Improving Fire Department Productivity: Merging Fire and Emergency Medical Units in New Haven

ARTHUR J. SWERSEY
Yale School of Management
Box 1A
New Haven, Connecticut 06520

LOUIS GOLDRING
Soros Fund Management
888 Seventh Avenue
New York, New York 10106

EARL D. GEYER, SR.
Department of Fire Service
PO Box 374
New Haven, Connecticut 06502

In September 1991, the New Haven Fire Department implemented an innovative reorganization plan having dual-trained fire medics responding to medical emergencies or fire incidents. The plan was the culmination of a 10-month problem-solving process that required redefining the original problem by shifting attention from closing fire stations to reorganizing the deployment of fire department services. The work made use of both a new spatial queuing model and the existing firehouse siting model, and required timely analysis under constraints of the budgetary process. In a matter of weeks and at times, days, we had to win the approval of the chief administrative officer, the board of finance, and the board of aldermen. The plan increased productivity by both reducing cost and improving public safety. Yearly savings are $1.4 million and amount to nearly 10 percent of the fire suppression budget, while small reductions in fire protection are more than offset by substantial improvements in emergency medical response time.

In the fall of 1990, New Haven, Connecticut, a city of about 130,000 people, was facing problems similar to those of many cities in the industrial regions of the northeast and elsewhere. Declining revenues and increasing costs were squeezing city agencies as they struggled to maintain service levels in the face of severe budget

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GOVERNMENT—SERVICES, FIRE
QUEUES—APPLICATIONS

constraints. A decline in the region's manufacturing sector meant a loss of jobs and tax revenues. At the same time, crime and drug-related activities were increasing. Within months, Bridgeport, a neighboring city of about the same size as New Haven, would declare itself bankrupt.

In December of 1990, Douglas Rae, New Haven's chief administrative officer who was on leave from Yale's political science department and Fire Chief Earl Geyer, Sr. asked Arthur Swersey to study the current distribution of fire companies in New Haven to see whether a company could be eliminated with an acceptably small risk to the public. Rae was familiar with the work Swersey had done as part of the Rand Fire Project activities in New York City and elsewhere. As chief administrative officer, he was responsible for preparing a city budget and presenting it to the board of finance and board of aldermen for approval.

Swersey and Louis Goldring agreed to perform a fire-station location study as consultants to the city with input to be provided by Chief Geyer and other New Haven fire officers. The consulting work was essentially pro bono; the city provided $3,000 to support data analysis and computer work. New Haven's fiscal year begins on July 1, and the budget had to be approved by the board of finance by April 15. Thus there was great pressure for timely analysis.

Related Research

The problem of deploying emergency service units (fire, police, ambulance) has received a great deal of attention in the management science literature beginning in the late 1960s. A range of useful deterministic and stochastic models have been developed and applied in numerous cities. Much of the work on fire engine deployment was done by the Rand Fire Project in New York City. Ignall, et al. [1975] give an overview of the work while Rand Fire Project [1979] treats it comprehensively. Other relevant fire research is the firehouse-siting work of Hogg [1968] and Public Technology, Inc. [1974].

A number of authors have developed models for deploying ambulances, including Swoveland et al. [1973] and Hall [1972]. The hypercube model of Larson [1974, 1975] and Larson and McKnew [1982] has been used for police beat design and for deploying ambulances in Boston [Brandeau and Larson 1986], while Chelst [1988] has modeled police/fire mergers. Kolesar and Swersey [1986] give the most recent survey of research on the deployment of emergency service units.

Political Issues

Closing a firehouse is not easy in the face of predictable opposition from fire unions, local residents, and political leaders. Walker [1978] reported on one noteworthy case in Trenton, New Jersey. The analysis showed that it was possible to both reduce the number of fire companies and improve fire protection. But at the last moment, the mayor gave in to political pressure in an election year, and implementation plans were abandoned.

In New York City, analysis using management science models has resulted in fire station closings in spite of strong opposition. But the implementation of such changes remains difficult and challenging. In 1988 a fire station was closed during the professional football super bowl game. Although this ploy lessened the immediate level of protest, it so enraged fire fighters that several weeks later 6,000 members of the department marched in protest across the Brooklyn Bridge to fire department headquarters.

The political challenges in New Haven were especially formidable. Political power was highly decentralized in 30 wards, each with an elected alderman. Although the new mayor, John Daniels, the first black chief executive in the city's history, was a Democrat, he had not been the party-endorsed candidate. Thus, although all but four of the aldermen were Democrats, the great majority had not been Daniels's supporters.

Our challenge was to bring to bear appropriate management science models under the time pressure of the budget process in a highly politicized election-year environment.

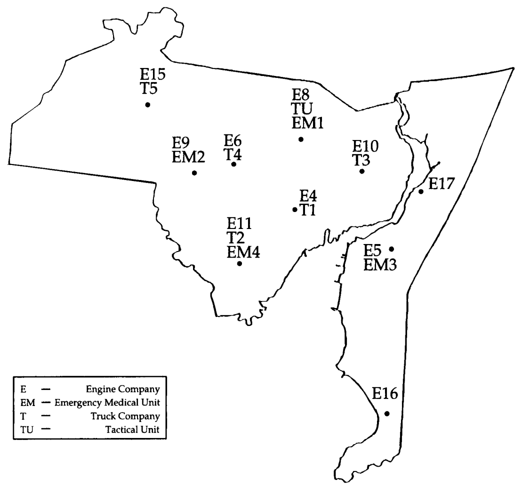

Figure 1: At the time of the study, New Haven had 10 engine companies, five truck companies, a tactical fire unit primarily for automobile wrecks and other emergencies, and four emergency medical units. These fire and emergency medical units were located in firehouses throughout the city.

Deployment of Fire and Emergency Medical Units in New Haven

The department deploys two basic types of fire fighting units: engine companies and truck companies. An engine company (usually four fire fighters assigned to a vehicle called a pumper) hooks up to the fire hydrant and delivers water onto the fire. A truck company (with the same complement of fire fighters assigned to a vehicle equipped with an aerial ladder) is responsible for lifesaving. Its personnel carry axes and special tools, which they use, if necessary, to force their way into a building and to break windows to allow the hot gases to escape. In New Haven, most members of the department are cross-trained to perform either engine work or truck work.

Figure 1 shows the locations of fire and emergency medical units at the time of the study. There were 10 engine companies and five truck companies. Almost all were staffed by four fire fighters around-the-clock. One exception was Engine 5, which had an additional fire fighter with its personnel responding on a combination pumper/ladder, a vehicle with normal pumping equipment and an aerial ladder.

The department also had one tactical unit centrally located and staffed by four fire fighters assigned to a truck carrying its specialized equipment. This unit responded to hazardous chemical spills, automobile wrecks, and other emergencies and provided additional manpower at fires.

The department deployed four emergency medical units located in firehouses, each staffed around the clock by two emergency medical technicians (EMTs), who ride in a van-type vehicle that has medical supplies and equipment. The

EMTs are fire fighters who have received additional emergency medical training. These units respond to emergency medical calls, ranging from minor illnesses to heart attacks, and provide emergency medical assistance. They do not, however, transport patients to the hospital. If transportation to a hospital is needed, a private ambulance is called. Although the emergency medical units were to become a crucial part of the analysis, as the problem was originally defined they were not included.

