advantage of directional signs or building familiarity. The path finding efficiency factors related to occupant evacuation are just as valid for firefighter access. The efficiency factors are related to building layout complexity. Some of the factors relating to complexity are unusual arrangement of corridors, obtuse angles, and exit doors that appear the same as every other door[26].

3.3.1 SPACES AND BARRIERS

In a building evaluation, all buildings are defined as assemblies of spaces and barriers. Where a space is the volume enclosed by barriers, and a barrier is any surface that will delay or stop the movement of a fire's combustion products[27]. Space-barrier assembly arrangements can either help and hinder a fire department. The arrangement can slow or stop fire extension, but it also can slow or stop a fire attack.

From the viewpoint of firesafety building spaces can be classified into four groups[28]: (1) Rooms, (2)Uncompartmented Spaces, (3) Corridors, and (4) Shafts. Uncompartmented spaces are large open floor areas. Corridors provide paths the horizontal movement of goods and people. Shafts(e.g. staircase, elevator) provide for vertical movement.

For the purposes of this thesis building space classifications are defined as the following:

1) Room
2) Corridor
3) Shaft

From the perspective of the fire department the building contains three space classifications:

1) fire
2) exposure
3) attack path

The fire space contains the flame-heat component of the fire. The attack path is the "space" used by the firefighters to access the fire space. The remainder of the building that is threatened by the fire is the exposure space.

The building, and fire department space definitions can be organized into a matrix (see Figure 4) showing all possible combinations for a space in the building. If the goal of the fire department is to reach the fire space, only the spaces encountered by the firefighters along an attack path need to be considered. From the viewpoint of a fire attack the remainder of the building is not a factor in the analysis.

Barriers separate spaces. For practical purposes, within the context of evaluating a fire attack, only barriers that contain large openings are of interest. Again, from a practical viewpoint, the only openings of interest are doors. The factors relating to a door's influence on a fire attack are as follows:

Position (open or closed)
Status (unlocked or locked)
Swing (inward or outward)
Construction (materials)
Locking mechanism

When the fire department is confronted with a barrier having a locked door, that door must be opened, forced, or bypassed. A locked door can be opened with a key or it can be opened by a person on the other side of the door. There are three ways to force a door. These include: (1) impact, (2) pry manually, and (3) pry power assisted.

The most appropriate method for forcing a door is determined by the need for speed and the method of construction. It is much quicker to "open" a glass door than a metal door with an axe. Ultimately, the entry tools available at door have the final say in the method used.

Considering spaces and barriers as they relate to manual suppression there is a relatively small number of building "states" that can be encountered by firefighters. This limited number of building states permits an evaluation framework to be developed.

3.3.2 WATER SUPPLIES

Water supplies for firefighting may be defined in terms of quantity (gal.), volume(gpm), pressure (psi), and location. An ideal water supply would be able to supply an attack line with just the opening of a valve. For example, a fire apparatus tank or building wet standpipe. Fire department equipment can make-up for volume and pressure deficiencies in a water supply. Moreover, there are situations where fire department equipment may be the only water supply. Correcting water supply deficiencies will require equipment, time, manpower, and skill.

A major factor in water supplies is quantity. The water carried on fire apparatus is a reliable supply. The department need not search for it. However, it is limited in quantity, carrying only 3 to 5 minutes of water for an attack line. On the other hand, a static supply such as a pond offers almost unlimited quantity. However, a static supply is not available immediately. Typically in urban areas, the most visible supply of water is the fire hydrant. Hydrants normally suggest access to a large quantity of water, although questions in pressure, volume, and reliability can arise.

A single modern 1 3/4-inch hand line fire nozzle requires upwards of 180 gpm at 100 psi[29]. Without advance planning, few supplies of water can provide both the volume and pressure needed for firefighting. A pump offers one solution to a problem of low pressure by increasing pressure downline of the pump, although a pump will not increase the volume of water available at the intake of the pump.

The location of the water supply often determines the complexity of the water supply evolution. The more distant a supply from the location where it is needed, the more manpower and equipment are required. Each additional control point in the path from supply to nozzle increases the manpower required and the potential to delay the fire attack.

