr>
<tr>
<td>1</td>
<td>.01487</td>
<td>.01735</td>
</tr>
<tr>
<td>2</td>
<td>.04462</td>
<td>.06197</td>
</tr>
<tr>
<td>3</td>
<td>.08924</td>
<td>.15120</td>
</tr>
<tr>
<td>4</td>
<td>.13385</td>
<td>.28506</td>
</tr>
<tr>
<td>5</td>
<td>.16062</td>
<td>.44568</td>
</tr>
<tr>
<td>6</td>
<td>.16062</td>
<td>.60630</td>
</tr>
<tr>
<td>7</td>
<td>.13768</td>
<td>.74398</td>
</tr>
<tr>
<td>8</td>
<td>.10326</td>
<td>.84724</td>
</tr>
<tr>
<td>9</td>
<td>.06884</td>
<td>.91608</td>
</tr>
<tr>
<td>10</td>
<td>.04130</td>
<td>.95738</td>
</tr>
<tr>
<td>11</td>
<td>.02253</td>
<td>.97991</td>
</tr>
<tr>
<td>12</td>
<td>.01126</td>
<td>.99117</td>
</tr>
<tr>
<td>13</td>
<td>.00520</td>
<td>.99637</td>
</tr>
<tr>
<td>14</td>
<td>.00223</td>
<td>.99860</td>
</tr>
<tr>
<td>15</td>
<td>.00089</td>
<td>.99949</td>
</tr>
<tr>
<td>16</td>
<td>.00033</td>
<td>.99982</td>
</tr>
<tr>
<td>17</td>
<td>.00012</td>
<td>.99994</td>
</tr>
<tr>
<td>18</td>
<td>.00004</td>
<td>.99998</td>
</tr>
<tr>
<td>19</td>
<td>.00001</td>
<td>.99999+</td>
</tr>
</tbody>
</table>
replace each alarm by several imaginary alarms that arrive simultaneously, each imaginary alarm representing an engine company that responds to the incident. This is called a "bulk arrival" model. Its bubble diagram would look like an extended version of Figure 7.6, with some arrows skipping over two or more states (representing alarms that involve three or more engine companies).

However, a bulk arrival model does not give accurate estimates of the probability that a large number of engine companies are busy. In the model, contrary to reality, each engine's service time is assumed to be independent of the service times of the other engines at the same fire. Thus, shortly after the start of a fire that requires 12 engines, the model envisions that there will be only 11 or 10 engines busy, whereas actually, the 12 engines could be busy together for a lengthy period.

To create a better representation of actual operations, Chaiken (1971) proposed a queuing model in which alarms pass through stages. A stage is a period of time during which a fixed number of engine companies are busy. For example, when a small fire occurs, three engines might be dispatched, and then two could be released as soon as the first one arrives at the scene. Such an incident has two stages. The first stage represents the time until the first engine arrives; in this stage three engines are busy. The second stage represents the remainder of the incident and has one busy engine. Table 7.3 shows a different kind of three-engine incident which has five stages. A large fire can have many stages. For example, there could be an eight-stage fire in which the successive numbers of busy engine companies are 3, 7, 9, and 11 (representing separate dispatches of groups of engines), and then 8, 5, 3, and 2 (representing engines being released in groups).

The results of the model are formulas for the average number of busy engine companies and for \( p(n) \), the probability that \( n \) engines are busy, \( n = 0, 1, 2, \ldots \). These are given in the Appendix to this chapter (Section A7.2). As mentioned earlier, the average number of busy engine companies turns out to be \( E(B) = \lambda E(S) \), where \( \lambda \) is the number of alarms per hour and \( E(S) \) is the average number of company hours per alarm. The formula for \( p(n) \) is more complicated but depends only on the

<table>
<thead>
<tr>
<th>Stage number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of companies working</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

TABLE 7.3. Number of engine companies working at each stage of an alarm that requires three engines.
products $\lambda \tau_k$, $k = 1, 2, \ldots$, where $\tau_k$ is the average length of time that exactly $k$ engines are busy. If two stages have the same number of busy engines, e.g., Stages 1 and 5 in Table 7.3, their durations are added together to calculate the associated $\tau_k$. The formula for $p(n)$ is very easy to program on a computer, and the numbers from the formula have been found to be close to the numbers obtained from the simulation model described in Chapter 13, which is a much more detailed model (Ignall, Kolesar, and Walker, 1975).

The essential idea of the queuing model is displayed in Figure 7.8, which represents the special case of an alarm type with only two stages. The states are described by pairs $(j,k)$, where $j$ is the number of alarms in stage 1 and $k$ is the number of alarms in stage 2. The average duration of stage $i$ is $1/\mu_i$, $i = 1, 2$. The diagram can be used to write equations for the steady-state values of the probability of State $(j,k)$, as described in Section 7.6.1. While these equations are correct only for exponentially distributed service times, Chaiken (1971) showed that the results are valid for any distributions with finite means. Once the state probabilities are found, $p(n)$ is the sum of the probabilities of all states that have $n$ busy companies.

To use the computer program that calculates the values of $p(0)$, $p(1)$, $p(2)$, $\ldots$, one must provide input data for $\lambda \tau_1$, $\lambda \tau_2$, $\lambda \tau_3$, $\ldots$. An example showing how these numbers can be estimated will be given in the next section.

### 7.2.3 Application to Estimating Travel Distances

In Chapter 6, the square-root law for travel distances was presented. If $N$, the number of firehouses with at least one available company in a region of area $A$, is known, one version of this law states that the average travel distance $D_1$ for the first-arriving engine company at alarms in the region will be approximately

$$E(D_1) = k_1 \sqrt{A/N},$$

(7.6)

where $k_1$ is a constant. (This is the same as Equation (6.7).) Chapter 6 also mentioned that a reasonable approximation to the average travel distance to alarms over a period of time when the number of available companies changes, can be found by replacing $N$ in Equation (7.6) with $E(N)$, the average number of stations with at least one engine company

---

10 A FORTRAN program that calculates $p(n)$ and also $E(B) = \lambda E(S)$ is given in Appendix A7.3.
11 Again, we illustrate the model for engine companies, but it can be applied equally well to ladder companies.
available. In this section we illustrate why the approximation is a good one and tell how to calculate $E(N)$. We begin with the assumption that each firehouse has one engine company; in this case $N$ is the number of engine companies and $E(N)$ is the average number of available engine companies.

We have seen, in Section 7.2.2, how to calculate the average number of busy engine companies, $E(B)$; and so it appears easy to calculate the average number of available engine companies: subtract $E(B)$ from the number of engine companies stationed in the region. However, a little reflection will reveal that this subtraction cannot be exactly correct because some companies might respond from outside the region to work at incidents in the region, and other companies might be relocated into the region. In this section we show how a somewhat more accurate calculation can be performed with the square-root law. While the discussion focuses on travel distances, the method can also be applied to travel times by using the conversion discussed in Section 6.5. The conclusion drawn from the more accurate calculation is that in most applications, the error in an approximate calculation of the average travel distance is only a few percent.

The more accurate calculation is based on using Equation (7.6) together with the probability $p(\hat{b})$ that $\hat{b}$ engine companies are busy, which was
derived in Section 7.2.2. If \( n^* \) engine companies are stationed in the region, and the number busy is small compared to \( n^* \), say \( b = 0, 1, \) or \( 2 \), then it will nearly always be true that the number available is \( N = n^* - b \). In this case, we assume that \( q(N) \), the probability that \( N \) engine companies are available, is given by the formula

\[
q(N) = p(n^* - N).
\]

(7.7)

However, if many units are busy in the region, the equation \( N = n^* - b \) cannot be correct. Indeed, \( b \) could possibly be larger than \( n^* \), leading to a negative value for \( N \). Various assumptions can be made about the relationship between \( N \) and \( b \) when \( b \) is large compared to \( n^* \). These would depend on the size of the region and the department's relocation practices. For example, we might assume \( N = 0 \) whenever \( b \geq n^* \). Or, we might assume that the department will always relocate enough companies into the region to keep \( N \geq 2 \). (If the probability is very small that \( b > n^* - 2 \), it will not matter exactly what assumption we make.)

Let us suppose that the number of available engine companies is always at least two. Then we can use Equation (7.7) for \( q(N) \) when \( N \geq 3 \), and we set

\[
q(2) = p(n^* - 2) + p(n^* - 1) + p(n^*) + p(n^* + 1) + \ldots
\]

\[
q(1) = q(0) = 0.
\]

(7.8)

The average of \( D_1 \) over time can be obtained by multiplying the probability \( q(N) \) that \( N \) engine companies are available by \( k_i \sqrt{A/N} \) and summing over the various values of \( N \):

\[
E(D_1) = \sum_{N=2}^{n^*} k_i q(N) \sqrt{A/N}.
\]

(7.9)

Example. We will use Equation (7.9) to estimate the average travel distance for the first-arriving engine in a region having area \( A = 20 \) square miles and \( n^* = 12 \) engine companies stationed in the region, one in each of 12 firehouses. Let us assume that the constant for the region has been determined to be \( k_1 = 0.6 \), as suggested in Section 6.4.2.

To calculate the probabilities \( p(b) \), the analyst needs to know the average length of time \( \tau_k \) that exactly \( k \) engine companies work at an alarm in the region (\( k = 1, 2, 3, \ldots \)). Ordinarily these data are not readily available to a fire department (although they could be calculated if the department's records show the time of arrival and departure for each company at each alarm). To obtain a reasonable estimate, alarms could be divided into types, and for each type the analyst could make
reasonable guesses at the service times or he could collect the required data for a sample of alarms.

The types might be:

Type 1, false alarms, or no work to do.
Type 2, phone alarms to which one engine is dispatched.
Type 3, alarms other than type 1 or 2 at which only one engine works.
Type 4, one type of alarms at which 3 engines work.
Type 5, another (more serious) type of alarms at which 3 engines work.
Type 6, alarms at which 4-7 engines work.
Type 7, alarms at which 8 or more engines work.

No matter how the types are defined, they should be related to the number of engines that will respond to and work at the incident. For the example we will assume that the initial dispatch to every alarm other than Type 2 is three engine companies.

After collecting data or making estimates, the analyst could prepare the required data in a form like Table 7.4. Next, he needs to calculate \( \lambda T_1, \lambda T_2, \ldots, \lambda T_{11} \). This is accomplished by converting service times to hours, multiplying each one by the alarm rate for its type of alarm, and adding down the columns. This calculation is shown in Table 7.5.

The results at the bottom of Table 7.5 must be entered into a computer program, such as the one listed in Section A7.3, that will calculate all

### TABLE 7.4.

<table>
<thead>
<tr>
<th>Type of Alarm</th>
<th>Alarm Rate (alarms/hour)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>1.00</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td>2.15</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 3</td>
<td>0.35</td>
<td>12</td>
<td>0</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 4</td>
<td>0.04</td>
<td>15</td>
<td>30</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 5</td>
<td>0.01</td>
<td>50</td>
<td>40</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 6</td>
<td>0.003</td>
<td>60</td>
<td>60</td>
<td>30</td>
<td>0</td>
<td>30</td>
<td>0</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 7</td>
<td>0.001</td>
<td>60</td>
<td>30</td>
<td>30</td>
<td>0</td>
<td>60</td>
<td>30</td>
<td>30</td>
<td>0</td>
<td>30</td>
<td>0</td>
<td>90</td>
</tr>
</tbody>
</table>
TABLE 7.5. Alarm rates multiplied by service times, for the example.