To provide around-the-clock staffing, the department needed four persons to cover each position. Thus, for example, an engine company with four fire fighters assigned at all times requires a total complement of 16 persons. The personnel cost of each fire company is about $750,000 per year.

Demand and Fire Company Work Load

Between 1983 and 1990, the total number of fire alarms remained fairly constant with between 4,000 and 5,000 alarms per year. Significantly, the number of structural (building) fires declined from 503 in 1983 to 262 in 1990. Some of the decline is due to a drop in the number of arson fires, which the department attributes to more vigilant prosecution of such cases (Figure 2). Also, a substantial increase in the number of smoke detectors in use has probably meant that more fires are detected in their incipient stages and extinguished without the aid of the fire department. At the same time, as structural-fire demand declined, emergency medical calls rose from about 10,000 in 1983 to about 16,000 in 1990 (Figure 3).

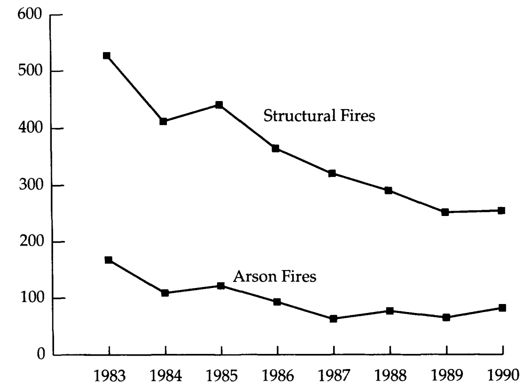

Figure 2: Structural (building) fires declined by 50 percent from 1983 to 1990 with a reduction in arson accounting for a substantial part of the decrease.

Fire company work load as measured by responses and hours worked is low in New Haven as it is in many cities of similar size (see Rand Fire Project [1979] for data from other cities). Table 1 shows number of responses and hours worked for each fire unit in New Haven in 1990. The busiest fire company, Engine 6, responded 1,286 times and spent a total of 397 hours at fire incidents. Thus the busiest company was unavailable only 4.5 percent of the time.

The Original Problem: Fire Station Location

The original problem presented to the consultants, Goldring and Swersey, by Chief Administrative Officer Rae and Fire Chief Geyer was to investigate whether a fire company could be eliminated with an acceptably small risk to the public.

Ideally in comparing alternative deployment plans, one would like to relate loss of life, injury, and property damage to the number and location of fire companies. Although attempts have been made to answer the question: "What is a minute of response time worth?" these studies have not yielded valid, generalizable results. Hence fire station location studies have

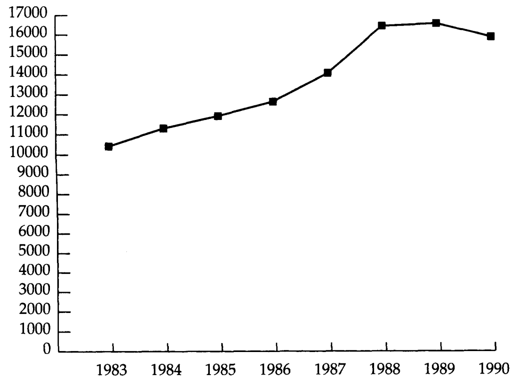

Figure 3: While structural fire incidence was declining sharply, emergency medical calls increased from about 10,000 in 1980 to about 16,000 in 1990.

focused on travel time as a surrogate measure of performance.

In the mid 1970s, Walker, Swersey, and others at the New York City Rand Institute developed an approach to fire station location analysis and applied it to a number of cities including Yonkers, New York, Trenton, New Jersey, and Wilmington, Delaware, all similar in size to New Haven [Hausner and Walker 1975; Hausner, Walker, and Swersey 1974]. Using this approach, Goldring and Swersey estimated fire company travel times with the Rand firehouse siting model. In this deterministic computer-based model [Dormant, Hausner, and Walker 1975], alarms are assumed to occur at existing street box alarm locations or at the intersections of a rectangular grid. The model assumes that fire companies are always available (a reasonable assumption in many cities, including New Haven) and estimates the travel distance from each demand point to each fire station location.

In the New Haven application, the consultants laid a rectangular grid over a large map of the city, creating 618 demand points, and located each fire company at its nearest grid coordinate. In previous studies [Rand Fire Project 1979], researchers had found that 1.15 times the Euclidian (straight line) distance gives a reasonable estimate of travel distance in most cities. The consultants took a sample of 50 fires and, using a map wheel, measured the distance along the street network from fire station to fire, regressing the actual distance against the Euclidian distance and finding that a constant of 1.19 provided the best fit with 95 percent confidence limits of 1.11 and 1.27. Since New Haven has many one-way streets and an irregular street pattern dating to the 19th century, the higher constant (1.19) was used.

Ideally it would have been useful to perform a stopwatch study of a sample of actual fire responses to relate travel time to

Company	Total Alarms	Time Worked Hours	% of Time Busy
Engine 4	845	320	3.7
Engine 5	319	151	1.7
Engine 6	1286	397	4.5
Engine 8	586	208	2.4
Engine 9	838	264	3.0
Engine 10	755	320	3.7
Engine 11	936	293	3.3
Engine 15	557	188	2.1
Engine 16	114	49	0.6
Engine 17	281	128	1.5
Truck 1	662	211	2.4
Truck 2	630	188	2.1
Truck 3	432	176	2.0
Truck 4	904	254	2.9
Truck 5	223	84	1.0
Tactical Unit	1186	384	4.4

Table 1: Fire company work load is low in New Haven. In 1990 the busiest engine company, Engine 6, was busy only 4.5 percent of the time.

travel distance. Given time pressures, the consultants decided to use a relationship that is based upon experimental results in Trenton, Denver, Wilmington, and Yonkers:

$$T = \begin{cases} 2.10\sqrt{D} & D < 0.38 \text{ mile} \\ 0.65 + 1.70D & D \geq 0.38 \text{ mile} \end{cases}$$

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

To validate these estimates, the consultants, Goldring and Swersey, took a random sample of 50 actual fires, comparing the actual average travel time to the average predicted by the model and found close agreement.

Eliminating Engine Company 9

It was immediately clear that eliminating a truck company would result in unacceptably high travel times in parts of the city. The logical choice for elimination was Truck 5 (Figure 1), which responded to only 223 alarms in 1990. Although this unit is underutilized, the siting model showed that eliminating Truck 5 would increase travel time for the closest (first-due) truck company in the surrounding area by about two minutes. In the late 1970s the city had proposed eliminating Truck 5, but in the face of strong opposition by firefighters, their union, neighborhood political leaders, and residents, the plan was abandoned.

Because eliminating a truck company appeared unacceptable from a fire protection point of view, Goldring and Swersey focused their attention on engine companies. We will not describe the complete analysis here; it is given in Swersey, Goldring, and Geyer [1992].