A large water supply with good pressure and flow rate readily available where it is needed is key to a successful fire attack. If the water supply is deficient, then the fire department must work to correct the deficiencies. The more firefighters, pumps, hose, tanks, valves, distance in a water supply set-up, the less reliable it will be and the longer it will take to provide the fire attack flow. Finally, resources drained by water supply needs are not available for other fire ground tasks.

3.4 THE EVALUATED SYSTEM

There is no established method for evaluating manual suppression effectiveness. This procedure is a first attempt at developing a technique for evaluating a building's design for fire attack route effectiveness. Because of the development effort in establishing the concept and its operation all fire situations can not be addressed. Nevertheless, the concept and its simplicity of application are able to compare fire attack routes for a building.

Consequently, this first attempt at a method will incorporate simplifying constraints for the building, fire, and fire department. The evaluation system proposed in the subsequent chapters of this thesis, which is based on the concepts discussed in this chapter, has limitations on the fire size that can be evaluated. However, the evaluation method can be used for any fire department or a specific fire department influence can be excluded.

The major tasks of a fire department have been offered as locate, attack, control, and extinguish. At any given fire incident the four tasks generally are not of equal difficulty. There is a sizable number of fires that can be reduced to just one task. For a well vented fire of several thousand square feet the locate task is trivial. A wastebasket fire poses little challenge to gaining control and extinguishment. Occasionally, a small smoldering fire can take hours, or days, to locate. The fire incident of greatest interest here is the fire which can be reduced to just the attack task. For this case evaluating the attack task completes the evaluation of manual suppression.

When can manual suppression be reduced to the attack task only? Quite often. In a large building the attack is carried out simultaneously to the locate task. The reflex time to get equipment from the arrival area to the fire area requires the attack equipment be brought along as the attempt to locate the fire is made. In a most situations the time spent exclusively on locate is minor in comparison with the time to mount the attack.

Even for many sizable fires, extinguishment occurs essentially at the time of agent application. For an even larger number of fire control is quickly gained with the first attack line. In other words, this procedure will address only those conditions where fire extinguishment occurs simultaneously with fire attack. Larger fires which use both barriers and fire department protection of those barriers to control a fire are not included in this analysis. Therefore, this evaluation method is limited to fires which are no longer a threat to the building or fire department after the first attack line is opened on the fire. The exact fire size that can be quickly extinguished is the subject of current study , but it is fair to say such a fire exists. Research has shown it is not beyond the capability of one hose line to extinguish a room 20 feet by 25 feet[30]. Therefore, for this evaluation fire size is defined as a building space that is assumed to be within the quick extinguishment capability of one hose line.

CHAPTER 4

THE OUTPUT-ATTACK PATH DIFFICULTY

The previous chapter proposes that for many building fires, the building can be evaluated for manual suppression effectiveness by looking only at the fire attack. Unfortunately, the attack occurs in the complex environment of a burning building. The task of attacking a fire is influenced by: the layout of the building, location of the fire, the fire products of combustion, the equipment used to make the attack, and the manpower available. In addition, the effectiveness of the fire department making the attack on the fire is important. The resources and skill of a local fire department must be considered to complete any evaluation.

A fire attack begins at the place a fire apparatus stops. The attack task ends, and the control task begins, when water is played on fire. The ideal evaluation process would input factors from the building, fire, and fire department, and then output the time it takes for the fire department to set-up and execute the attack. However, any evaluation process which allows comparisons of attack situations would be of value. While time is a major concern, it is possible to evaluate path difficulties in other ways.

An easy attack route evaluation process which incorporates time as an output, plots a path through a building from the entry point to the fire space. Then the time it takes to travel the path is determined by dividing the path distance by an assumed rate of travel along the path. The rate of travel used would be constant. For the hypothetical constant travel rate, all doors will be open, the stairs cause no fatigue, there are no way finding delays, and there is no fire. This time is useful because it establishes a base for comparison for fire conditions. Thus, a minimum* time required for a fire attack has been calculated.