<table>
<thead>
<tr>
<th>Type of Alarms</th>
<th>k = Number of Companies Working</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Type 1</td>
<td>0.1333</td>
</tr>
<tr>
<td>Type 2</td>
<td>0.7167</td>
</tr>
<tr>
<td>Type 3</td>
<td>0.0700</td>
</tr>
<tr>
<td>Type 4</td>
<td>0.01</td>
</tr>
<tr>
<td>Type 5</td>
<td>0.0083</td>
</tr>
<tr>
<td>Type 6</td>
<td>0.003</td>
</tr>
<tr>
<td>Type 7</td>
<td>0.001</td>
</tr>
<tr>
<td>Total</td>
<td>0.8090</td>
</tr>
</tbody>
</table>

The $p(b)$ values from which the values of $q(N)$ can be determined. The $q(N)$ values corresponding to the numbers in Table 7.5 are:

$q(2) = 0.0038$
$q(3) = 0.0022$
$q(4) = 0.0043$
$q(5) = 0.0095$
$q(6) = 0.0164$
$q(7) = 0.0282$
$q(8) = 0.0671$
$q(9) = 0.1102$
$q(10) = 0.1251$
$q(11) = 0.2832$
$q(12) = 0.3500$

These are entered in Equation (7.9) to obtain the average travel distance. Since $A = 20$, we have $\sqrt{A} = 4.47$ and therefore $k_1\sqrt{A} = 2.68$ (using $k_1 = 0.6$). Equation (7.9) becomes

$$D_1 = 2.68[0.0038\sqrt{A} + 0.0022\sqrt{A} + \cdots + 0.3500\sqrt{A}]$$

$$= 0.843 \text{ miles}.$$}

This is the estimated average travel distance for the first-arriving engine in the region. Of course, to perform these calculations repeatedly for different alarm rates and regions, and to calculate the average first-arriving distance for ladders as well as for engines, the analyst will want to have a computer program written to perform all the steps described in this example.
The example has shown that using Equation (7.9) to estimate the average travel distance is fairly complicated. It requires detailed data about the lengths of time that companies spend at different types of alarms, as well as a computer program to calculate the probability \( q(N) \) that \( N \) companies are available. For this reason, the approximation to the square-root law based on the average number of companies available, \( E(N) \), is much more convenient when it is sufficiently accurate. This approximation is

\[
E(D_1) = k_1 \sqrt{A/E(N)}.
\]  \hspace{1cm} (7.10)

As a rule of thumb, Equation (7.10) is sufficiently accurate when the average number of available companies is at least two; i.e., when \( E(N) \geq 2 \). Here we shall show how well it works for the 12-company example given above.

The most accurate way to calculate \( E(N) \) is from the equation

\[
E(N) = \sum_{N=0}^{n^*} Nq(N),
\]  \hspace{1cm} (7.11)

which is simply the definition of the average. Using Equations (7.7) and (7.8), this sum can be calculated for the example as

\[
E(N) = (2 \times 0.0038) + (3 \times 0.0022) + \cdots + (12 \times 0.35)
\]

\[= 10.470.\]

However, we have not saved any effort, because all the probabilities \( q(N) \) must be known in order to use Equation (7.11). The only way that Equation (7.10) can be a simplification is if there is a quick way to estimate \( E(N) \). We have seen in Section 7.2.2 that the average number of busy engine companies is \( E(B) = \lambda E(S) \), where \( E(S) \) is the average number of engine company-hours per alarm, so an approximation to \( E(N) \) is \( E(N) = n^* - E(B) = n^* - \lambda E(S) \).

For our example, \( \lambda E(S) \) can be determined by multiplying the numbers in the last row of Table 7.5 by 1, 2, 3, ..., 11 and adding the products: it turns out to be 1.536. Thus, \( n^* - \lambda E(S) = 12 - 1.536 = 10.464 \), which is practically identical to the more exact calculation done, 10.470. Thus, when the average number of companies busy is small compared to \( n^* \), the approximation \( E(N) = n^* - \lambda E(S) \) is excellent. Since \( \lambda E(S) \) can be estimated directly from data showing the length of time companies work at incidents, without going through all the calculations shown in Tables 7.4 and 7.5, this constitutes a substantial simplification.\footnote{The computer program listed in Appendix A7.3 also prints out the value of \( \lambda E(S) \).}
Entering the value \( E(N) = 10.47 \) into Equation (7.10) gives \( D_1 = 0.829 \) miles. Comparing this with the more accurate answer derived earlier, \( D_1 = 0.843 \) miles, we see that for our 12-company example the error is only 1.7 percent. Since the square-root law is itself an approximation that can lead to errors of a few percent, the use of Equation (7.10) is fully justified as a good approximation.

7.2.4 Adjustment when Two Companies Occupy a Single Firehouse

In most fire departments, some or all of the fire stations house more than one company. If these companies are of different types (e.g., an engine company, a ladder company, and perhaps an emergency medical unit), there is no need to adjust the calculations of average travel distance that are described in Section 7.2.3. The analyst simply calculates the average travel distance for engine companies separately from the average travel distance for ladder companies. For example, when using Equation (7.9) to calculate the average travel distance for first-arriving engine companies, \( q(N) \) is the probability that \( N \) engines are available. When using Equation (7.10), \( E(N) \) is the average number of engines available. Similarly, either equation can be used for ladder companies.

However, when two or more companies of the same type occupy a single firehouse, we must adjust the square-root law. For specificity, we will discuss the situation for engine companies, although the calculations are identical for ladder companies. In addition, we assume that, at most, two engine companies occupy a single firehouse. Suppose that there are \( M \) engine companies, and they are located in \( R \) firehouses, where \( R < M \). We will show that the average travel distance for the first-arriving engine company at an alarm will be higher than if the \( M \) companies were dispersed, one to a firehouse. Thus, a fire department that has consolidated firehouses suffers a penalty in its average first-arriving travel distance. However, the average travel distance for the second- or third-arriving engine company may be higher or lower than if the \( M \) companies were dispersed, depending on the department's dispatching policy and the relationship between \( M \) and \( R \):

When All Engine Companies are Available. Consider the situation when all engines are available. In this case the average travel distance for first-arriving engines will be \( E(D_1) = k_1\sqrt{A/R} \), as compared to \( k_1\sqrt{A/M} \) if the engines were dispersed. Since \( R < M \), \( \sqrt{A/R} \) is larger than \( \sqrt{A/M} \). As an example, suppose that every firehouse has two engine companies, so that \( M = 2R \). The average travel distance for first-arriving engines is \( k_1\sqrt{2A/M} = \sqrt{2}k_1\sqrt{A/M} \), when all the engines are available. Thus the average travel distance is larger by a factor of \( \sqrt{2} \),
or 1.414 (41.4 percent), than it would have been if all the engines were dispersed, one to a firehouse.

To estimate the average travel distance for second-arriving companies, we need to know the department's dispatching policy. If the department dispatches two engines from the same firehouse, then of course the second-arriving travel distance is exactly the same as the first-arriving travel distance at all alarms that are near a firehouse having two or more engines. For simplicity, assume that every firehouse has either one or two engines. If \( R_1 \) stations have one engine and \( R_2 \) stations have two engines \( (R_1 + R_2 = R) \), then roughly a fraction \( R_2 / R \) of all the alarms will have their second-arriving engine housed in the same station as their first-arriving engine.\(^{13}\) Hence the average travel distance for the second-arriving engine will be approximately

\[
E(D_2) = \frac{R_2}{R} k_1 \sqrt{A/R} + \frac{R_1}{R} k_2 \sqrt{A/R}.
\]

Continuing the example, suppose that all the stations house two engine companies. Then \( R_1 = 0 \) and \( R_2 = R \), so

\[
E(D_2) = k_1 \sqrt{A/R} = \sqrt{2} k_1 \sqrt{A/M}.
\]

Since \( \sqrt{2} k_1 \) is smaller than \( k_2 \), the average travel distance for the second-arriving engine is lower than it would have been if all the engine companies had been dispersed, one to a firehouse. (In Section 6.4.2, we saw that \( k_1 \) is approximately 0.6, so \( \sqrt{2} k_1 \) is approximately 0.84; but \( k_2 = 1.2 \), which is larger.)

If, on the other hand, the fire department never dispatches two engines from the same firehouse to the same alarm, then the average travel distance for the second-arriving engine is \( k_2 \sqrt{A/R} \) when all engines are available. This, of course, is larger than \( k_2 \sqrt{A/M} \). With this dispatching policy, both first-due and second-due travel times will be higher than if the engines were dispersed.

**When Some Engine Companies Are Busy.** We now turn to calculating estimates of average travel distances that take into account the unavailabilities of engine companies. To obtain accurate estimates one must use fairly complicated models, such as the Hypercube Queuing Model\(^{14}\) or the simulation model described in Chapter 13. However, it is not too difficult to obtain a useful approximation for the average travel distance

\(^{13}\) This assumes that the two-engine houses are not concentrated in the areas with the highest alarm rates. Since this assumption may be incorrect, the resulting calculation is only an approximation.

\(^{14}\) This model, which was designed by Larson (1975), will be briefly described in Section 7.3.2. An overview of the model's design and capabilities is given by Chaiken (1975).
of the first-arriving engine. We begin with Equation (7.10), which gives the approximation

\[ E(D_1) = k_1 \sqrt{A/E(R)}, \]

where \( E(R) \) is the average number of stations with an available engine company. Our task is to estimate \( E(R) \). We found that when there is only one engine in each firehouse, \( E(R) \) is approximately \( R - E(B) \), where \( E(B) \) is the average number of busy engine companies. This approximation is unsatisfactory when several engines share a station. For example, it is possible that three engines might be busy and yet every firehouse might have an available engine present.

In fact, the average number of stations with an available engine will depend on the method used by dispatchers in selecting engines to dispatch. To simplify matters, we assume here that all firehouses that contain any engines are equally likely to be chosen for dispatch of the next engine. In other words, at any particular moment there may be \( r_1 \) stations having one engine and \( r_2 \) stations having two engines. If \( r = r_1 + r_2 \), we assume that the chance of choosing any one of these stations is \( 1/r \). Such an assumption is not entirely realistic, since it ignores the fact that alarms are more likely to occur near some stations than near others, but it is accurate enough for deriving an approximate square-root law.

Let us say that \( R_1 \) of the \( R \) stations house one engine and the remaining \( R_2 \) stations each house two engines. As a rough approximation, one might guess that the average number of empty stations is \( E(R_E) = R_1 E(B) / R \). In fact, this is exactly right when \( R_1 = R - 1 \)—that is, when only one station houses two engines and all the rest house one engine. It is also a moderately good approximation when \( R_1 / R \) is large, but it is an underestimate. A better estimate for the average number of empty stations is

\[ E(R_E) = \frac{R_1}{R} E(B) + \frac{1}{2} \frac{R_2(R_2 - 1)}{R^2(R - 1)} [E(B)]^2. \tag{7.12} \]

This approximation is very accurate whenever \( E(B) \) is small compared to \( R \) (say, \( E(B) < 0.3R \)), which is nearly always true in practical applications. One simply enters \( E(B) = \lambda E(S) \) in Equation (7.12) and subtracts the result from \( R \) to obtain a value of \( E(R) \) for the square-root law.

The remainder of this section is devoted to a derivation of Equation (7.12) and can be skipped by the reader who is willing to accept the estimate as satisfactory. The result is obtained by writing \( R_E(b) \), the average number of empty stations when \( b \) engines are busy, in the form

\[ R_E(b) = c_1 b + c_2 b(b - 1) + c_3 b(b - 1)(b - 2) + \cdots + c_b b!, \quad b = 1, 2, \ldots \]
and then ignoring all terms after the second to get

\[ R_E(b) = c_1 b + c_2 b(b - 1), \quad b = 1, 2, \ldots \] (7.13)

We shall show that \( c_1 = R_1 / R \) and

\[ c_2 = \frac{1}{2} \frac{R_2(R_2 - 1)}{R^2(R - 1)}. \]

With these values of \( c_1 \) and \( c_2 \), Equation (7.12) is a direct consequence of Equation (7.13) when the number of busy engines has a Poisson distribution with mean \( E(B) \). Since the number of busy engines typically has a distribution which is close to a Poisson distribution, Equation (7.12) is a reasonable approximation.

To find the values of \( c_1 \) and \( c_2 \) in Equation (7.13), we only have to consider the cases \( b = 1 \) and \( b = 2 \). However, the method we shall follow can be iterated to higher values of \( b \), thereby verifying that the coefficients \( c_3, c_4, \ldots \) can be ignored in comparison to \( c_1 \) and \( c_2 \).