The siting model showed that average citywide travel time for the closest (first-due) engine company was 2.01 minutes, which was comparable to that found in siting model studies of other cities [Walker 1978]. The analysis identified Engine 9 as the company that could be eliminated with least risk. Eliminating Engine 9 would increase average citywide first-due engine travel time by less than five seconds, but this measure is misleading. Removing a company does not change first-due travel time except in the affected region, the area surrounding the company that was removed (Figure 4). Although the first-due engine travel time is most important, the travel time for the second closest (second-due) engine company is also relevant. Keeney [1973] made the only attempt to develop a utility function for first-due versus second-due: based on interviews with a single New York City fire officer, he assigned twice the weight to first-due response time.

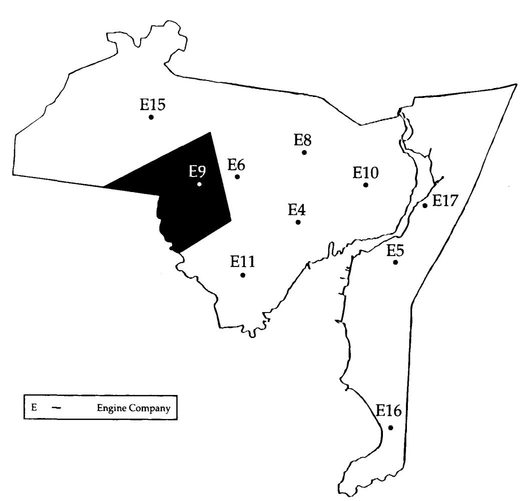

Figure 4: Eliminating Engine 9 would increase first-due engine travel time in the affected region shaded. The shaded area is the set of all points to which Engine 9 was closest.

In comparing deployment options, it is important to focus on serious fires, those for which a slow or inadequate fire department response could affect fire losses. In New York City, the Rand Fire Project used the following definition of serious: any incident in a nonvacant structure that requires two truck companies working. In New Haven, about 20 percent of the structural fires are extremely minor incidents with no dollar loss. Applying the Rand Fire Project definition of serious fire to New Haven results in classifying about 10 percent of all structural fires as serious.

Goldring and Swersey found that eliminating Engine 9 would result in an average increase in first-due engine travel time in the affected region of about 45 seconds to an average of about two serious fires per year and an average increase in second-due travel time in the affected region of about the same magnitude (45 seconds) to an average of eight serious fires per year, while saving about $750,000 per year.

In the middle of March, they presented their results to Chief Geyer and Chief Administrative Officer Rae, concluding that Engine 9 could be closed with small risk.

Redefining the Problem: The Development of the Fire/Medic Plan

In response to the consultants' conclusion concerning the elimination of Engine 9, Chief Geyer proposed an alternative to Rae, the chief administrative officer. Under the chief's plan, Emergency Medical Unit 1 and the tactical unit would be eliminated. From a political point of view, this suggestion was appealing: an emergency medical unit does not have the same sense of identity with its neighborhood as an engine or truck company and the tactical unit responds citywide and is therefore not seen as a neighborhood company. Until this point, the four emergency medical units had not been part of the consultants' study. Each responded to roughly 4,000 calls per year, far more than each fire unit, and because only four had to cover the whole city, they did not seem to be logical candidates for elimination. The consultants, Goldring and Swersey, would soon learn that the original fire station location study had been too narrowly defined.

The consulting work was essentially pro bono.

The consultants set out to evaluate the chief's proposal by first examining the emergency medical response system. Eliminating a medical unit would increase travel time even if the remaining three units were redeployed, and the degradation of travel time would depend on how often each unit was unavailable. By dividing each unit's work load in hours by the number of hours in a year, they found the capacity utilization to be about 15 percent for each unit. This relatively low utilization in part reflected the fact that the emergency units do not transport patients to the hospital.

The observation that emergency medical units were busy only 15 percent of the time coupled with the fact that fire units were busy less than four percent of the time led Swersey and Goldring to devise an innovative new proposal: have the two EMTs on an emergency medical unit who were already cross-trained as fire fighters respond to fires as well as medical emergencies. These two fire/medics would replace two of the four fire fighters assigned to a fire company. The fire/medic concept is analogous to pooling servers in a queuing system, the benefits of which are well known. Under a pooled system, rather than assigning customers to specific servers (for example, by geographic region), all servers would provide service to all customers.

The fire/medic concept was the following: an emergency medical unit team of two technicians would be paired with a fire unit in the same firehouse. Assume initially that both units are in the firehouse. If an emergency call is received, the two emergency medical technicians respond on their vehicle, leaving the fire unit and its fire fighters out of service. If both units are in the firehouse and a fire call is received, the two emergency medical personnel (cross-trained as fire fighters) and the fire fighters assigned to the fire unit respond to the call on the fire truck (Figure 5).

Under this plan, when the emergency unit is out at an emergency medical call, the paired fire unit will be out of service, while when the fire unit is out, the emergency medical unit will be out of service as well.

The fire/medic concept dominates either eliminating emergency medical units or closing fire companies. Pairing an emergency medical unit with a fire company would put the fire company out of service about 15 percent of the time (when the emergency unit was busy) while saving two positions. Creating two fire/medic units would save the equivalent of one fire company (four positions) but would only put each of two fire companies out of service 15 percent of the time. Thus the loss of fire protection would be only 30 percent of the loss from closing a single company. Creating four fire/medic units would save the equivalent of two fire companies. Equally important, creating additional fire/medic units throughout the city without adding personnel would dramatically improve travel time to medical emergencies with no additional loss of fire protection. The loss of fire protection under the fire/medic plan is governed by the total emergency medical work load. Adding fire/medic units simply spreads the emergency medical work load (and the loss of fire protection) across more units. For example,

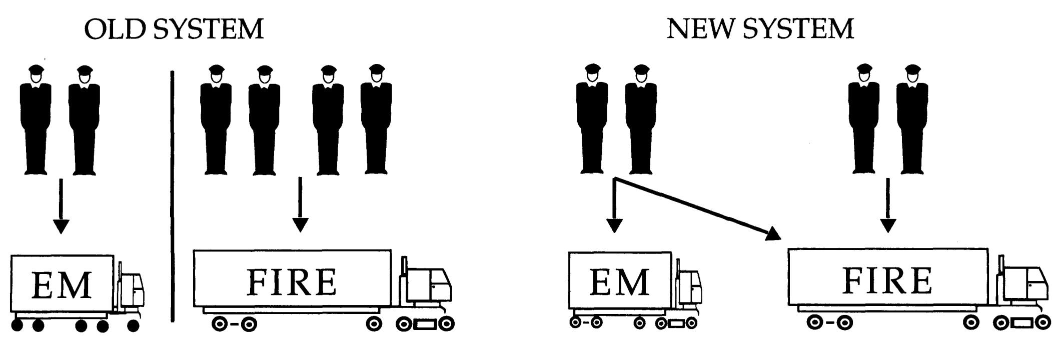

Figure 5: Under the old system, the emergency medical unit and fire unit operate independently. Under the fire/medic plan, the two fire/medics either respond to an emergency medical call or with the two firefighters respond to a fire call. The new system would save two positions.

doubling the number of fire/medic units from four to eight would put each paired fire unit out of service 7.5 percent of the time. Also, from a political point of view, spreading the loss of fire protection across more neighborhoods is desirable.