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* This would not be true in the case of a path that includes the use of an elevator to reach a floor many floors above the entry floor.

4.1 ATTACK PATH DIFFICULTY VALUE .

The reason no fire department can better the time calculated by the above process is that the fire department must deal with actual building conditions. The previous attack occurs in a "friction free" building. The presence of time robbing factors related to the building, fire, and fire department will make the actual time for a fire department to travel the path different from the calculated time.

The ratio of the actual time to make a fire attack divided by the calculated time is defined as the Path Difficulty value, Pd. This ratio is shown in equation {1}:

$$Pd = T_a/T_c \qquad \{1\}$$

Where: T_a = actual time of fire attack

T_c = calculated time to travel path

4.2 EFFECTIVE DISTANCE

The challenge of evaluating equation {1} is to establish appropriate values for T_a. However, because the time to travel a distance is equal to the distance divided by the rate of travel, time can be represented by the distance divided by rate half of the equality. This equality is shown as equation {2}:

$$T = D/R \qquad \{2\}$$

Where: D = distance

R = rate of travel

For T_c, the rate of travel is a fictitious constant, but for T_a, the actual travel rate varies along the path. Therefore, T_a is best represented by a summation of path segments where a specific travel rate can be determined. By substituting equation {2} and including the summation of path segments, equation {1} becomes:

$$Pd = \sum_{i=1}^{n} (D_i/R_i)/(D/R_c) \qquad \{3\}$$

Where
D = path distance
R = attack travel rate
R_c = constant travel rate
i = path segment

Different rates of travel for equation {3} can be related as follows:

$$R_i = R_c/C_i \qquad \{4\}$$

Where:
C = a constant for segment i

Substituting equation {4} in equation {3} and simplifying, yields,

$$Pd = \sum_{i=1}^{n} (D_i C_i)/D \qquad \{5\}$$

Equation {5} contains the constant, C_i, which is effectively a multiplier on the path segment distance, D_i.

The product D_iC_i is defined as the "effective" distance, De_i, of a path segment. This definition is shown as equation {6}:

$$De_i = D_iC_i \qquad \{6\}$$

Substituting De for DC in equation {5}:

$$Pd = \sum_{i=1}^{n} De_i/D \qquad \{7\}$$

When appropriate values for C_i are established for building feature difficulties, the effective distance, De, in equation {7} can be established. Then, the relative difficulty of any path, Pd, through a building can be calculated.

CHAPTER 5

THE EVALUATION METHOD

One of the important difficulties in analyzing a fire attack is that it progresses at different rates at different locations on the attack path. In other words, the building "distorts" distance. For example, the effective distance of a locked door can be infinite if the door can not be opened. The effective distance may be established as De = $R_c T$ by determining the time to open the door and multiplying that time by the constant rate of travel in an unimpeded path. Travel path location delays also can make the path though spaces effectively longer.

The rate of progress along the attack path is related to the condition of the building, the fire, and the fire department at many points along the path. Therefore, it follows the effective distance, De, of equation {7} is also determined by the state the same three components. The remainder of this chapter describes a method for determining De for an attack path.

5.1 EQUIVALENT DISTANCE

This thesis develops an evaluation process where the time to move along any specific fire attack path is evaluated, and the influences of building, fire, and fire department factors are incorporated. This process computes an effective distance of travel. Assuming a constant rate of movement, the effective distance provides a measure of the realistic fire attack difficulty. The influence of factors is incorporated through a process of equivalence. When a factor causing a change in the rate of progress along an attack path is encountered, the factor is converted to an equivalent distance at the fictitious constant progress rate selected for the real non-fire distance.

5.2 ASSEMBLY MULTIPLIER

The rate that progress is made through a building is a function of the building assemblies encountered. Depending on the assembly there can be a wide variety of travel rates. This is why most individuals choose an elevator instead of a stairway to traverse vertical distance through a building.