Denote by \( p_b(j, k) \) the probability that, when \( b \) engines are busy, there are \( j \) empty one-engine houses and \( k \) empty two-engine houses. When \( b = 1 \), there is one busy engine. Then \( p_1(1, 0) \) is the probability that the engine comes from a one-engine house, which, according to our assumption about the dispatching practice, is \( R_1 / R \). Similarly, \( p_1(0, 0) \) is the probability that the engine comes from a two-engine house. (No houses are empty because it is impossible to have an empty two-engine house when only one engine is busy.) Thus \( p_1(0, 0) = R_2 / R \). Multiplying the probabilities by the number of empty stations and adding gives us \( R_E(1) = p_1(1, 0) = R_1 / R \) for the average number of empty stations when \( b = 1 \). Thus the approximate formula \( R_E(b) = R_1 b / R \) is in fact exactly correct when \( b = 1 \), and we have shown that \( c_1 = R_1 / R \), as desired.

The formulas for \( p_2(j, k) \) can be calculated similarly. For example, \( p_2(2, 0) \) is determined by starting with the state in which one one-engine house is empty, and noting that the chances are \( R_1 - 1 \) out of \( R - 1 \) that the next busy engine also comes from a single-engine house. Hence, \( p_2(2, 0) = R_1(R_1 - 1) / R(R - 1) \). After finding all the \( p_2(j, k) \), the average number of empty stations is then

\[ R_E(2) = 2p_2(2, 0) + p_2(0, 1) + p_2(1, 0), \]

which turns out to be

\[ R_E(2) = 2 \frac{R_1}{R} + \frac{R_2(R_2 - 1)}{R^2(R - 1)}. \]

Comparing this with Equation (7.13), with \( b = 2 \), shows that

\[ c_2 = \frac{1}{2} \frac{R_2(R_2 - 1)}{R^2(R - 1)}, \]

which is the desired result.
Note that \( c_1 \leq 1 \) and \( c_2 \leq 1/R \). By iteration of the derivation one can find \( c_3, c_4, \ldots \) and show that \( |c_3| \leq 1/R^2, |c_4| \leq 1/R^3, \ldots \). That is why Equation (7.13) is a good approximation when \( b/R \) is small. Attempting to obtain a more accurate estimate of \( E(R_k) \) is not warranted, because the square-root law is itself an approximation.

### 7.3 DECIDING WHICH COMPANIES TO DISPATCH

Upon the initial receipt of an alarm, most fire departments determine how many engine companies and ladder companies to dispatch according to the location of the incident and its apparent nature. For example, four engines and two ladders might be dispatched in response to a telephone report of a structural fire in a downtown area, while only one engine would be dispatched to an automobile on fire at the same location. Once the number of companies to be dispatched has been determined (a matter which will be discussed in Section 7.4), standard practice is to dispatch the closest available units. In this section we will see that such a practice is not always the best policy.

The idea behind dispatching the closest available companies is to ensure the lowest possible response times. However, in some cases the incident may be of such a type that waiting an extra 30 seconds or so for the arrival of the second-closest company will not make any difference in the outcome. In such cases, one should think about the effect that the current dispatch will have on response times to future alarms that may occur while the dispatched companies are busy. In fact, we will see that the average of response times over a period of several hours can be reduced by making occasional exceptions to the closest-company dispatch rule.

The simplified example in Figure 7.9 illustrates the possible value of dispatching a company other than the closest one. In this figure, Com-

\[ \text{FIGURE 7.9. An example of when dispatching the closest company is not the best policy. (Company 1 is located in an area of high alarm rate.)} \]
PTI FIRESTATION LOCATION FIRE HAZARD SURVEY

LIST NUMBER: __________
Structure Name: ____________________________________________________
Structure Address: ___________________________________________________
Type of Occupancy: __________________________
Survey Date: __________________________

Total floor area of structure: __________________________
Height of structure: __________________________

Fire Protection Systems

Sprinkler System: No Yes Wet Dry Full Partial
FD Intakes - No Yes

Standpipe System: No Yes Wet Dry Full Partial
FD Intakes - No Yes

Fire Pump: No Yes

Alarm System: No Yes (Describe)

Other Fire Protection Features: (Describe)

Occupants

Type of Occupant: Needs Assistance
Doesn’t Need Assistance

Day Care Center in Basement: Yes No

Fire Load

Hazardous Materials Storage: No Yes
Above Average Fire Load: No Yes (Describe)

Water Supply Needed: ________ gallons per minute
Available Unavailable

Miscellaneous

Extraordinary Life Threat: No Yes ( Describe)

Code Compliance History: Acceptable Unacceptable Unknown
Exposure Hazard: No Yes (Describe)

Shake Shingle Roof: No Yes

***********************************************************************
PTI HAZARD CATEGORY: Maximum High Moderate Low Minimum
***********************************************************************
file: hazards (on PTI disk)
Analysis of Fireground Tasks
Olathe Fire Department
September, 1991

Recently a series of fireground scenarios have been conducted utilizing members from A and B shifts. The objective of these scenarios was to determine the efficiency of varying sizes of crews. The crew sizes studied consisted of crews of three, four and five men. In each of these scenarios, there were three areas of importance to this study.

First, we wanted to gain a better knowledge of the time differences when three, four and five men crews performed the same fireground objective. Secondly, this study will compare certain vital signs such as blood pressure, pulse, respirations and air consumption of each individual participant when he worked in a three, four and five man crew. Lastly, we decided that each participant in the study would be able to voice his observations and analysis of working in the various crew sizes.

Prior to conducting these scenarios, I researched various articles and reports that were written on this subject of varying fire suppression crew sizes. In my research, I discovered a study of fire suppression crew sizes conducted by the Dallas Fire Department. The scenarios used in our study are quite similar to the scenarios used in the Dallas study. I would like to make clear that some modifications had to be made in our study due to the lack of available training facilities and manpower capabilities.

It is important to remember that the scenario times recorded in our study are not entirely accurate. Due to the size of this department and the time allotted to conduct this study, it was not possible for each participant to participate in every scenario and crew size. This study would, for example, use a certain individual in a three man exercise and then again in another exercise if time and his availability permitted.

Many different groups of teams were utilized to obtain the most possible data. This study will assume that each of our firefighters is trained as equally as another; however, some crews were found to be more capable than others because of experience and aerobic capacity.

As the results of this study are reviewed, please remember that these are average times of fire suppression crews simulating three, four and five man operations and that the crew members varied throughout the study. This study did result in discovering some good data, and I am hopeful that it can be useful in convincing the decision makers of the need for larger size fire suppression crews.
Critical Tasks

These are the critical tasks conducted by the participants. These tasks consisted of assignments that could most likely occur at a fire involving a single-family residence.

First due engine scenario (three, four, five men)

1. Stretch a 200 foot 1 3/4" pre-connected hose line to the front door of the residence.

2. Stretch a second 200' 1 3/4" pre-connected hose line to handle the simulated exposures.

3. Operate pump and hook up a 4" hydrant line.

Second due engine scenario (three, four, five men)

1. Stretch a 200' 1 3/4" pre-connected hose line to provide protection for the line at the front door pulled by the first due engine.

2. Stretch a second 200' 1 3/4" pre-connected hose line to the simulated basement.

3. Stretch a 200' section of a 2 1/2" hose, which is wyed into a 100' section of 1 3/4" line. Also stretch the 1 3/4" line.

4. Operate pump and hook up a 4" hydrant line.

Truck company scenario (three, four, five men)

1. Search a smoke filled area on hands and knees and find a simulated victim.

2. Raise a 24' extension ladder to the roof (two man minimum).

3. Extend a 14' roof and wall ladder to the roof peak and secure the ladder.

4. Bring an axe, pikepole and saw to the roof.

5. Simulate breaking a window on the second floor.
6. Raise a secondary 14' roof and wall ladder for escape purposes.

7. Simulate shutting off utilities.

NOTE 1: All participants wore self-contained breathing apparatus throughout every scenario in order to obtain the air consumption data.

NOTE 2: Vital signs were obtained before and after each scenario on each participant.

NOTE 3: These scenarios were conducted on Station One grounds and also at a donated house on 127th Street and Blackbob.

It should be noted that marked rises in these particular vital signs were recorded as the workload of the individual increased. The vital signs of a typical three man crew showed significantly higher numbers than those of the four and five man crews. If desired, I can make available bar graphs depicting the average rises in blood pressures, pulses and respirations.

The final objective of this study was to allow all participating members an opportunity to voice the pros and cons of the varying crew sizes. As expected, there were a great many cons with regard to the three man crew operations. These included concerns such as excessive fatigue and potential prolonged fire attack, which could result in flashover or backdraft. The participants also expressed that three man crews made efficiency almost impossible.

One pro that was consistently reported with regard to the three man crews was simply that the scenarios were possible to complete.

Four and five man operations included many more pros, such as less fatigue, quicker times and the opportunity for the captain of the crew to be a supervisor, which provides for a better degree of safety for the entire crew.

In summary, I hope this study provides some useful information to the department and to those people who will determine our manning levels.
Figure 1. First-due Engine Company Tasks

Figure 2. 2nd-due Engine Company Tasks
Figure 3. Ladder Company Tasks

- "3-man": 6:18 minutes
- "4-man": 4:07 minutes
- "5-man": 3:12 minutes

Company Size
Appendix B

Fire Station Location Analysis – 1998
CITY OF OLATHE

Fire Station Location Analysis – 1998

*** A CHANGE OF CONDITIONS ***

City of Olathe

May 27, 1998
File: report98.doc
Introduction

A Change of Conditions: 1991 versus the Present

The 1991 Report on Fire Station Locations

In 1991, the Olathe Fire Department published a study entitled "Station Location Analysis for the Olathe, KS Fire Department." That study analyzed staffing, equipment issues, and prospective fire station locations, dividing the report into four sections. The report restricted its field analysis, however, to fire threat only.

Section One explained why a poorly planned network of fire stations financially burdens a community and how a well-planned network provides financial benefits and enhanced protection to the city and its citizens.

Section Two described key aspects of fire behavior and fire department operations and how the analysts measured the fire department's capabilities.

Section Three discussed the analytical methodology used for the study, comparing two competing analysis models: the Insurance Services Office (ISO) rating and the Public Technology, Inc. (PTI) street network/travel time analysis. The discussion explained why the PTI model was chosen as the analysis methodology in 1991.

Section Four presented the study's conclusions.
- Part 1 described the risks in Olathe in 1991 and the fire department's capability in handling those risks.
- Part 2 contained the analysis for relocation of Station 4.
- Part 3 compared eight potential sites for Station 6.
- Part 4 discussed improvements that would be necessary if Olathe wishes to improve its fire insurance (ISO) rating.

Also presented in Section Four were the total number of new stations, staffing, and equipment that would be needed to provide a reasonable level of fire safety when the city is fully developed.

This report builds on and expands the findings in 1991, but increases the scope of analysis well beyond fire threat.

Much has changed since 1991.

Let's begin a look at the changes with a few statistics that compare 1991 with the present.
Changes Since 1991

In 1991, the Olathe Fire Department ran 1,954 alarms. Of those, 42% were fire calls and 35% medical.

In 1997, the Olathe Fire Department ran 4,748 alarms, an increase of 240% in just six years. Of those responses in 1997, 25% were fire calls and 50% medical.

Clearly a reversal of dominant call type (from fire to medical), and a large growth in total calls. Figures 1, 2, and 3 (below) express these major changes graphically.

Figure 1 - Projected and Actual Total Alarm Increases
1991 - 1997

Interestingly, the 1991 report (see Figure 1 above) projected two possible growth trends for future calls, a "conservative" growth of 5 percent and a rate of 7 percent, which tracked the actual growth in 1991. The present rate (1997), as illustrated above, has been steadily climbing, however, at 16.6 percent rate for the last six years -- almost double the rate of 1991 -- and far beyond the projections of 5 and 7 percent.

Also, note that the analysts in 1991 saw no reason to break this "total alarm" projection separately into fire and medical alarms. At that time, it was not foreseen that medical calls would accelerate so rapidly -- that they would overtake, then outstrip and double, fire calls -- nor that fire calls would nearly level off with little increase in actual numbers.