Goldring and Swersey had argued that the cost savings from closing a single fire company justified the small loss in fire protection. The fire/medic proposal would save twice as much money with only 60 percent of the fire protection loss. Moreover, creating additional fire/medic units in the future would greatly improve emergency medical travel time. In particular it was clear that adding a fire/medic unit in the firehouse of Engine 15 and Truck 5 (Figure 1) would dramatically improve emergency medical travel time in that area.

Winning Approval for the Plan

At this point, the April 15th deadline for the fire budget to be approved by the board of finance was approaching. Goldring and Swersey presented the proposal to Chief Geyer and Rae. Rae was enthusiastic, while the chief was more cautious but optimistic. Obviously, many logistical details needed to be worked out: the most important being which fire units would be paired with the emergency medical units, and how would communications handle the somewhat more complicated dispatching protocols.

Events moved quickly once the concept was approved by Rae and Chief Geyer. Our strategy for winning approval was to make it clear that the original fire station location study had identified Engine 9 for elimination and that the fire/medic plan was preferable to cutting an engine company. Within days, Chief Geyer and the consultants, Swersey and Goldring, presented the plan to the board of finance with a proposal to cut the fire budget by 32 fire fighter positions. (Converting the four emergency medical units to fire/medic units saves eight positions, which require 32 persons for around-the-clock staffing.) The board of finance approved the plan, and it was reported in the press for the first time the next day.

Over several weeks in May, we presented the plan to the board of aldermen at a series of public hearings with the president of the fire union arguing vehemently against it. At one meeting, Swersey was subjected to a succession of what-if questions about how the plan would perform when serious fire and medical emergencies occurred simultaneously. The nightly television news showed a highly edited version of the proceedings with Swersey responding that under a particular scenario a fire company would indeed be delayed. The union arguments against the plan seemed to be that no increase in fire risk was acceptable.

In a letter to the board of aldermen, the fire union proposed as an alternative to the fire/medic plan, that a fire company be eliminated. In private discussions with the authors, a representative of the union suggested eliminating the underutilized truck 5. (Earlier we pointed out that such a move would significantly increase first-due truck travel times in its surrounding region.) We suspected that the motivation for that suggestion was political: The mayor's Republi-

Closing a firehouse is not easy.

can opponent in the upcoming election and many influential citizens lived in that region. Eliminating Truck 5 would likely cause a storm of protest and pressure for the board of aldermen to restore the fire department cuts.

At the end of May, the board of aldermen approved the fire department budget and the new plan. Now that the concept was approved, much work remained to work out the details of the plan.

Two Important Additions

During July and August of 1991, the department tested the fire/medic concept during several periods. During these tests, Chief Geyer devised an important modification to the original concept. Under the original plan, it was assumed that a fire/medic unit would be staffed by two fire/medics and two fire fighters (thereby saving two positions) and that the fire company would not respond to a fire incident if the emergency medical unit was out at an emergency medical call since two fire fighters could not adequately perform fire fighting operations. Chief Geyer's idea was to increase the fire/medic team to five persons by adding an additional fire fighter. The cost savings would be less since one fewer position would be saved, but under this scheme, when the emergency medical unit was out, the fire company would still respond with three fire fighters. The chief felt that having three fire fighters respond was adequate in the case of truck companies and for those engine companies located in residential regions of low fire incidence.

Another important modification was initiated by Lt. William Seward of the department's training division. It had been recognized that establishing a fire/medic unit in the firehouse of Engine 15/Truck 5 would be valuable, but extensive building renovations would be needed. Seward proposed equipping Engines 15 and 16, two units in outlying areas of the city (Figure 1), with medical life-support equipment and training its fire fighters to provide CPR and other basic emergency medical care. Each of these units would respond to emergency medical calls in their surrounding areas in addition to their normal fire duty.

A Spatial Queuing Model

Swersey developed a spatial queuing model to estimate the improvements in emergency medical travel time under the fire/medic plan and to evaluate the effects of changing the locations of emergency medical units (appendix). The model assumes Poisson arrivals and exponential service times for fire and emergency medical calls and that the system consists of fire/medic units as well as separate emergency medical units. Each fire/medic unit can be in one of three states: available, busy at a medical emergency, or busy at a fire incident, while each separate emergency medical unit can be in one of two states: available or busy at a medical emergency. Transitions from state to state are governed by a system of steady-state balance equations that are solved numerically to obtain the steady-state probability of each system state. The probabilities are then used to calculate the expected travel time to each demand point (the center of a census tract) and citywide.

Queuing Model Results

We used 1990 emergency medical and fire alarm data as input to the queuing model. We assumed that emergency medical calls originated from the approximate center of each of the city's 28 census tracts and estimated the travel times from each unit to each tract using the distance and time functions used in the siting model analysis described earlier. For travel across the New Haven Harbor or Quinnipiac River, we assumed that the unit first traveled to a crossing point and then to the call.

We first evaluated emergency medical unit travel times under the pre-fire/medic plan system in which there were four

The original fire station location study had been too narrowly defined.

emergency medical units. With only separate emergency medical units (that is, no fire/medic units), the queuing model reduces to the hypercube queuing model [Larson 1974]. We solved the steady-state balance equations for the 16 system-state probabilities. For each census tract, we calculated the travel time to that tract given each possible system state. We then estimated the average travel time to the tract by weighting each travel time by the probability of being in that state (Figure 6).

We recognized that the fire/medic plan represented a major organizational change, and given continued strong opposition from the fire union, Chief Geyer decided to implement the plan incrementally by creating three rather than four fire/medic units. We used the model to evaluate two alternative configurations under the fire/medic plan. In both options, EM2 operates independently, EM4 is paired with Truck 2, and EM3 is paired with Engine 5 with these three emergency medical units remaining at their usual locations. In the case of the paired units, the fire companies respond with three fire fighters when the emergency medical unit is busy at an emergency medical call. The difference in the options relates to the location of EM1. Under one option, EM1 is paired with Truck 3 to form a five-person fire/medic unit with the truck company responding with three fire fighters when the emergency medical unit is busy. Under the other option, EM1 is paired with Engine 8 to form a four-person fire/medic unit and remains at its usual location. In this case, if the emergency medical unit is busy, Engine 8 would not respond with only two fire fighters but would be out-of-service. Creating a five-person fire/medic unit of EM1 and Engine 8 would not be feasible. Chief Geyer viewed a three-fire-fighter response as adequate for truck companies and for engine companies in residential areas of low fire incidence. Engine 5 is such a company but Engine 8 is not. Under both of the fire/medic options, Engines 15 and 16 respond to medical emergencies.