Because the attack path evaluation method described here is built on equivalence, a base is needed to relate results to non-fire conditions. This base has been selected as a corridor. All assemblies of space-barrier on an attack path are made equivalent to travel along a corridor. The corridor is selected as the nominal base because the rate of travel along a corridor can be considered constant. Stairways cause fatigue. Elevators change speed. Rooms can disorient or delay for many reasons. Tables of assembly multipliers, A, can be developed considering the space-barrier factors influencing movement and used in the following equivalence equation:

$$De = DA \qquad \{8\}$$

Where: De = effective distance of path

D = actual distance of path

A = assembly multiplier

5.2.1 MULTIPLIER FOR A SPACE

The most important characteristic about a multiplier for a space is the type of space being traversed. Shafts and rooms have different factors that affect fire attack progress. However, corridors, being the equivalence base, have a space multiplier value of one.

There are only two types of shaft that are practical for use in an interior fire attack. They are the elevator and stairway. The two shaft types have a huge impact of vertical travel through a building, the impact is in different directions. Stairways lengthen distance; Elevators shorten distance. After climbing stairs for a length of time fatigue causes a decrease in the vertical travel rate. On the other hand, the longer the distance traveled by an elevator the greater the vertical rate of speed. In both cases, the multiplier, A, is a function of D, the actual distance traveled. Knowing the shaft type and D, the proper multiplier can be determined from Figure 7 or Figure 8. It may be noted that the factors have been selected to demonstrate the process. Realistic values must be developed by experimentation and observation.

Way finding time in rooms can be considerable. Rooms have the greatest ability of all space types to confuse. Generally, because of limited options corridors and shafts provide a direct and clearly delineated path of movement. On the other hand, rooms normally have more decision locations and therefore take longer to analyze. Room vary in size, shape, and number of openings. In addition, rooms are more likely than corridors and shafts to have contents forcing a detour from the most direct path through the space.

Finally, when a rooms are not part of the common area of the building, often there are times when they are unlighted. Taking the way finding considerations noted above into account becomes the basis for selecting values for A. Table 3 contains values for A based on the room factors mentioned above.

5.2.2 MULTIPLIER FOR A BARRIER

How long before a fire attack advances past a barrier depends on the door present in a barrier opening. But given the important door factors, there are only a relatively small number of combinations. A table containing the average time it takes to progress past any given combination can be developed. In keeping with the equivalence concept, the time to progress beyond a door is be converted to an equivalent distance to be traveled. Information in Table 4 illustrates assembly multipliers for doors. Finally, the distance, D, used in barrier calculations is defined as 1 foot.

5.2.3 ATTACK PATH DISTANCE LINE PLOT

The space-barrier arrangement encountered along the attack path can be displayed in the form of a number line. The line's origin is placed at the entry point to the building, and the space-barrier arrangements encountered along the attack path are represented as coordinates on the line. The distance along the attack path and the points graphed have a one-to-one correspondence. The display of the attack path in a distance line plot like that shown in Figure 6 clears the clutter. The line offers some insight into the difficulties in attacking a fire. The line easily displays the what is along an attack route. The three levels of the line represent the following: (1) the space-barriers along the attack path, (2) the environmental conditions, and (3) the status of the hose used.

Such a graph can be made from the building layout shown in Figure 5. The attack path is the wavy line. Figure 6 is the distance line of the path through the building. Table 2 contains the key for the symbols used in Figure 6.

The space-barriers encountered along an attack path are assigned identifying number. The first digit of the number represents the path number; the second digit, the story of the building; the third digit, the space-barrier number. With this numbering system; 314, for example, is the forth space-barrier encountered on the first floor along path number three. However, due to the simpleness of the building in Figure 5 sequential numbers are not used in the distance line plot of Figure 6.

5.2.4 ASSEMBLY MULTIPLIER EXAMPLE

The attack path shown in Figure 5 is displayed on a distance line in Figure 6. For an illustrative example consider space-barrier(s-b) number 7, which is the locked metal door from the stairway into the fourth floor corridor; and s-b number 8, which is the 4th floor corridor. From Figure 5, D_8 equals 30 ft, and since number 7 is a barrier by definition D_8 equals 1 ft. By definition A for a corridor equals 1. The door for this case will be opened with a key. From Table 4, A equals 50. inserting these values in equation 2 gives the following:

$$De_i = D_iA_i$$

$$De_7 = 1\ ft(50) = 50\ ft$$

$$De_8 = 30\ ft(1) = 30\ ft$$

This illustrative procedure must be done for each space and barrier link along the path.