As Figure 1 illustrates, this sharply rising trend in total alarms doesn't appear likely to diminish in the near future. The acceleration is strong and steady – mirroring, but more than quadrupling, the steady growth of Olathe itself.
The Meaning of the Changes

Looking into the near future, then, if we project growth rates of 7, 10, and 16.6 percent out a few years, the Fire Department will surpass 10,000 total calls as early as 2002 -- in less than five years -- and no later than 2009, eleven years (see Figure 2 below), a doubling of the present call load.

Next, Figure 3 shows how the number of general types of calls have changed in the last several years.
As displayed in Fig. 3, in 1991, fire calls led all alarm types, followed by medical, then miscellaneous, then hazardous materials. Presently, in 1997, not only have medical calls changed places with fire calls, but hazardous materials incidents have leveled off, and miscellaneous activities jumped upward — paralleling the growth of medical calls (and total calls).

The simple but telling representations illustrated in the above three charts, also point out that the list of “things” the Fire Department does has ballooned far past just “firefighting.” In 1991, 42% of the total calls were fire-related (520 calls), almost half. In 1997, only 25% were “fire-related” (1167 calls) — down to one quarter of total calls. Additionally, not only has the percentage of the call load for fires been cut dramatically, but the absolute number of fire calls has only increased by 200 a year (less than one a day) — even though the rest of the call load has more than doubled — in fact, in 1997 the absolute number of fire calls only increased by 63.

In summary:

- “Firefighting” has dropped to one fourth of what the Fire Department “does” — from 42% in 1991 to 25%.
- Medical calls have risen from 35% to half of total calls.
- Hazardous Materials calls have dropped from 10% to 5%.
- Miscellaneous calls have risen from 13% to 19%.

Simplified, these numbers mean that the Fire Department does a great deal more now than fight fire. In fact, a more descriptive name for the organization might be “The Emergency Services Department” — since seventy five percent of the Fire Department’s alarms are for medical calls, hazardous materials spills, and other greatly varied miscellaneous alarms (police assists, public non-emergency assists, water rescues, high angle rescues, trench rescues, bomb investigations and removal, water evacuations, mass event standbys, lock-outs, and helicopter standbys) — and only twenty five percent of the calls are fire-related.

And, of course, the statistics and graphs don’t reflect the many other non-emergency tasks for which the Fire Department is responsible — including public education, training, fire inspection, plan review, and emergency management.

Given the major changes illustrated above, we must go well beyond a simple look at where to put the next fire station — and then the next, and the next . . . We must look at the entire system of public safety responsibility shouldered by the Fire Department — and the direction it leads into the foreseeable future.
To illustrate this need to look beyond the traditional role of a fire department, the front and rear covers of the 1991 report are fire engine red. The illustration on the front cover depicts an ordinary checkerboard -- and the pieces on the checkerboard are of only two types: fire trucks and fire.

If we were to carry these same illustration concepts onto the covers of this new report, the fire engine red covers would be replaced with a rainbow of colors -- and the simple checkerboard would morph into a three-dimensional chessboard -- with many, many different kinds of pieces moving around the board simultaneously -- and operating under different rules that only apply to specific pieces.

The winning strategy for effective public safety has gotten a lot more complicated.

This Report

Which leads us to this report.

This report analyzes not only the need for and placement of future fire stations but will also analyze the broadened spectrum of public safety issues that impact the effective operation of the Fire Department and the safety of Olathe's citizens.

The issues analyzed that influence the siting of future fire stations will be:
- Travel time from the station to the emergency incident
- The new responsibility of response to medical calls
- Staffing requirements that affect effective response

The report begins with a list of definitions and then a look at the informational foundation for all the sections listed above -- the new hazard analysis.
Definition of Terms

ACTORS - Structures, businesses, or situations that by their very existence pose a potential danger to an area or an area's population. Examples of actors are a superhighway carrying tons of hazardous material through an area, or an unsprinklered building housing a high-density population. These actors pose a potential danger to the area and/or the population of that area.

DISPATCH TIME - The portion of a fire department's response time that begins when the dispatcher receives an alarm and ends when the dispatcher assigns response companies to the call.

DOUBLEHEADER - When a response company is already active on a call, receives another, and cannot respond.

EFFECTIVE RESPONSE FORCE - The minimum amount of staffing and equipment that must reach a service demand zone within the maximum prescribed travel time.

FIRE DEMAND ZONE (FDZ) - A standard geographic area of the city used as the analysis foundation for the 1991 report. Each FDZ was analyzed solely for the fire vulnerability of the structures in that zone.

FIRE FLOW, AVAILABLE - The amount of water available for firefighting.

FIRE FLOW, REQUIRED - The quantity of water required to be available for a 2 or 3 hour period at a minimum pressure of 20 psi to extinguish a fire in a structure. The gallonage required is calculated for each structure, and is based on the structure size, compartmentation within the structure, construction material and exposure to other structures. The water must be available in addition to the highest domestic demand on the water system. This figure is a significant feature of the Insurance Services Office evaluation.

FIRST-DUE AREA - The portion of the city that each response company has been assigned as the first to arrive at an alarm.

FIRST-DUE SERVICE DEMAND ZONES - The total number of service demand zones within each company's first-due area.

FUTURE GROWTH AREA (FGA) - An extended area beyond the present municipal borders of Olathe that is considered by the Olathe Planning Department to comprise the eventual growth limits of the community. The FGA serves as the geographical basis of this report.
INSURANCE SERVICES OFFICE (ISO) - A national organization that evaluates each city's public fire protection and provides rating information to insurance companies. The insurers use the rating to set their basic premiums for fire insurance. The ISO inspects and tests each city's fire department and public water supply system about every 10 years.

MAXIMUM PRESCRIBED TRAVEL TIME - For each risk category, the maximum travel to a service demand zone that is deemed necessary for the responding units to be considered an effective response force.

POTENTIAL - The latent possibility for an occurrence of an emergency event.

PROBABILITY - The statistical and/or reasonable likelihood that an emergency event will actually occur.

RESPONSE EFFECTIVENESS - A measure of the fire department's capability, expressed by the number of service demand zones in the city that can be reached by an effective response force in the maximum prescribed travel time. It is expressed as a ratio of the service demand zones within the time limit with the service demand zones beyond the time limit.

RESPONSE EFFICIENCY - A measure of an individual fire station's productivity which grades the duplication of coverage within each company's first-due area. This measure has two components. The first is the number of service demand zones that can be reached from the assigned fire station within the maximum prescribed travel time. The second component is a weight that is a function of the difference between the number of service demand zones actually covered and the number of service demand zones that the company would cover if it had an equal share of them.

For example, in a five-station arrangement, each station would ideally handle 20% of the service demand zones that can be covered by the five stations. In reality, though, each district varies because the street layouts and street speeds vary in each district. The Response Efficiency Measure takes this into account by giving a positive weight to stations that handle more than the equal share of service demand zones and a negative weight to stations covering less than the equal share. In the five station illustration, a station which covers 25% of the service demand zones would get a weight of 1.25, and a station which covers 15% would get a weight of .75.

RESPONSE RELIABILITY - The percentage of the time that all response units are available for a call. This is a function of the average time that a unit is unavailable for an alarm because it is already at another call. Values for the formula for average time unavailable are taken from a Poisson distribution.
When a station is unavailable, the response time will be longer because a more distant station will have to fill in for the unavailable station. Response Reliability is a statement of the probability that an effective response force cannot be provided when an alarm is received.

RESPONSE TIME - The total time that elapses from the time the dispatcher receives an alarm until the companies are prepared to respond. Response time is composed of the following segments: dispatch time, turnout time, travel time, and setup time.

RISK CATEGORY - A rank assigned to each service demand zone (SDZ) that reflects the degree of risk to life and property safety - and hence the demand upon the fire department - that exists in the SDZ. Five categories are used, ranging from maximum to minimum.

SETUP TIME - After arrival of a company on an emergency scene, the time it takes the company to prepare before beginning their actions. This preparation includes donning of proper safety apparel and unloading of equipment from the response unit.

SERVICE DEMAND ZONE (SDZ) – A one quarter mile square area within the city limits of Olathe used as the analysis foundation for this report. Each SDZ is analyzed for both service demand potential and probability.

STANDARD FIRE DEMAND ZONE AREA (SFDZ) - A uniform area used for comparison of future stations in the 1991 report. The SFDZ included some areas that aren't within Olathe's boundaries but will be in the future. The purpose of the SFDZ is to provide a common denominator for calculating the response efficiency and response effectiveness scores for stations that will cover those areas.

THREAT - the potential for “actors” (see definition above) in an area to pose a danger to the area or to the area's population.

TRAVEL TIME - The portion of response time when the response companies don their personal protective gear and go to their assigned apparatus. The time begins when the companies receive an assignment from the dispatcher and ends when the apparatus leaves the station.

TURNOUT TIME - The portion of response time when the fire companies don their personal protective gear and go to their assigned apparatus. The time begins when the fire companies receive an assignment from the dispatcher and ends when the apparatus leaves the station.

VULNERABILITY – The susceptibility of an area and its population to damage.
Section One

A New Hazard Analysis for the City of Olathe: Service Demand Zones

Threat and Vulnerability

In 1991, the station location analysts divided the city of Olathe into hundreds of small areas called “Fire Demand Zones” (FDZ). These FDZ’s were then individually scrutinized for the maximum fire vulnerability in each one of the zones. The potential maximum fire vulnerabilities in each FDZ were then catalogued into five levels: minimum, low, moderate, high and maximum.

Structures studied included high-density residential areas, unsprinklered and large commercial occupancies, hospitals, mobile home parks, ordinary residential buildings -- every building type in the city. The analysts classified each type of fire vulnerability into one of the five hazard categories -- and only as they were vulnerable to fire in a worst case scenario.

This was a limited analysis -- not studying the other possible categories of jeopardy: medical, hazardous materials, and civil. The fire-centered analysis also didn’t consider the concept of “threat” -- the 1991 analysis only studied “vulnerability” to fire.

Threat is defined as: the potential for “actors” in an area to present a danger to the area or to the area’s population. Examples of actors are: a superhighway carrying tons of hazardous material through an area, or an unsprinklered building housing a high-density population.

Vulnerability is defined as: the exposure of an area to damage. Examples are: areas that include hospitals, day-care centers, schools, high-density apartment complexes, or large, dense commercial areas (malls).

As an example, in the 1991 study, no consideration was given to threat in the form of the major transportation corridors that slice through our community and bring hundreds of tons of hazardous materials through our city each day. Additionally, no consideration of threat in the form of site-built hazardous materials businesses was considered, and no consideration of threat in the form of civil disorder, terrorism, mass casualties -- or a disaster.

Potential and Probability

Secondly, the 1991 report limited its investigation to “potential.” “Probability” of occurrence of that potential threat was not examined or weighed.

As an example, the 1991 report ranked the FDZ containing the Johnson County Courthouse as a maximum FDZ -- strictly because of the potential for fire -- not considering the fact that the building has no history of fire and no reason to think that would change. Additionally, the report did not take into account the vulnerabilities the occupants and structure have to terrorist attack, civil disorder,
mass casualty, and hazardous material release. The structure is a courthouse, an obvious civil target, and does have a history of such events. In addition, the presence of the railroad a few hundred feet west was not considered for its hazardous material and mass casualty threat against the courthouse.

**This Report and the New Hazard Analysis**

This report, however, looks at the full hazard spectrum in each Service Demand Zone (SDZ): potential threats and vulnerabilities, and the probability of occurrence of those threats and vulnerabilities.

Indeed the name change from *Fire* Demand Zone to *Service* Demand Zone reflects this enlargement of the scope of the analysis.

**How the Analysis was Done**

The 1997 analysis began by dividing all of the area inside the city limits study areas labeled *Service Demand Zones (SDZ)*.

A Service Demand Zone (SDZ) is a parcel of land that has been analyzed for potential and probable emergency service demand (threats and vulnerabilities, potentials and probabilities). The parcels are one quarter mile square, 16 per square mile, approximately 1000 for the entire city of Olathe.