Table 2 compares the three options. We used several alternative measures in comparing the plans, estimating average travel time to all alarms, to priority 1 calls (heart attack, gun shot victim, unconscious person, and so forth), and to cardiac emergencies (cardiac arrest, myocardial infarction, and heart failure). We estimated average travel time to any point by taking a weighted average of census tract travel times with the weight for each tract's travel time being its area. This estimate is a measure of geographical coverage, ignoring

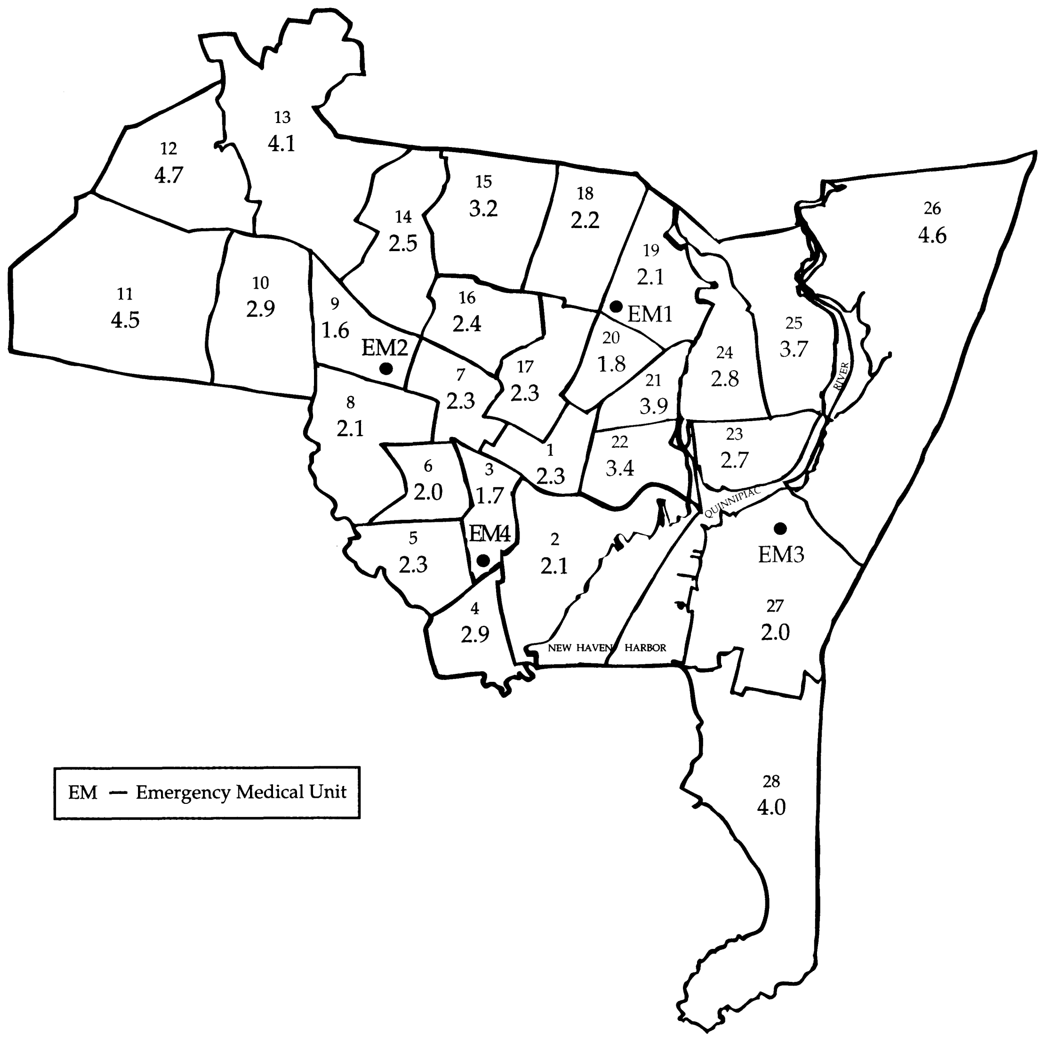

Figure 6: The queuing model was used to estimate the average travel time in minutes to emergency medical calls in each of the city's 28 census tracts under the pre-fire/medic plan with four emergency medical units.

the pattern of alarm incidence. Table 3 gives the data by census tract, showing area, priority 1 calls and cardiac calls. The fire/medic option of EM1 with Engine 8 compared to EM1 with Truck 3 results in some small improvements in city-wide travel time for three of the four measures. Also work load is somewhat more balanced under this option (Table 4). Chief Geyer chose the EM1/Truck 3 option. Figure 7 shows the average travel time to each census tract under this plan. Both he and his training officers preferred this option because it keeps all fire units in service at all times. Pairing EM1 with Engine 8 would save more money, two positions compared to only one position saved under the option of EM1 with Truck 3. But pairing EM1 with Engine 8 would put Engine 8 out of service 15 percent of the time

Option	All Alarms	Any Point	Priority 1 Calls	Cardiac Calls
Pre-fire/ medic plan	2.80	3.24	2.96	3.01
EM1 with Truck 3	2.69	2.65	2.66	2.74
EM1 with Engine 8	2.64	2.61	2.63	2.79

Table 2: The spatial queuing model showed that keeping EM1 at its usual location and pairing it with Engine 8 was slightly better than moving it to the firehouse of Truck 3 and pairing it with that unit. The EM1/Engine 8 option produced small improvements in average citywide travel time to all alarms, to any point, and to priority 1 calls, while the EM1/Truck 3 option was slightly better to cardiac calls. Both of these fire/medic options result in large decreases in travel time to any point, to priority 1 calls and to cardiac calls.

when EM1 is busy at a medical emergency (Table 4).

As Table 2 shows, citywide improvements in average travel time under the fire/medic plan (EM1 with Truck 3) are large with the greatest benefit being improved coverage: the average citywide travel time, weighted by census tract area, is reduced by more than half a minute from 3.24 minutes to 2.65 minutes. Gains in average citywide travel time to priority 1 and cardiac calls are also large.

Because Engine 15 and Engine 16 respond to medical emergencies under the fire/medic plan, the improvements in average travel time to tracts 10, 11, 12, 13, and 28 are very large (compare Figures 6 and 7). Table 5 shows the improvements, which average more than two minutes, as well as the number of priority 1 and cardiac emergencies in each of these census tracts.

We also used the queuing model to evaluate the effect of reducing the number of separate emergency medical units from four to three as had been proposed. We kept EM2 and EM3 at their usual locations and put the third unit in the firehouse of Engine 4 and Truck 1 (Figure 1), a central location. We found that average emergency medical travel time increased by about 0.4 minutes citywide and more than 1.5 minutes in the central regions of the city, areas with a high incidence of priority 1 and cardiac calls.

In New Haven in 1990, there were a total of 16,434 emergency medical calls, with 2,530 of these being priority 1 and 571 of the priority 1 calls being cardiac calls. These numbers, when compared to the fire demand, show that there is a much greater potential for saving lives in the emergency medical area than in fire protection (Table 6). In addition to the 571 cardiac calls citywide in 1990 in which people were taken to the hospital, there were almost 100 cases in 1990 in which the patient was dead when the emergency medical unit arrived. In contrast, in 1990 there were three fire deaths. Moreover, researchers have shown that reducing emergency medical response time to heart attack victims can significantly improve survival probabilities [Pozen et al. 1977; Urban, Bergner, and Eisenberg 1981].