5.3 TENABILITY

The equivalence concept of the previous section can be carried further to include an "tenability multiplier". This multiplier is needed because some of the fire attack path will pass though the smoke and heat conditions near the fire. Usually, the products of combustion spread by a fire make everything take longer. Again, introducing the concept of equivalence, a travel distance through combustion products is converted to a travel distance of travel in clear non-fire conditions. The distance equivalence of equation 8 then becomes:

$$De = DAT \qquad \{9\}$$

Where:
D = distance of path
A = assembly multiplier
T = tenability multiplier

To apply Equation 9, the environmental conditions for every D_i along the attack path must be determined. If conditions throughout the space are considered uniform, which is a reasonable assumption for smoke-gas spread, then the tenability of the entire space can be evaluated at once. However, there is nothing to prevent the creation of "virtual" barriers along the path and assigning different conditions for each "new" space on either side of the barrier. Virtual barriers are defined to have a distance, D, equal to zero.

Two indirect method, each working in opposite directions along the attack path, are used to evaluate the smoke/heat conditions. Both methods assign a environmental condition number between zero and ten. Zero indicates clear non-fire conditions, and ten indicated heat-flame conditions.

Determining conditions by working from the fire back along the path is relates to the building assembly. As barriers and spaces are encountered, adjustments are made for the expected improvement in smoke and heat conditions.

When looking at conditions from the opposite direction (i.e. moving toward the fire), the condition value is made from a firefighters viewpoint. Predicting how firefighters will operate in a space will allow an assessment of heat-smoke conditions. Table 5 illustrates the form that the conversion table could take.

After the conditions are determined, they must be related to a tenability multiplier. The multiplier, T, will have a value of 1.0 when no combustion products are present. Table 5 and Figure 9 have been included in the appendix to illustrate representative values for T. Table 4 is used to determine the smoke and heat conditions and assigns an environment value. Figure 5 equates the conditions to the tenability multiplier, T, of Equation 9.

Because the fire attack progress will pause when SCBA use begins, the point where this event occurs must be determined. The pause is caused by the time needed by firefighters to put on and adjust the SCBA facepiece. This point is incorporated as a feature in the attack path analysis, and it is assigned a distance equivalence of 100. That is, the product, DAT, is defined as 100 where SCBA use begins.

5.3.1 TENABILITY EXAMPLE

An example including tenability can be developed using the same door and corridor of the assembly multiplier example in Section 5.2.3. It seem reasonable to expect the conditions in the stairwell to be clear. A firefighter moving through the corridor could be anticipated to be using SCBA while crawling under a two-layer fire environment.

Using space/barrier number 7, which is the door to the fourth floor corridor in Figure 5:

$D_7 = 1$ ft (by definition)

$A_7 = 50$ (see section 3.1.3)

$E_7 = 0$ (clear conditions)

$T_7 = 1.0$ (from Figure 9)

$De_7 = D_7 A_7 T_7$ (equation 3)

$De_7 = 1.0 \text{ ft}(50)(1.0) = 50 \text{ ft}$

Thus, the door opened with a key is equivalent to 50 ft of corridor travel.

Considering space-barrier number 8 in Figure 5, which is the fourth floor corridor, yields

$D_8 = 30$ ft (from Figure 5)

$A_8 = 1.0$ (see section 3.1.3)

$E_8 = 6$ (from Table 5)

$T_8 = 1.9$ (from Figure 9)

$De_8 = D_8 A_8 T_8$ (equation 3)

$De_8 = 30 \text{ ft}(1.0)(1.9) = 57 \text{ ft}$

Therefore, traversing 30 feet of smoke filled corridor is equivalent to traversing a 57 feet of clear corridor.