*This calculation of service demand in a specific area is a measurement of the personal threat to and vulnerabilities of the citizens who live and work in that SDZ, and to their property, and their livelihood.*

Examples of potential threats are the large amounts of hazardous materials carried through the railroad corridors and certain hazardous industries. Examples of potential vulnerabilities are schools, nursing homes, and critical infrastructure.

The SDZ analysis assesses these threats and vulnerabilities for both potential and probability.

**Calculating Service Demand: Potential and Probability**

Each SDZ has 100 possible points of service demand (emergencies that might happen). Each of the 4 service demand categories (Fire, Medical, Haz Mat, Other) contributes 25 points of threat/vulnerability potential (possible service demand) to the total for each SDZ (equaling the 100 points maximum).

In addition, each potential threat/vulnerability is analyzed for probability of occurrence (likelihood that a service demand would actually occur). The calculation of the threat equation (potential X probability) can then be modified or mitigated by factors not precisely quantifiable. These mitigating factors may lower or raise the final numbers of the calculated threat (service demand). An example of a mitigating factor that would modify the final threat equation is a
semi-rural area that contains a high fire threat, but that threat is isolated and/or is confined to a small set of structures, e.g., a mobile home court. This court may be judged to have a high threat potential for fire, but because it has very few homes and/or is isolated, the potential can be downgraded. If however, the court contains a large number of structures and/or has a history of fire, then the probability of occurrence is raised.

Finally, after all the calculations outlined above, the SDZ's total threat is quantified from 1 to 100 -- systematically defining the likely service demand for each SDZ as a whole.

**Categories of Service Demand Potential**

1. **Fire**
   - Minimum risk (1 point):
     - Rural land with no occupied structures
     - Recreational areas with no population peaks
   - Low risk (2 points):
     - Semi-rural
     - Small commercial structures that are remote from other buildings
     - Detached residential garages, other out-buildings
   - Moderate risk (3 points):
     - Commercial buildings under 10,000 square feet without high-hazard contents
     - Detached 1 or 2 family homes
     - Apartment buildings of two stories or less where all areas are accessible to pre-connected attack lines
   - High risk (4 points):
     - High-rise buildings with adequate built-in fire suppression
     - Commercial buildings over 10,000 square feet with occupants who would not normally need assistance
     - Buildings with built-in fire suppression but with occupants who need assistance
     - Apartment buildings over two stories or with areas beyond the reach of pre-connected attack lines
     - Buildings with low occupancy but which use or store high-hazard material
     - Mobile homes, lumber yards, schools, historic structures
   - Maximum risk (5 points):
     - High-rise and large-area buildings that lack built-in fire suppression or inadequate built-in fire suppression
     - Buildings that contain large numbers of occupants who are not capable of self-preservation or who need direct assistance for self-preservation
     - Explosives or extremely hazardous materials storage
- Periodic events involving fire or explosives (July 4 celebration)
- The "worst case" scenario

2. Medical
- Minimum risk (1 point):
  - Rural or undeveloped land
  - Low population density or no population
  - Areas with little or no history of medical alarms
- Low risk (2 points):
  - Semi-rural
  - Low population density
  - Recreational areas with low visitation
- Moderate risk (3 points):
  - Single or two-family residential areas
  - Non-hazardous businesses
- High risk (4 points):
  - High population density (typical malls, retail districts, apartment complexes)
  - Recreational areas, periodic events, or tourist visitation points with occasional high influxes of patrons
  - Businesses or industries that deal in hazardous materials
  - Dangerous hazards present in the SDZ or in adjoining SDZ's that could affect the local area
  - High speed automobile corridors
  - Dangerous areas (cliff at lake, swimming areas)
  - Schools, elementary
- Maximum risk (5 points):
  - Very high population density (super malls, very large apartment complexes, junior and senior high schools, MANU)
  - History of high numbers of or life-threatening medical alarms
  - Especially medically vulnerable populations (elderly, impaired)
  - Life-threatening hazards present in the SDZ or in adjoining SDZ's that could affect the local area
  - The "worst case" scenario

3. Hazardous Material
- Minimum risk (1 point):
  - Rural
  - No or almost no use of hazardous materials
- Low risk (2 points):
  - Semi-rural or low density populations
- Moderate risk (3 points):
  - Typical residential areas
- High risk (4 points):
  - Non-interstate, truck transportation routes
  - Commercial businesses dealing in non-life threatening hazardous materials
  - School laboratories
- Maximum risk (5 points):
  - Interstate automobile and truck transportation routes
  - Railroads
  - Commercial businesses dealing in life-threatening hazardous materials
  - The "worst case" scenario

4. Other
- Minimum risk (1 point):
  - No mass casualty and little damage potential
  - No obvious terrorist targets
  - No disruption potential
- Low risk (2 points):
  - Little mass casualty minor damage potential
  - No obvious terrorist targets
  - Little disruption potential
- Moderate risk (3 points):
  - Moderate damage potential
  - No obvious terrorist targets
  - Moderate disruption potential
- High risk (4 points):
  - Schools, junior and senior
  - Historic structures
  - Critical infrastructure
  - Mass casualty or high damage potential
  - High disruption potential
  - One or more potential terrorist targets, but no record
  - One or more bullseye terrorist targets, but no record
  - No history of terrorist attacks or threats of attack
- Maximum risk (5 points):
  - Super critical infrastructure (FAA, governmental buildings)
  - Mass casualty or maximum damage potential
  - Maximum disruption potential
  - One or more bullseye terrorist targets
  - History of mass casualty incidents
  - History of maximum damage incidents
  - History of terrorist attacks or threats of attack
  - The "worst case" scenario
Risk Modifiers: Probabilities and Mitigating Circumstances

Probabilities:

Given the above service demands as potentials, that doesn't automatically make them likely. Consideration must also be given to their probability of occurrence.

Probability is the likelihood that an event will occur.

A probability factor must be integrated into the final point score for an SDZ to more closely approximate its practical and real service demand potential. This probability factor will reduce the number of points that an SDZ scores as the probability (likelihood of occurrence) is reduced or raise it if the likelihood of occurrence is judged to be high. Following are the definitions of the various levels of probability and their numerical assignment.

Levels of probability:

- Minimum (1 point): Impossible
  - Conditions are such that the event cannot happen
- Low (2 points): Unlikely to occur
  - The event has never happened, but is not impossible
- Moderate (3 points): Likely to occur
  - The event has never happened, or has only happened occasionally, but is likely to happen
- High (4 points): Very likely to occur
  - The event happens regularly, and will reoccur regularly
- Maximum (5 points): Has often occurred before and will again
  - The event happens almost daily, and will reoccur almost daily

Mitigating Circumstances:

In a few cases the scoring of an SDZ may be modified upward or downward by the recognition of mitigating and special circumstances.

For instance, fire potential for a certain SDZ may be initially rated as maximum because of the type of building structures in the SDZ. However, the score for fire potential may be lowered if there are only a very few of the target structures in the SDZ.

On the other hand, if a particularly threat/vulnerability potent building is found in an SDZ, the final rating of that area may be raised because of the special circumstance of a single high-threat/vulnerability building.
FIG-5
SDZ - Potential Maximum and High Hazard

- □ Maximum
- □ High
SDZ - Probable Maximum, High, Moderate Hazard

- Maximum
- High
- Moderate
Calculating Final Point Score for an SDZ

Final point tabulation for each SDZ is a product of: 1) the points accumulated from the potential of a threat/vulnerability in an SDZ and 2) that sum multiplied by the probability of the event actually occurring.

Final points scored (threat/vulnerability) = potential X probability

For example: Each category in an SDZ is analyzed separately (Fire, Medical, Hazardous Materials, Other). The points calculated in each category (separately) are multiplied by the probability factor. For instance, if the fire calculation in an SDZ is calculated as 3 and the probability of the fire occurring is calculated as 2, then the grand total for fire exposure in that SDZ is 6 (3 times 2).

Each of the 4 categories is then added together for the grand total of that SDZ. For example: if Fire = 6, Medical = 4, Hazardous materials = 8, and Other = 1 - - - - the grand total = 19.

This grand total represents the spectrum of known potential threats and vulnerabilities in an SDZ and the likelihood of occurrence.

Once the grand total for an SDZ is calculated, that score is compared against the SDZ Exposure Scale, below.

SDZ Exposure Scale:

Total points scored in the SDZ:
- Minimum - Less than 10 points
- Low - 10 to 29
- Moderate - 30 to 69
- High - 70 to 89
- Maximum - 91 to 100

These scores are then mapped and displayed graphically to illustrate service demand across the city.

On the following pages are displays that illustrate the findings of the analysis.

Figure 4, entitled “The Service Demand Zone Analysis Grid” illustrates the 50 plus square miles of Olathe that was analyzed in 1/16 of a square mile areas (called Service Demand Zones).

Figure 5, entitled “SDZ – Potential Maximum and High Hazard” maps the potential maximum and high hazard SDZ’s within the total analysis area (note potential).

Figure 6, “SDZ – Probable Maximum, High, Moderate Hazard” illustrates the probable maximum, high, and moderate SDZ revealed by the analysis (note probable).

Comparison of Figures 5 and 6 graphically reveals the dramatic disparity between the potential for an emergency occurrence and the probability.
### Service Demand Scores by Potential and Probability

#### Fire

- Minimum (1 pt.) X Probability =  
- Low (2 pts.) X Probability =  
- Moderate (3 pts.) X Probability =  
- High (4 pts.) X Probability =  
- Maximum (5 pts.) X Probability =  

**Total**

#### Mitigators

- Minimum (1 pt.) X Probability =  
- Low (2 pts.) X Probability =  
- Moderate (3 pts.) X Probability =  
- High (4 pts.) X Probability =  
- Maximum (5 pts.) X Probability =  

**Total**

Remarks: [Remarks]

#### Medical

- Minimum (1 pt.) X Probability =  
- Low (2 pts.) X Probability =  
- Moderate (3 pts.) X Probability =  
- High (4 pts.) X Probability =  
- Maximum (5 pts.) X Probability =  

**Total**

Remarks: [Remarks]

#### Hazardous Materials

- Minimum (1 pt.) X Probability =  
- Low (2 pts.) X Probability =  
- Moderate (3 pts.) X Probability =  
- High (4 pts.) X Probability =  
- Maximum (5 pts.) X Probability =  

**Total**

Remarks: [Remarks]

#### Other

- Minimum (1 pt.) X Probability =  
- Low (2 pts.) X Probability =  
- Moderate (3 pts.) X Probability =  
- High (4 pts.) X Probability =  
- Maximum (5 pts.) X Probability =  

**Total**

Remarks: [Remarks]

**Final Score:** [Score]

**Service Category:**

- Minimum: < 10 pts.
- Low: 10-29
- Moderate: 30-69
- High: 70-89
- Maximum: 91-100

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(likelihood) of that emergency actually occurring. As Figure 5 shows, Olathe has an enormous potential for major emergency occurrences. This potential tends to follow the routes of the major transportation corridors: the BNSF Railroad, I-35, and K-10 highways – because those routes produce potential high threats. However, Figure 6 illustrates that if we filter potential through a probability matrix, the map changes from lines of maximum and high hazard to a wide-spread pattern of moderate probability that tends to cover nearly the entire geographical area of the city.

SDZ Potential/Probability Form and Working Analysis Map

On the following pages are examples of the analysis forms and maps used for the 1997 all-hazards study of Olathe (Figures 7 and 8).

Figure 7, a typical example of a Service Demand Zone, is the working map for Section 201, a mile-square portion of Olathe that includes I-35, the BNFR Railroad, a school, apartment complexes, and residential neighborhoods - - a good representation of general Olathe demography and geography. This section is divided into 16 Service Demand Zones (SDZ) and each is studied for the four major types of potential and probable threats (fire, medical, hazardous materials, other). This analysis is then assigned a numeric value, totaled, and given a hazard value for that specific SDZ: minimum, low, moderate, high, or maximum. This assignment then identifies both the potential and the probable hazard vulnerability of that 1/16th of a square mile.

That value (from minimum to maximum) is then used as a yardstick by the Fire Department to assess whether their resources and training are sufficient for covering the identified hazards in that specific area – both by potential and probability.