Final Plan

The final plan had three fire/medic units (EM3/Engine 5, EM4/Truck 2, and EM1/Truck 3) and one separate emergency unit (EM2). In addition, Engine 15 and Engine 16 would respond to medical emergencies.

We also recognized that the pooling concept employed in the fire/medic plan

Census Tract	Land Area (sq. mi.)	Persons	% of Total Calls	% of Priority 1 Calls	% of Cardiac Calls
1	0.27	908	5.2	3.1	2.6
2	0.82	1676	3.9	4.1	3.3
3	0.27	3173	4.7	3.0	1.2
4	0.35	3380	2.3	2.1	0.9
5	0.39	4684	3.9	3.6	1.4
6	0.29	6261	7.4	7.2	4.6
7	0.30	6799	5.0	3.7	3.9
8	0.62	4525	3.9	4.1	6.0
9	0.38	4371	2.2	2.7	2.6
10	0.72	3827	1.1	1.1	2.8
11	1.50	3077	1.0	1.5	2.1
12	0.73	4548	3.0	4.9	2.1
13	1.30	6772	4.3	3.8	1.9
14	0.59	4953	2.4	2.5	3.3
15	0.63	7806	7.8	9.1	5.8
16	0.41	6298	7.1	3.6	3.7
17	0.38	5383	2.0	1.4	1.6
18	0.36	4402	1.9	2.5	2.5
19	0.50	4969	1.5	1.7	2.8
20	0.26	4321	1.3	1.6	1.1
21	0.21	1535	2.2	2.4	1.8
22	0.35	1526	1.7	1.2	0.9
23	0.40	4909	3.3	2.8	4.9
24	0.49	4866	5.0	4.9	5.3
25	0.72	4770	3.9	4.2	5.4
26	2.44	10346	6.9	10.6	16.8
27	1.27	5362	3.3	3.6	6.5
28	1.50	5113	1.8	3.2	4.9

Table 3: Citywide in 1990 there was a total of 16,434 emergency medical calls, of which 2,530 were priority 1 calls, and 571 of the priority 1 calls were cardiac calls. The data by census tract were used to determine the average citywide travel times shown in Table 2.

	EM1	EM2	EM3	EM4
EM1 with Truck 3	0.12	0.20	0.12	0.16
EM1 with Engine 8	0.15	0.16	0.13	0.16

Table 4: Work load is somewhat more balanced under the EM1/Engine 8 option compared to the EM1/Truck 3 alternative. The table entries give the fraction of time each emergency unit is busy at emergency medical calls. Under both options, EM2 is a separate unit, EM3 is paired with Engine 5, and EM4 is paired with Truck 2.

could be extended to the tactical unit. This unit staffed by four fire fighters responds to hazardous chemical spills and other special emergencies and is equipped with special equipment to handle such incidents. They responded to 127 such calls in 1990. In addition, the tactical unit was used to provide additional personnel at fires.

The tactical unit is in the same firehouse as Engine 8 which has four fire fighters as-

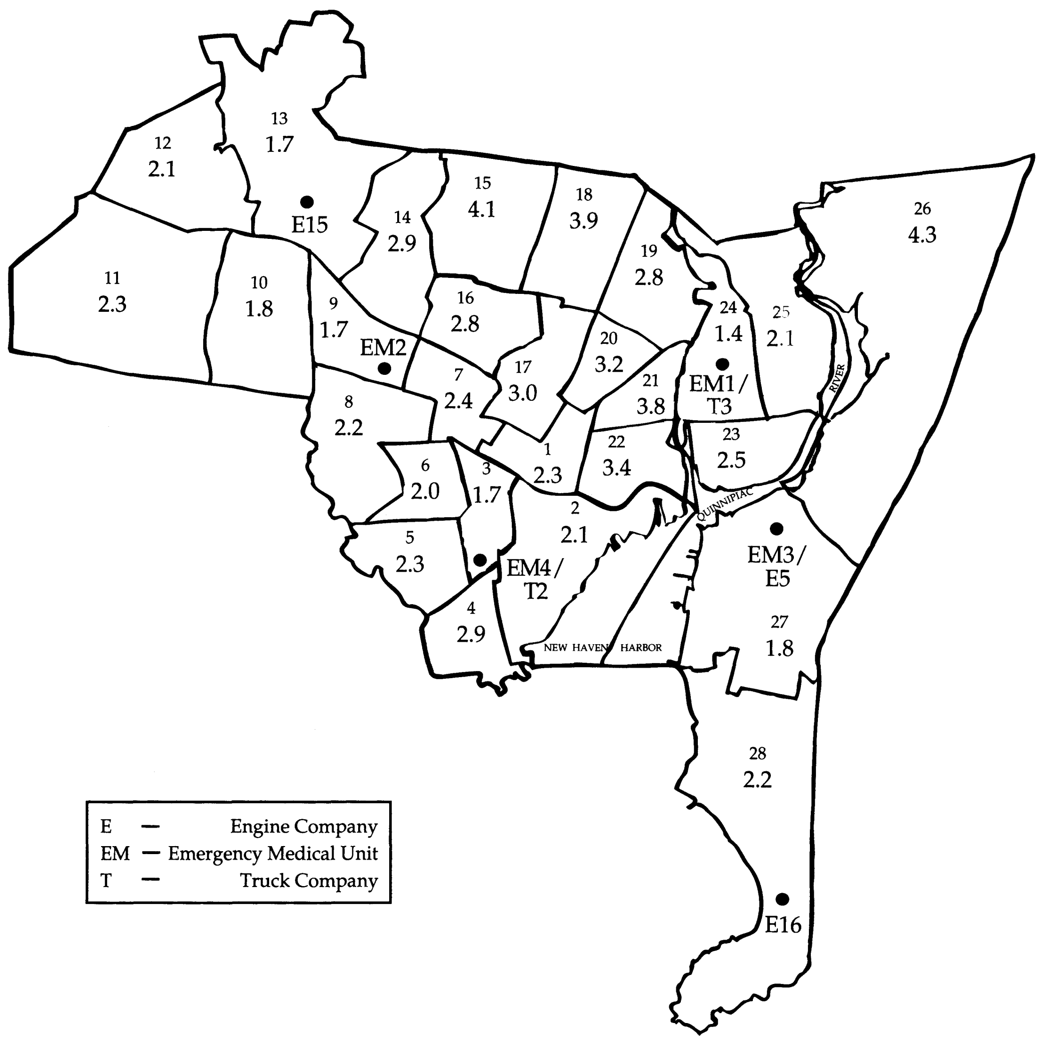

Figure 7: This option of the fire/medic plan has EM2 as a separate emergency medical unit and three fire/medic units: EM4/Truck 2, EM3/Engine 5 and EM1/Truck 3. Engine 15 responds to all emergency medical calls in census tracts 10, 11, and 12, and to priority 1 emergency medical calls only in census tract 13. Engine 16 responds to all emergency medical calls in an area near its firehouse encompassing about 80 percent of census tract 28 (See appendix). The average travel time of 1.7 (minutes) shown for tract 13 is to priority 1 medical calls (the average travel time to all emergency medical calls in that tract is 3.7 minutes). For all other census tracts, the figures shown are the average travel time in minutes to all emergency medical calls in the census tract.