5.4 HOSE LINES

While reaching the fire is the goal of the fire attack, the primary work of any attack is the laying of a hose line. The hose lines transfer water from a water source to the fire location, only a locked door slows a fire attack more than the work of laying a hose line. An easy hose lay does much to quicken the attack.

5.4.1 HOSE FACTOR

For the evaluation process outlined here, hose is categorized by location. All hose between the nozzle and the previous control point (valve or shut off) is referred to as the attack hose. Any hose between the water source and the last control point before the nozzle is the supply hose. Given these hose definitions, a fire attack need not have supply hose. If the water source is the fire apparatus tank or a building standpipe, there is only one control point between the source and nozzle.

Only hose laid down along the attack path is considered here. The influences from transporting hose from the arrival area to an attack launch point is factored into the attack manpower evaluation. In addition, it is assumed the hose advanced along the attack path is of adequate length.

Developing a hose equivalence factor has difficulty not found in the other components considered up to this time. The work of advancing a hose along a path is not constant. When firefighters are crawling down a smoke filled corridor, their crawling rate can be considered constant. Yet, when a hose line is being advanced down a corridor, the work gets harder as they go, which slows the advance. In general, 200 to 250 feet is considered the practical maximum length for an attack line. But distance is not the only influence on hose lines.

Each time an attack line turns a corner, advancement becomes more difficult. An attack line making two turns becomes immobile. To continue the advance, someone must be placed between the turns to ease the hose along.

Hose, as it is advanced along the attack path, can have the following states: dry, charged with water, flowing water. The work of advancing a hose line is related to its state, as well as its diameter.

The hose line effort, h, becomes a function of the work done to move hose. The work is a function of the amount of hose being advanced, the hose diameter, and the hose state.

Since the amount of hose being advanced changes across any evaluation distance it must be evaluated at the beginning and the end of the distance of interest.

$$h = f(l,d,s) \tag{10}$$

Where:

l = current length of hose line
d = diameter of hose line
s = state of hose line

Knowing l, d, s, the line effort, h, can be determined from Figure 10, Figure 11, or Figure 12 when d = 1 3/4-inch

The hose distance factor, H, for a space is evaluated across D. The hose distance factor for a barrier need not calculated. The point where hose use begins is assigned a hose distance value of 300. This value incorporates the effort in setting-up the hose line prior to any advance of the hose. Therefore, the hose distance factor as the line is moved through a space is calculated through equation {11}:

$$H = h(l_o) - h(l_i) \ . \tag{11}$$

Where:
h = hose effort
l_o = length of hose as it exits feature
l_i = length of hose as it enters feature

The hose effort is added for any bends in the hose line as the hose line is advanced along the path. The effort is included by adding 50 feet to l^i at the point the turn occurs. The additional 50 feet is carried through the remaining the evaluation segments.

Combining equations {9} and {11} gives the following:

$$De = DAT + H \qquad \{12\}$$

Equation {12} considers the influence of building, fire, and hose line as they relate to a fire attack.

5.4.2 HOSE EXAMPLE

Again using s/b number 8 from Figure 5 , the fourth floor corridor. Assuming a charged 1 3/4-inch line will be advanced along the corridor. The value for H can be found as follows:

$li = 0$ (from Figure 5)

$h(li) = 5$ (from Figure 11)

$lo = 30$ (from Figure 5)

$h(lo) = 10$ (from Figure 11)

$H = 10 - 5 = 5$, ft (equation 11)

It can be seen from the result, that initially the effort to advance the hose line is not a major factor, However, as more hose is required the hose factor becomes a major influence in the effective distance value.

5.5 EFFECTIVENESS

Every fire department has different capabilities. A fire which challenges one fire department may be routine to another. To be complete, the evaluation of manual suppression for a building must consider the effectiveness of the local fire department. The department's resources and skill determine the effectiveness of the department. Resources are manpower, water, and equipment. Skill is founded on experience, training, and leadership.