For instance, on the following pages are Map 201 and the SDZ potential/probability analysis form for SDZ 201-2 (one of the 1/16 sections of Sector 201). That SDZ (201-2) contains a section of I-35 and the BNFR railroad. Threats are evaluated for each general category: fire, medical, hazardous materials, and other. The numeric evaluations for each category are then totaled to give a bottom line score for SDZ 201-2. In this case, the final score is 46, which falls into the moderate category for the SDZ as a whole.

This type of analysis is done for each of the SDZ's in the city and then converted for ease of reference to generalized maps (see Figures 4, 5, and 6). This study was done for the entire city limits of Olathe (1997) and used as the underlying basis for the conclusions and recommendations of this report.

This particular type of study is an evolution from the Fire Demand Zone (FDZ) concept utilized in the 1991 study. As stated in the introduction to this document, the 1998 analysis studies a much wider spectrum of threat and potential.
Section Two

Olathe's Emergency Services Needs and Community Expectations

In 1991 the term "Fire Department" described the overwhelming public safety role of the Olathe Fire Department as perfectly as selling software described Microsoft at that time. Since 1991, however, the world has changed – since the rise of the Internet, Microsoft no longer relies solely totally on software sales for financial success and the Olathe Fire Department no longer responds to fire alarms as its primary community service role.

These changes are only partially because Microsoft and the Olathe Fire Department decided to change. Primarily, these changes are because the community they serve changed -- the community's expectations have changed, evolved, and expanded.

Coinciding with this change in the community's expectations is a change in the conceptual framework of fire departments and their service delivery role nationwide. Across the United States, fire departments have greatly expanded their public safety delivery to include advanced rescue capabilities, medical and ambulance service, hazardous materials response, bomb and terrorist response, and programs aimed at mitigating hazards before they threaten the community. This last area, mitigation, has resulted in the new concept of partnering with the private sector with the goal of reducing vulnerabilities to hazards.

In short, the community has grown to expect more and the fire department has grown to meet that expectation.

Today, alarm responses include near paramedic-level medical response, police assists for clandestine labs, public assists for checking carbon monoxide and radon levels, fast water rescues, ice rescues, animal rescues, high angle rescue, trench rescues, confined space rescues, bomb investigations and removal, flood rescues and evacuations, airplane and helicopter emergencies, county and metro-wide mutual and automatic aid, technician-level hazardous materials spill response, disaster response coordination, and . . . fire.

The community expects more and better service.

Ten years ago, the Olathe Fire Department annually responded to less than 2000 fire and medical alarms from two stations and with 10 firefighters on duty. Today the department responds to over 5000 alarms with (by the end of 1998) six stations and 22 firefighters. In the same period of time, the city of Olathe has grown from 63,000 citizens to a projected population of 115,000 in the year 2000 (The Olathe Comprehensive Plan - 1997).

Growth in service expectation has paralleled growth in the city.
Today, alarm responses include near paramedic-level medical calls, police assists, public assists, fast water rescues, ice rescues, animal rescues, high angle rescues, trench rescues, confined space rescues, bomb investigations and removal, drug lab investigations and standbys, water evacuations, mass event and special event standbys, lock-outs, helicopter standbys, airplane emergencies and crashes, county and metro-wide mutual aid, technician-level hazardous materials spill response, disaster response coordination . . . and fire.

Today, that long list of responsibilities requires equally long hours of training, highly specialized equipment, local, state, and national certification — and then recertification. Ten years ago, literally, no aspect of the Fire Department response was certified and specialized life-saving equipment was nearly non-existent.

Rising community service and public safety expectations have led us to this level of service here and will continue to lead us in the future.

Given this, emergency service programs that effectively meet this rising set of expectations are vital to the protection of Olathe’s residents and their livelihood. Effective protection comes at a cost, however – economic efficiency is an overriding consideration. Everyone will agree that they want the highest level of protection possible, but every dollar devoted to emergency service is one less dollar that can be used for other city services such as street and park maintenance. Therefore, it is imperative that the most valid and reliable methods be used for planning public safety programs and then executing delivery effectively.

Safety saves money. For instance, fire insurance companies base their premiums on the quality of public fire protection, and they assign every city an insurance rating that denotes that quality. Prospective business owners and homeowners check the rating to evaluate their insurance burden, and lower fire insurance premiums make Olathe more appealing to new businesses and residents. In addition, safety planning, in the form of emergency plans for homes, businesses, and institutions, translates directly into money saved as the planners mitigate the hazards around, plan for emergencies, and plan for quick recovery after an emergency.

A rationally planned fire department, one that must meet the full-spectrum of emergency service demand daily, must be equipped and staffed to gain the highest attainable effectiveness for the least cost, both to the tax burden and the insurance burden. Station locations, staffing, equipment choice, specialized training, and focused programs are critical to this effectiveness/efficiency balance.

For instance, a station that is placed too close to another will be inefficient, while a station placed too far from others will render the responding emergency unit less effective because of the slower response time. However, this desire to make locations highly efficient (as few stations as possible) must be balanced by the equally important desire to make their response as effective
as possible – effectiveness which is translated to the length of time it takes to travel to an emergency incident from those stations.

Therefore, it is important that decision makers rigorously study all of the relevant factors in order to select a station site that is the best balance between effectiveness and efficiency. Then everyone can be confident that the money spent on emergency service is a wise investment.

To give a background for that discussion about the relevant factors in selecting a station site, the following sections discuss the operations of the fire department at fires and then at medical scenes. The staffing, equipment, and tactical operations at these two types of alarm scenes differ greatly, and both significantly influence the siting of fire stations because of these major differences.

Section Three

Response Effectiveness, Efficiency, and Reliability

Given universal economic concern, it’s important to understand how effectiveness and efficiency goals are reached in emergency service delivery. Following is a detailed explanation of how those goals are reached, followed by a discussion of how those concepts directly apply at emergency scenes.

Response effectiveness is the percentage of Service Demand Zones (SDZ) that can be reached by an Effective Response Force.

Response effectiveness measures the fire department’s potential to deliver emergency service in a timely manner. This potential is limited and determined by the amount and type of equipment, the staffing available to operate the equipment, and how long it takes to reach the emergency scene. Given these limiting factors, a balance must be achieved between “perfect” numbers of staff, equipment, and response time and the public safety needs, levels of desired service, and standards of care specific to the culture of the protected community. This study takes these mitigating factors into consideration in the final response effectiveness equation.

Using nationally recognized standards and data, specific assumptions are made about the combined effect of risk/threat level and community standards on the successful delivery of emergency resources. After performing the SDZ data analysis, the analysts then used the nationally accepted standards of public safety performance to lay out the staffing, equipment, and response time needed to effectively and efficiently answer the service demand.

It is important to keep in mind that assumptions about risk level and response place conditions on the analysis model. Every statement about fire department effectiveness or efficiency should presuppose the caveat under ideal conditions. The assumed conditions for an effective response are: optimum
dispatch, travel, setup, and suppression times, and that a hazard will not have grown beyond the capability of the responding group to control.

Response efficiency is the measure of each station's contribution to capability.

Theoretically, stations are 100% efficient if located such that their maximum "first due" travel times don't overlap. Using a first-due travel time of 4 minutes, for instance, every station, ideally, should be 8 minutes apart with no overlap. But there is a negative correlation between efficiency and effectiveness. Perfect efficiency will lower effectiveness because the number of fire companies needed to make up an effective response force would be too far apart to meet the maximum prescribed travel times for the full assignment.

With the maximum prescribed travel times used in the Olathe study, the equilibrium point in the effectiveness/efficiency tradeoff is 67%. In a hypothetical city with 100% right-angle travel routes having uniform street speeds a response effectiveness score of 100% would limit the station efficiency scores to 67%. Conversely, a uniform set of efficiency scores of 100% would limit the department's effectiveness to 67%. Some degree of overlap is desirable, however, to keep response reliability at a reasonable level. Areas that have a low response capability score need more available response companies to make up for busy companies.

Response efficiency is based upon the number of SDZ's that are within each response units' first-due district. Each district's boundary is drawn by mapping the maximum prescribed first-due travel time from each station and then counting the number of SDZ's in that area.

Response reliability is the probability that a new call will be received while a response company is already busy on another call.

Response reliability is defined as the probability that the required amount of staffing and apparatus will be available when a fire call is received. If every piece of response apparatus were available every time a service call was received, then the department's response reliability would be 100%. If, however, a call is received for a particular company but that company is busy at another call, a substitute company must be assigned from another station. If the substituting company is too far away, that company cannot respond in the maximum prescribed travel time.

As the number of emergency calls per day increases, the probability increases that a needed piece of apparatus will already be busy when a call is received. Consequently, the department's response reliability decreases as calls increase in number, if there is not accompanying rise in force numbers.

To illustrate, consider a detached single-family home. It is in the moderate risk category, so the alarm assignment for a fire is 4 fire units, 12 firefighters, and one Battalion Chief. The maximum prescribed travel time is 4 minutes for the first-due company and 6 minutes for the remainder of the assignment. If one of the units is already busy at another call, the minimum staffing and equipment
cannot reach the scene in one of both of the maximum prescribed travel times. The probability of this unavailability is the measure of the department’s reliability.

Another illustration, however, if the department receives a life threatening medical alarm at that same residence, only one unit is sent, and that unit must have a travel time no longer than 3 minutes (per Johnson County Medical Action Advanced Life Support Standards). Therefore, if that first-due unit is not available, the person needing life support is going to be waiting many extra minutes for help.

To summarize, the Olathe fire department’s response effectiveness is the percentage of SDZ’s in the City of Olathe where it can respond with the minimum-required amount of staffing and equipment within the maximum prescribed travel time. Its response efficiency is the weighted percentage of each first-due district that is overlapped by another district. Its response reliability is the percentage of the time that at least one company will be unavailable when a call is received.

To put the above explanation in more understandable terms, the real-world effectiveness of service delivery by the fire department rests upon a juggling act among three factors: effectiveness (actual delivery of the service), efficiency (delivery in a cost-efficient and resource-efficient manner), and reliability (the assurance that the delivery will occur). If these three “service balls” are not juggled well, the system of emergency service delivery crashes.

To further understand how this delivery of service actually works, Section Three explains the Alarm Response Time Continuum.
Section Four

The Alarm Response Time Continuum

Travel time is only one of several variables related to an effective and efficient response. This point is usually overlooked and leads to overly optimistic — and very misleading — conclusions about how long it takes to respond to emergency alarms. The illustration below represents the Alarm Response Time Continuum that shows all of the action variables to response in their time order.

Time is critical because fires grow exponentially, and life-threatening medical emergencies complete their cycle in 4-6 minutes, ending in death if there if critical intervention isn’t timely. Everything the fire department does in answering emergency service demand is time-critical.

Table No. 1

<table>
<thead>
<tr>
<th>Event Starts</th>
<th>Alarm Reported</th>
<th>Unit Notified</th>
<th>Unit Leaves Station</th>
<th>Unit Arrives At Scene</th>
<th>Unit Begins Work</th>
</tr>
</thead>
</table>

Obviously, the further a station is from an emergency call, the slower the response. Therefore, the location of stations has a major impact on one segment of the continuum, travel time. The diagram above illustrates an important point that frequently is overlooked — *travel time and response time* are not the same thing. When we say that a particular station has a 4 minute travel time to an address, it doesn’t mean that a unit will arrive there in 4 minutes. Dispatch time can add up to two minutes, turnout time can add another two, and setup time another two. Consequently, the unit’s full response time can be ten minutes or more.
Section Five

Evaluating Fire Department Capability: At Fire Scenes

On one hand, classic fire department performance capability is easy to measure (the fire goes out or a victim is rescued), but at the same time difficult to interpret as to quality of service delivery (was the fire extinguished in the shortest possible time or the patient saved without further harm).