signed to it. By creating a merged Engine 8/tactical unit with around-the-clock staffing of five fire fighters, three positions would be saved. The merged unit would respond to hazardous spills and special emergencies as the tactical unit or to fire calls as Engine 8. Also under this plan, the tactical unit would no longer respond to fire incidents to provide additional personnel. Instead the nearest available engine

Census Tract	Decrease in Average Travel Time in Minutes	Number of Priority 1 Calls in 1990	Number of Cardiac Calls in 1990
10	1.1	28	16
11	2.2	40	12
12	2.6	124	12
13	2.4	96	11
28	1.8	81	28

Table 5: Having Engine 15 and Engine 16 respond to emergency medical calls greatly reduces average travel time in the surrounding census tracts. These improvements are important since there are a significant number of priority 1 and cardiac cells in these census tracts.

company would be sent.

Implementation

On September 27, 1991, Chief Geyer in a department bulletin announced the implementation of the fire/medic plan, which improves productivity by both reducing cost and improving public safety. The yearly personnel savings due to the plan are $1.4 million, which represents 10 percent of the fire suppression budget. The detailed breakdown of these savings is given in the appendix. The personnel cuts did not require layoffs but were achieved through attrition (retirements). The improvement in public safety results from large reductions in emergency medical travel time that offset slight decreases in fire protection. Equally important, the plan represents a major organizational change that shifts the department's traditional focus on fire fighting to a greater emphasis on emergency medical service.

Discussion

The key insight of our work was the realization that separate emergency units were not justified from the standpoint of cost and effectiveness. Our basic idea is that existing fire fighting personnel can also provide emergency medical services with no increase in personnel cost.

Fire companies in New Haven and nearly all cities (New York City is one exception), are busy at fire incidents a very small fraction of the time. Having cross-trained fire fighters respond to medical emergencies, as in the fire/medic plan, results in a very small loss of fire protection that is offset by large decreases in emergency medical response time.

When our work began, New Haven had a system that provided very good emergency medical service but at too high a cost. Under the fire/medic plan, emergency medical service is now even better and much less expensive. An important part of the New Haven system is the private ambulance service that provides highly trained paramedics who provide on-scene care and transport patients to the hospital. These units operate at a very high utilization, which reduces cost. The rapid response of the fire department brings emergency care to the victim prior to the arrival of these ambulances.

Independent of our work, a number of innovative cities seem to recognize the principles we have identified. For example, Fremont and Anaheim in California provide emergency medical service by having

Fire	Emergency Medical
4,534 Alarms	15,649 Total calls
259 Structural fires	2,530 Priority 1 calls
29 Serious fires	571 Cardiac calls

Table 6: The demand for emergency medical service is greater and more serious than the fire demand as these 1990 citywide figures show.

engine companies with fire fighters cross-trained as medical technicians respond to emergency medical calls in addition to their fire duty, while St. Paul, Minnesota operates a system in which four-person teams respond to fires on a pumper or to medical emergencies in an emergency van, an approach similar to the fire/medic plan. In addition, many cities have engine companies respond to apparent cardiac arrests.

Although increasingly fire departments are making use of personnel who are cross-trained to provide both fire and emergency medical service, the predominant organizational structure is separate fire and emergency medical systems. According to a recent survey of the nation's 200 largest cities [Cady 1991], in more than 70 percent, primary provision of emergency medical service is through a separate system either within or outside the fire department. These cities are not taking advantage of the pooling benefits that derive from merging services.

Acknowledgments

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APPENDIX: Description of the Spatial Queuing Model

We are given n emergency units, each of which either operates as a fire/medic unit or as a traditional emergency unit. We assume that emergency medical calls occur at a set of demand points. Let b_i represent the state of unit i for $i = 1, \ldots, n$. If unit i is an emergency unit responding only to emergency medical calls, then $b_i = 0$ if unit i is available and $b_i = 1$ if unit i is busy at an emergency call. If unit i is a fire/medic unit, then $b_i = 0$ if unit i is available, $b_i = 1$ if unit i is busy at an emergency medical call, and $b_i = 2$ if unit i is busy at a fire incident. We represent the state of the system of n units by an n-dimensional vector $b = (b_i, \ldots, b_n)$.

The model assumes that

(1) Emergency medical calls arrive at each demand point j according to a Poisson process with mean arrival rate λ_j.

(2) The service time for emergency medical calls is exponential with mean $1/\mu$.

(3) Fire calls for each fire/medic unit i arrive according to a Poisson process with mean p_i. If the fire/medic unit is busy when a fire call for it arrives, it is lost, that is, we assume that another city fire unit outside of the system being modeled handles the call.

(4) The service time for a fire call to fire/medic unit i is exponential with mean $1/\phi_i$.

(5) For each demand point, the n emergency units are ordered from highest preference to lowest preference for dispatching to a call from that point. For each call, from among the available units, the one with the highest preference is dispatched.

(6) The travel time from each demand point to each unit is specified.

(7) If all units are busy and an emergency medical call is received, it is lost, that is, it is handled by a unit outside of the system.

(In New Haven this would be one of the private ambulance units.)

A separate emergency unit is either available or busy at a medical emergency. A fire/medic unit can operate in either of two ways in the event of a fire call being received for the unit when the emergency unit is out: (1) the fire unit does not respond, that is, the call is handled by a New Haven fire company outside of this system; or (2) the fire unit responds with fewer personnel. Let us first examine how the system operates under case 1. If the fire/medic unit is available (state 0) and a medical call is received, the emergency medical unit responds, leaving the paired fire unit off duty, and the fire/medic unit is in state 1. If the fire/medic unit is available and a fire call is received, both units respond and the fire/medic unit is busy at a fire (state 2). Under case 2, the available fire/medic unit moves from state 0 to state 1 when a medical emergency call is received, and the fire unit remains available for service. If the next event is a fire call, the fire unit responds, both units become busy, and the fire/medic unit is busy at a fire (state 2). Under case 2, we add an additional assumption to the model:

(8) If both the emergency unit and its paired fire unit are busy, we assume that the emergency unit returns first and joins the fire unit at the fire incident.

Assumption 8 allows us to simplify the state description by allowing each fire/medic unit to be in only one of three states 0, 1, 2. Assuming that the emergency unit returns first is reasonable: our data show that the emergency-call average service time is about 25 percent less than the fire-call average service time. Also, for the units to become busy at both an emergency and a fire incident, the emergency medical incident must begin before the fire incident. In other words, the only way the situation that is described in assumption 8 can arise is if a fire call is received while the emergency unit is busy.

Each individual unit can be in either two or three states depending on whether it is a separate emergency unit or a fire/medic unit. Of the n units, let $k \leq n$ be the number of fire/medic units, then the total number of system states is $3^k 2^{n-k}$.

Given the above assumptions, the model describes a continuous time Markov chain. The system satisfies the steady-state balance equations, which specify for each state that the rate of transitions into the state equals the rate of transitions out of the state. A complete specification of these balance equations is given by Swersey, Goldring, and Geyer [1992]. We solved the system of balance equations numerically to get the steady-state probability of each system state and then using these probabilities calculated the expected travel time to each demand point citywide.

Validation

The spatial queuing model assumes a constant average hourly call rate, but calls vary over the day (Figure 8). Using the average over the day as we have done will give a lower bound on system performance measures [Green and Kolesar 1991]. We solved the model hour by hour, varying the call rates according to the data in Figure 8. We then took a weighted average of the resulting steady-state probabilities with each hour's results weighted by its call rate. This procedure should give close to an upper bound on the actual probabilities [Green and Kolesar 1991]. We found that this procedure yielded steady-state probabilities that were within a few percent of our original results. When we calculated the expected citywide travel time using these new probabilities, we found virtually no increase compared to the estimate based on a constant average call rate over the day.

Our model assumes exponential service times. The variability in actual service times is less than under the exponential assumption—the ratio of the standard deviation to the mean is typically about two

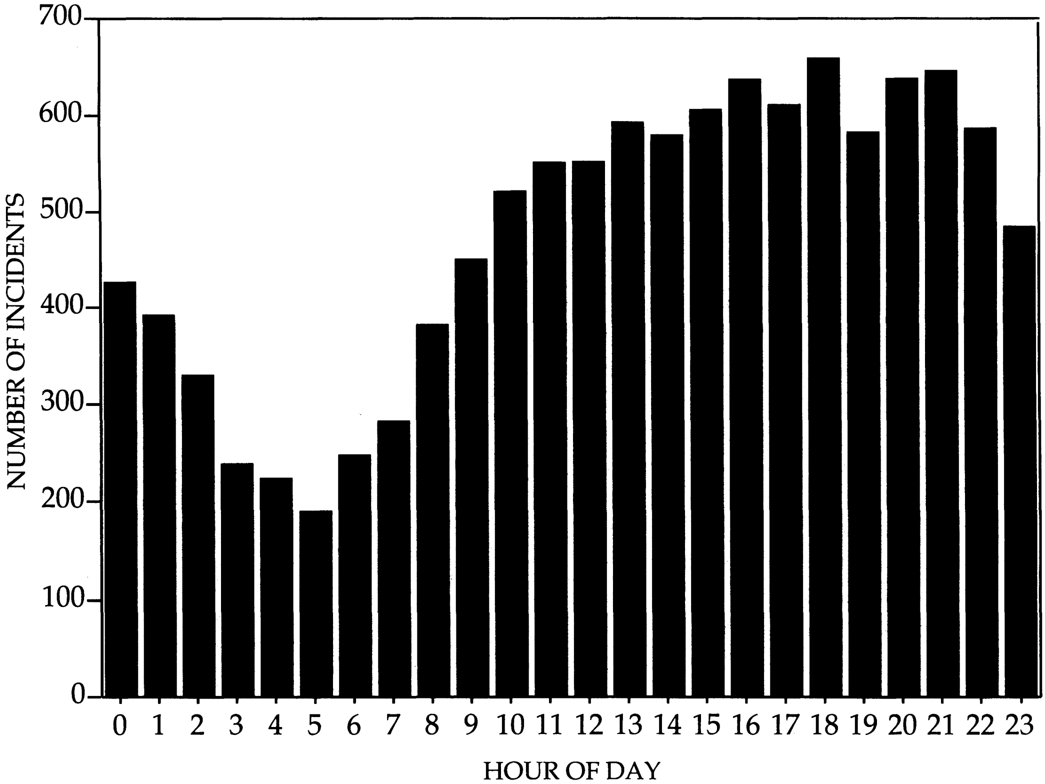

Figure 8: Emergency medical call rates vary significantly over the day. Although the spatial queuing model uses the average rate over the day, we found that the results would not be affected.

thirds. It is likely that this difference would have little effect. Both the loss model (M | G | c | c) and the infinite server model (M | G | ∞) are insensitive to service-time distribution. Given our low traffic intensities, which yield virtually no lost calls, we expect that our spatial model would not be sensitive to the exponential service time assumption.

In our model we assume that if a fire call is received for a fire/medic unit and it is busy, the call is handled not by another fire/medic unit but by another New Haven fire company outside of the system being modeled. Since the fire/medic units are geographically far apart, this is a reasonable assumption.

The main effect of the fire/medic plan on emergency medical travel time occurs in census tracts 10, 11, 12, 13, and 28, where the model predicts large decreases in travel time. We estimated the actual decreases by comparing actual travel times to emergency medical calls in these census tracts in September 1991, prior to implementation of the plan, and in January and February 1992, after implementation. The differences between the actual and predicted decreases were found to be small and not statistically significant.

M | G | 1 | 1 Queuing Model

Under both of the fire/medic options, Engines 15 and 16 respond to medical emergencies. We dealt with these units in the following way. The department decided to assign Engine 15 to all emergency medical calls in census tracts 10, 11, and 12 and to priority 1 calls in census tract 13, while Engine 16 was assigned to cover all emergency calls in about 80 percent of tract 28 in the area surrounding its house. In addition, the closest emergency medical unit would also be dispatched to all priority 1 calls responded to by Engine 15 and Engine 16. Engine 15 and Engine 16 respond to both fire calls and emergency medical calls. Based on 1990 data for each unit, we estimated the average service time for a call by taking a weighted average of the average fire service time and the average emergency medical service time with the weights being the fraction of calls of each type. Each unit could then be viewed as a single server loss model; using queuing notation, the $M|G|1|1$ model. Using Erlang's loss formula, we calculated the steady-state probability that each unit was busy and the fraction of calls lost. These lost calls would become additional demands on the four-unit fire/medic system.

Fire/Medic Plan Personnel Savings

The original fire/medic concept called for creating four fire/medic units, each staffed around-the-clock with four persons. Each of these four fire/medic units would save two positions, the total of eight positions saved requiring 32 positions around-the-clock.

The final fire/medic plan as implemented saves 28 persons. The two fire/medic units (EM4/Truck 2 and EM1/Truck 3) are five-person teams that each save one position compared to the normal staffing that requires four fire fighters on the truck company and two EMT's on the emergency medical unit. The fire/medic unit EM3/Engine 5 saves two positions since the normal staffing of Engine 5 was five positions which were needed to staff the combination pumper/ladder. Since the budget was cut by 32 positions and the implemented plan saves 28, additional overtime would be needed to cover the difference.

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Ralph W. Halsey III, Controller, Kennedy Mitchell Hall of Records, City of New Haven, 200 Orange Street, New Haven, Connecticut 06510, writes ". . . the redeployment plan in the City of New Haven Department of Fire Services . . . resulted in our ability to reduce the fire department manpower by 28 positions without negatively affecting fire service delivery. The elimination of these positions saved $1,420,706 in the current fiscal year in a department with a total budget of $18,307,187.

"The shift in deployment patterns will ultimately result in a higher percentage of firefighters being trained and certified in emergency medicine and in more effective services in emergency medicine in general."