Specific performances are not difficult to record chronologically. Travel time data will show how long it will take to get fire companies to a fire. Likewise, fireground tasks such as operating an attack line or raising ladders are easy to measure. But these measurements by themselves don't say what can be accomplished in the time frames recorded. More needs to be known before concluding what fire companies are capable of when they get to a fire. Two significant factors which must be known are:

- The threat of the fire - Is it small and isolated from other combustible material? Are occupants trapped by smoke or flames? How fast is it growing?
- The number of fire suppression tasks involved - A small fire with little smoke might require only a few firefighters to extinguish and remove from the building. A larger fire will require a greater number of firefighters, and a fire where lives are threatened will require still greater numbers of firefighters.

In order to make valid comparisons of fire department capability, the comparisons must control for the variation in the fire threat factor and the fireground task factor. This section describes the dynamics of fire growth in order to acquaint the reader with how the analysis controls for the variation of fire growth. The section goes on to describe the fire suppression tasks that are required at a typical fire scene. This will introduce the reader to what the fire companies must do - simultaneously and quickly - if they are to save lives and limit property damage. The analysis controls for the variation in staffing needs by matching the staffing with a specific point of fire growth.

Dynamics of Fire Growth

The answer for controlling the variation in fire dynamics lies in finding a common reference point, something that is common to all fires regardless of the risk-level of the structure, the material involved, or the length of time the fire has burned. Such a reference point exists. Regardless of the speed of growth or length of burn time, all fires go through the same stages of growth. And, on particular state emerges as a very significant one because it marks a critical change in conditions. It is called flashover.
The flashover stage of a fire marks a big turning point in fire conditions - escalating the challenge to a fire department's resources. How and why this is so is explained in the following descriptions of each stage of fire growth.

Smoldering Stage: This is the first stage of any fire. When heat is applied to a combustible material, the heat oxidizes the material's surface into combustible gases. This process is exothermic, meaning that the oxidation process itself produces heat. The heat from oxidation raises the temperature of more material, which increases the rate of oxidation and begins a chemical chain reaction of heat release and burning.

A fire can progress from the smoldering phase immediately or slowly, depending upon the fuel, nearby combustibles, and the surrounding air. For example, a wad of newspapers will smolder only a few seconds before progressing to the next stage, but a couch with a burning cigarette may continue smoldering for over an hour.

Incipient Stage: When the temperature gets high enough, visible flames can be seen. This stage is called incipient or open burning. The visible burning at this stage is still limited to the immediate area of origin. The combustion process continues to release more heat that heats nearby objects to their ignition temperature, and they begin burning.

Flashover: Not all of the combustible gases are consumed in the incipient stage. They rise and form a superheated gas layer at the ceiling. As the volume of this gas layer increases, it begins to bank down to the floor, heating all combustible objects regardless of their proximity to the burning object.

In a typical structure fire, the temperature of the gas layer at the ceiling can quickly reach 1500 degrees F. As the gas layer moves down it begins heating combustible objects in the room to their ignition temperature. The gas layer is mostly carbon monoxide, so the absence of oxygen prevents the heated objects from bursting into flame. Oxygen gets introduced in two ways. There is often enough available oxygen near floor level to start the open burning process when the gas layer reaches that level. Or, the high heat breaks a window and the incoming oxygen allows the burning to begin. It should be noted that the room becomes untenable long before flashover. Even though open flaming may not be present until everything reaches 500 degrees F and the oxygen is introduced, the room becomes untenable for human survival at 212 degrees F.

When flashover occurs, everything in the room breaks into open flame at once. The instantaneous eruption into flame generates a tremendous amount of heat, smoke, and pressure with enough force to push beyond the room of origin through doors and windows. The combustion process then speeds up because it has an even greater amount of heat to move to unburned objects.
Flashover (see graph above) is a critical stage of growth for two reasons. First, no living thing in the room of origin will survive, so the chances of saving lives drops dramatically. Second, flashover creates a quantum jump in the rate of combustion, and a significantly greater amount of water is needed to reduce the burning material below its ignition temperature. A fire that has reached flashover means it is too late to save anyone in the room of origin, and a lot more staffing is required to handle the larger hose streams needed to extinguish the fire. A post-flashover fire burns hotter and moves faster, compounding the search and rescue problems in the remainder of the structure at the same time that more firefighters are needed for fire attack.

Table No. 2

The Significance of Flashover

<table>
<thead>
<tr>
<th>Pre-Flashover</th>
<th>Post-Flashover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limited to one room</td>
<td>Has spread beyond one room</td>
</tr>
<tr>
<td>Requires smaller attack lines</td>
<td>Requires larger/more attack lines</td>
</tr>
<tr>
<td>Search and rescue is easier</td>
<td>Compounds search and rescue</td>
</tr>
<tr>
<td>Initial assignment can handle</td>
<td>Requires additional companies</td>
</tr>
</tbody>
</table>

To summarize the above, it is clear that the stage of a fire affects staffing and equipment needs. Both of these needs can be reasonably predicted for different risk-levels and fire stages. This ability to correlate staffing and equipment needs with fires according to their stage of growth is one of the bases for this study. The analysts selected the following objective as the mark of effectiveness for the Olathe fire department for fire response: maintaining enough on-duty firefighters and equipment, strategically located, so that the
minimum acceptable response force can reach a reasonable number of fire scenes before flashover is likely.

It us unreasonable to expect a fire department to reach all fires before flashover, even the most heavily staffed and equipped department. As for the reasonable number of fires that an effective response force should reach before flashover, the following point must be kept in mind. Given that some fires will reach flashover before the fire department can respond – either because the materials involved are very volatile, because the fire accelerated with flammable liquids, or because the fire went unreported – it is unreasonable to expect the fire department to save every life or stop all significant property loss. An effective response force should be able to handle fires that are reported shortly after they start and are within the maximum prescribed travel time for the full assignment of fire companies according to the risk level of the structure. In this study, the staffing, equipment, and travel times that accompany each of the risk categories are based on that premise.

Considering that the fire department cannot hold fire risk to zero, the study’s objective was to find a balance between effectiveness, efficiency, and reliability that will keep fire risk in Olathe at a reasonable level and at the same time yield the maximum insurance savings at the least cost. The maximum prescribed travel times act as the limit to efficiency – put stations too far apart and the minimum effective response force cannot get to a service demand zone in time.

It is important to get all of the required firefighters to a fire scene quickly because fire suppression is a simultaneous and coordinated activity. The following discussion explains why this is so vital to safe and effective fire operations.

Fire Scene Operations

In the discussion above, it was shown that the variables of fire growth dynamics and property/life risk combine to determine the fireground tasks that must be accomplished to stop the loss. These tasks are interrelated but can be separated into two basic types, fire flow and life safety. Fire flow tasks are those related to getting water on the fire. Life safety tasks are those related to finding trapped victims and removing them from the building.

The required fire flow is based on the building – its size, structural material, distance from other buildings, horizontal and vertical openness (lack of partitions), and its contents – type, density, and combustibility (BTU’s per pound). In fact, the ISO bases its rating on fire flow, and classifies areas of the city by its fire flow requirement, i.e., areas requiring up to 3000 gallons per minute (GPM) and those requiring over 3000 GPM.

Fire flow tasks can be accomplished with hand-held hoses or master streams (nozzles usually attached to the engine or ladder). Each 1 ¾” hose requires a minimum of 2 firefighters. The hose can flow 130 GPM, so when those
lines are used the fire flow is 65 GPM/firefighter. The 2 \( \frac{1}{2} \)" hoses can flow 250 GPM and require a minimum of 5 firefighters, yielding a flow of 50 GPM per firefighter. Master streams can flow from 500 to 1000 GMP each. They take relatively fewer firefighters to operate because they are fixed on the apparatus or tied to the ground and cannot be moved once placed without shutting down.

The decision to use hand lines or master streams depends upon the stage of the fire and the threat to life. If the fire is in a preflashover stage, the firefighters make an offensive inner attack with the small hand lines. The lines are used to attack the fire and shield trapped victims until they can be removed from the building. If the fire is in its postflashover stage and the structural damage is a threat to the firefighters' life safety (e.g., weakened roof, burned out stairs), then the structure is declared lost and master streams are deployed to keep the fire from advancing to surrounding buildings.

As the number of larger commercial occupancies (>10,000 sq. feet), high rise buildings and occupancies with high value contents increase, the required fire flow increases. Areas with very large and very valuable buildings can require fire flows of 8-10,000 GPM. The staffing needed to generate these fire flows can also be calculated, and this is how the ISO determines the number and placement of engine and ladder companies. The ISO evaluation for cities with a lower fire flow (mostly residential, small and low-rise commercial buildings) will require fewer firefighters, engines, and ladder trucks. As the required fire flow increases, the number of fire companies gets larger.

The life safety tasks based upon the number of occupants, their location in the building, their status (awake, asleep), and their ability to take self-preservation action. For instance, ambulatory adults need less assistance than non-ambulatory. The elderly and small children always require more assistance.

The key to a fire department's success at a fire is coordinated with teamwork, regardless of whether the fireground tasks are all fire flow related or a combination of fire flow and life safety. At a fire in an occupied structure, a minimum of eight tasks (see below) must be simultaneously conducted in order to stop the loss of civilian lives, stop further property loss, and do so while keeping the risks to firefighters' lives at a reasonable level. The number and type of tasks needing simultaneous action will dictate the minimum number of firefighters needed at the fire at the same time. The discussion following the table describes each of these tasks and shows why they must be performed simultaneously.
Table No. 3

Minimum Tasks Necessary at a Moderate-Risk Structural Fire

<table>
<thead>
<tr>
<th>Task</th>
<th>Number of Firefighters</th>
<th>Company Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attack line</td>
<td>2</td>
<td>1st Fire unit</td>
</tr>
<tr>
<td>Search and Rescue</td>
<td>2</td>
<td>2nd Fire unit</td>
</tr>
<tr>
<td>Ventilation</td>
<td>2</td>
<td>3rd Fire unit</td>
</tr>
<tr>
<td>Back-up line</td>
<td>2</td>
<td>4th Fire unit</td>
</tr>
<tr>
<td>Safety officer</td>
<td>1</td>
<td>Training officer</td>
</tr>
<tr>
<td>Pump operator/Water Supply</td>
<td>2</td>
<td>1st/2nd Fire unit</td>
</tr>
<tr>
<td>Incident Commander</td>
<td>1</td>
<td>Battalion Chief</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>12</strong></td>
<td></td>
</tr>
</tbody>
</table>

The two fire scenarios used here will illustrate the importance of simultaneous and coordinated action, and also demonstrate why different levels of fire risk require different amounts of staffing and equipment. The first example is a fire in a detached single-car garage, and the second is a house fire.

Several important factors make a house fire a higher risk than a burning garage. The first is size. Garages are much smaller than houses and thus require less water to extinguish than house fires. Another factor is life risk. A garage fire is not likely to be a threat to life. Exposure is another factor. A garage is usually separated far enough from other structures so the fire cannot spread to them. In addition to these factors, the combination of small size and access around all sides allows firefighters to extinguish the fire from the exterior, and this removes the need for a backup crew. All of these factors mean that a relatively smaller force of firefighters can handle the risks of a detached fire than is needed for other types of structures.

Compared to the garage example, a house fire poses a higher level of risk and requires a correspondingly larger force of firefighters. A house's larger area and contents generate hotter and faster-growing fires that require more water – and consequently more hose lines – for extinguishment. The threat to occupants requires search and rescue to be conducted simultaneously with fire suppression. And, the fire attack cannot be safely done without the simultaneous ventilation of rooftop or wall openings. A backup crew is necessary anytime the firefighters are inside the building, adding to the staffing need.

These examples show that significantly greater number of firefighters and equipment is needed for a house fire than for a detached garage. As the discussion below will show, the tasks must be performed simultaneously, so the necessary manpower must arrive in a minimum amount of time so the crews can coordinate their actions.
Other structure such as apartment complexes, nursing homes, or large warehouses pose still higher risks than house fires because they require greater levels of manpower and equipment to arrive in a reasonable time and work in a coordinated manner. The discussion of risk categories includes details explaining why the higher risks increase the need for additional manpower and equipment.

The fire attack practices used by the Olathe fire department are similar to accepted practices throughout the country for urban fire departments. Our activities at fires conform to nationally recognized safety practices for structural firefighters, and they comply with federal Occupational Safety & Health Administration (OSHA) rules for the same. The following terms describe the work units and tasks that are routinely performed at a structure fire.

**Attack line:** A 1 ¾" hose that produces 130 GPM and is handled by a minimum of 2 firefighters or a 2 ½" hose that produced 250 GPM and is handled by 5 firefighters. Each fire unit carries a set of attack lines that are either preconnected to the pump, are folded on the hosebed, or are in a special pack for carrying into high-rise buildings.

**Search and Rescue:** A minimum of 2 firefighters assigned to search for victims and to remove them from danger while the attack crew moves between the victims and the fire to stop the fire from advancing to them. More crews are required in multi-story buildings or structures with people who are not capable of self-preservation.

**Ventilation Crew:** A minimum of 2 firefighters to open a ventilation channel when the attack crew is ready to enter the building. Ventilation in a multi-story building can require more than 2 firefighters. Ventilation removes superheated gases and smoke, preventing flashover and allowing attack crews to see and work closer to the seat of the fire.

**Back-up Line:** A hand line that is taken in behind the attack crew to cover the attack crew in case the fire overwhelms them or a problem develops with the working of the attack line.

**Safety Officer:** A minimum of one firefighter (usually assigned to the Training Officer) is assigned to oversee the safety of all operations. This officer has the ultimate responsibility to cease any and all unsafe operations and to remove fire personnel from overly hazardous conditions.

**Pump Operator/Water Supply:** One firefighter assigned to each engine to deliver pressurized water to the attack, back-up, and exposure lines – monitoring the pressure changes caused by changing flows on each line, and ensuring that water hammer doesn't endanger any of the hose line crews. These firefighters also complete the hose hookups to the correct discharges, and complete the water supply hookup to the correct intake.
**Command:** An officer (termed the Incident Commander) assigned to remain outside the structure to coordinate the attack, evaluate results and redirect the attack if needed, arrange for more resources, and monitor conditions that might jeopardize crew safety.

**Fireground Tasks and Fire Department Capability**

When a fire starts, the fire risk factors for the structure, contents, and occupants will control the fire growth dynamics. The rate of fire growth and its threat to life will determine the tasks that must be performed to stop the fire, save lives, and minimize property loss.

The number of tasks and their need to be performed simultaneously determine the amount of staffing and equipment that must respond. The fire department’s effectiveness will be determined by its ability to get its resources to a fire early enough in the process so that its on-duty resources can adequately handle all the needed tasks quickly and simultaneously.

For instance, for a fire in a moderate risk SDZ, the fire department will respond with 12 firefighters, 4 fire units (currently staffed with 3 firefighters each), and a Battalion Chief. If the department is to be capable of doing this, then its fire stations must be located strategically so that the travel time to the SDZ is short enough for all of the manpower and equipment to arrive before flashover occurs. This level of resources can set up the equipment and simultaneously handle the tasks of fire attack, search and rescue, ventilation, backup lines, pump operation, water supply, and command all within a few minutes. If fewer firefighters and equipment are available, or if they have longer travel distances to cover, then the fire department will not be successful.

Since the average time from a fire’s incipient stage to flashover is five minutes, the travel times selected for Olathe should allow the fire department to arrive before flashover in the majority of cases. The prescribed times are longer than the five minute flashover time, but this is compensated for by the fact that a portion of the fires will still be in the smoldering stage when reported, which will normally mean a longer time before flashover occurs. In the long run, then, the fire department will get to most fires before they reach flashover. The other fires that are not reached before flashover are those cases noted earlier when the fire went to flashover rapidly due to flammable accelerants, because the fire burned a long time before it was reported, or because the fire department was “blacked out” and could not respond in time.

In summary, some operations that the fire department performs, e.g. fires, mass casualty incidents, rescues, require a system of response – a coordinated grouping of units and staffing that respond and operate together. However, since 1991, a different kind of incident requiring a different kind of response has
emerged to become the main incident type in emergency response – the single medical call. Responding to this single medical call has now become the major response incident type in this city and requires a very different response concept. The next section will discuss the differences and how this has a major effect on the placing of fire stations.

Section Six

Evaluating Fire Department Capability: At Single Medical Scenes

In the extended discussion above of fire operations, it was explained why firefighting (and certain other large-scale emergencies) require an extended system of operations -- the use of multiples of staff, equipment, and fire stations. This multi-response method greatly changes for a single medical call, becoming much more like a "school district system", i.e. one station responds to the single medical event much like one school covers a particular school district, independently and without the assistance of other schools.

When a single medical alarm is called (e.g., one or two victim car wrecks, heart attacks, strokes, broken bones, severe bleeding, etc), only one fire unit responds, and this unit is staffed with three firefighters. No other unit will respond unless this first-in company asks for additional help when it reaches the scene (which is not common).

It will be remembered from the prior discussion that the concept of "flashover" is used as the touchstone against which adequate fire response is measured. With medical calls, however, that touchstone changes from flashover to the time that a patient has to live when he is threatened by a major medical threat such as a heart attack – the golden 8 minutes. Per Johnson County Medical Action (JCMA), from the time a call for help reaches a dispatch center, the victim has approximately 8 minutes before irreparable harm is done that may lead to death. Given this 8 minutes time constraint, per JCMA, travel time cannot exceed 3 minutes. The rest of the response time is lost in the chronology of the Alarm Response Time Continuum (see Table No. 1).

Given then, this 3 minute travel time limit, fire units (all of whom respond to life-threatening medical calls as first responders and emergency medical technicians) must be even faster than they are for fire fights. This necessity for even greater speeds has significantly changed the approach to fire station siting since the standard for quick response has risen with the new responsibility, since 1991, of responding to single medical alarms.

This points to the new and significant problem in fire station siting: the fire department is now required to respond not only in an extended, systematic way to large incidents but also to respond to single medical incidents, even faster, with single units. Both types of incidents can be fatal and/or destructive – in fact, medical alarms tend to be even more likely, statistically, than other alarms to endanger life. Lack of speed kills.
4 Minute Travel Times - 6 Stations
3 Person Units

Denotes Effective Coverage for Fire Calls
4 Minute Travel Times - 6 Stations
4 Person Units

Denotes Effective Coverage for Fire Calls
FIG-12

3 Minute Travel Times - 6 Stations

[Map diagram showing a network of 3 minute travel times with 6 stations marked on a city map.]
In parallel and reflecting the task breakdown of the previous table on tasks at fire scenes, the following table illustrates how staff is deployed at single medical scenes (see Table No. 2 for comparisons).

**Table No. 4**

**Minimum Tasks Necessary at a Single Medical Alarm**

<table>
<thead>
<tr>
<th>Task</th>
<th>Number of Firefighters</th>
<th>Company Assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMT</td>
<td>2</td>
<td>First-due unit</td>
</tr>
<tr>
<td>Incident Commander</td>
<td>1</td>
<td>First-due unit</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3</strong></td>
<td></td>
</tr>
</tbody>
</table>

As noted in the above table, a responding fire unit to a single medical call is composed of 3 personnel. Two of the firefighters operate as the emergency medical technicians (EMT). Their actions are supervised by the company officer (who is also an EMT). In addition, Johnson County Medical Action will respond an ambulance to coordinate with the fire unit.

The maps that follow these sections illustrate the differences in coverage with our present set of stations to medical and other calls. These maps illustrate the gaps in our present coverage.

**How staffing affects effectiveness of response**

Referring to Figure 10, entitled “4 Minute Travel Times – 6 Stations, 3 Person Units”, we see that the fire department is only able to cover a small percentage of the SDZ’s in a 4 minute travel interval. The exact total of SDZ’s covered by an effective force in 4 minutes is 63, out of a total of nearly 1000.

However, increasing the unit force from 3 firefighters per unit to 4, as illustrated in Figure 11, “4 minute Travel Times – 6 Stations, 4 Person Units”, increases covered SDZ’s from 63 to 203, an improvement of 310 percent.

In addition, Figure 12, “3 Minute Travel Times – 6 Stations,” reveals that the southeastern portions of Olathe, the area in which we expect the most and the fastest growth are already uncovered for effective medical response. In addition, 3 minute medical response cannot reach the northcentral part of Olathe’s future growth area, or the western portion.

Which leads us to the next section which discusses the analysis of the minimum and maximum allowable travel times to the various categories of Service Demand Zones.
Section Seven

Risk Categories and Travel Times

This study, as explained in earlier sections, assigns 5 levels of total risk in its analysis of each SDZ: maximum, high, moderate, low, and minimum. The risk levels are defined by the following factors:

- The ability of the occupants to take self-preserving actions
- Construction features of structures
- Passive fire protection
- Built-in fire protection
- Required fire flow
- Exposure to other buildings
- Nature of the building contents
- Implicit threat to the building or inhabitants by terrorist or civil unrest
- Vulnerability to hazardous materials release
- Vulnerability of residents to medical need

Each of these factors contributes a variable demand on the fire department's resources, and these demands are known through experience or estimated through analysis. The relative demands are matched with the staffing, equipment, and training necessary to stop or minimize life and property loss if those resources can arrive before a fire reaches flashover or before a critically injured or ill victim goes beyond the golden 8 minutes.

To gauge the adequacy of the response in terms of travel time each risk level was analyzed and prescribed two different maximum prescribed travel times. Those maximum prescribed travel times are displayed in the following table.

Table No. 5

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>First Due</th>
<th>Other Assigned Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>3.0 minutes</td>
<td>5.0 minutes</td>
</tr>
<tr>
<td>High</td>
<td>3.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Moderate</td>
<td>4.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Low</td>
<td>5.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Minimum</td>
<td>6.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>

(Note: Medical calls are classified as "maximum risk" and respond, normally, only the first due unit)
Like the staffing and equipment needed, the maximum prescribed travel times vary for each risk level because the tasks that will need to be completed vary per the circumstances of each incident. The shorter travel times are related to the same factors noted above that dictate higher numbers of staff and equipment. The setup time is also longer at the higher-risk levels, so travel time is shortened to compensate.

Note also that medical alarms fall under the maximum category and are responded to, unless a second alarm is called, by only one response unit.

The risk categories are described in great detail in Section One.

Section Eight

Conclusions: Future Placement of Olathe Fire Stations

Given all the information that has been presented here, what can be concluded about the placement of future fire stations in the City of Olathe?

Figure 13, "Growth Estimate Areas," displays the future growth pattern of Olathe as analyzed by the Planning Department and discussed in the 1997 Comprehensive Plan and the K-7 Corridor Study. The growth is displayed geographically and notated chronologically.

As illustrated in Figure 13, Olathe is predicted to grow primarily south from the area of 151st Street towards the community of Springhill. In addition, significant growth will occur in the Cedar Creek area, in the area along and either side of College Boulevard east of K-7, in the K-7 corridor. Infilling of areas adjacent to Overland Park will also continue.

Far and away, however, the significant growth in the foreseeable future (10 years) will occur in the corridor between Springhill and southeastern Olathe. This is predicted to occur for the next 15 years.

Given this growth pattern, and the considerations for effective response to fire and medical emergency scenes discussed in the above sections, Figure 14 displays the probable placement needs for fire stations out to the ultimate growth limits of our city.

Placements:

Station 7 - In the area of 159th Street between Ridgeview and Blackbob.
Station 8 - Along the College Boulevard corridor in the approximate area of Woodland.
Station 9 - Should the area develop, south of Persimmon Hills.

At this point, 1998, these additional three stations will cover the future growth of the City of Olathe as presently predicted into the foreseeable future. However, should community expectations continue to rise and the need for shorter and shorter travel times, the number of stations will increase.
A ---- Cedar Creek Area: 2 years
B ---- Woodland Area: 2-5 years
C ---- Persimmon Hill Area: 3 years
D ---- Cedar Niles/143rd Area: 5 years
E ---- East of Blackbob Area: Working
F ---- South of 151st Area: 15 year buildout
G ---- K-7 Corridor Area
H ---- Convention Center Area

To Springhill
Station 7 - In the area of 159/Ridgeview/Blackbob

Station 8 - College Blvd. East of K-7

Station 9 - South of Persimmon Hill