The value of De calculated for a particular space or barrier situation requires adjustment for the effectiveness of the fire department that ultimately responds to the fire. When fire department effectiveness is factored into equation {12} it gives the following:

$$De = (DAT + H)RS \qquad \{13\}$$

Where: R = resource multiplier

S = skill multiplier

A great deal of work will be needed to establish a process for determining a "total" effectiveness value for a fire department. For the purposes of this thesis a effectiveness value for illustrative purposes is developed, and considerations for the components are discussed. Manpower is selrcted to illustrate the evaluation framework because it is felt to have the greatest impact on firefighting efficiency.

5.5.1 RESOURCES

Lack of adequate resources could stop a fire attack before is starts. However, a resource deficiency normally just serves to produce a less effective, more time consuming attack. A less effective attack decreases the chance of quick extinguishment.

Resources can be divided into three categories:

Water
Equipment
Manpower

Even though three categories of resource are described, they can be reduced to manpower. .The water and equipment resources are a function of manpower. Tools and hose lines do not move without manpower.

Manpower is consumed as the attack is made. A fire attack can begin with more firefighters than available work, but they are used up as the advance is made along the attack path. This means manpower must be evaluated continuously along the attack path. At each point along the attack path there is a manpower ratio, M, defined as:

$$M = M_a / M_u \tag{14}$$

Where: M_a = manpower available

M_u = manpower used

The value of M is used with Figure 13 to determine an resource multiplier, R. M_a is set by the fire department response. M_u is evaluated by considering the tools, hose, water control points used so far in the attack. Table 6 illustrates a method for assigning M_u

5.5.2 SKILL

Every fire department has a certain level of proficiency or skill. The skill level is determined by the experience, training, and leadership of the department.

Fire experience is vital to the rapid set-up and execution of a fire attack. A fire department's experience can be developed by considering three functions. Over a defined time period, the number of fires per firefighter in similar occupancy and similar construction.

Training is an component of the skill level of a fire department. Training can come from several sources and occurs at several levels within a fire department. Quality of the training is as important as the quantity.

Regular training should be done at all levels in the organization. Training can and should occur at the individual, company, and divisional levels.

Training instructors may be assigned to suppression forces or they may have only training duties. However, it is important for a department to receive instruction from outside its jurisdiction. This is the best way for new ideas to be introduced.

The quality of the command officers plays an important role in the effectiveness of a fire department. The apparent ease with which the command officers carry out their responsibilities says much about a fire department.

The discipline level in a fire department should also be considered. Just because a fire department has standardoperating-procedures in a file cabinet does not mean they are used.

5.5.3 EFFECTIVENESS EXAMPLE

For purposes of illustration the example will consider only manpower influences on effectiveness. As in previous examples the building layout and attack path shown in Figure 5 will be used. It will be assumed one piece of fire apparatus with three men are available to make the attack.

A examination of the attack path and the manpower requirement values in Table 6 results in the following manpower used:

Standpipe valve	1
100 ft of 1 3/4 hose	1
Force entry to corridor	1
Total	3

From the above information:

$Ma/Mu = 4/3$ (equation 14)

$R = 1.00$ (Table 6)

In this example there is an "excess" of manpower at this point in the attack. Therefore, the value for R does not change the effective distance.

CHAPTER SIX

ILLUSTRATIVE EXAMPLE OF EVALUATION METHOD

An evaluation is completed in three steps: (1) the builsing design is examined for the attack paths to the fire space, (2) building, fire, and fire department features along the attack paths are developed, and (3) the equivalence values and multipliers are used to calculate the effective distance for each space and barrier along the paths. Because the purpose of this example is to demonstrate the evaluation framework, a detailed calculation process is not shown.

A four story office building that is 100 feet by 300 feet will be used in an illustrative example of the evaluation method developed in this thesis. Figures 14 and 15 show the show the lobby and 4-th floor plans of the building to be evaluated. An office space on the 4-th floor will be selected as the fire space..

Assumptions about the fire incident are as follows:

(1) The response was initiated by an automatic alarm.

(2) The fire department response is one engine company with four firefighters.

(3) There are no building occupants.

(4) Upon arrival smoke can be seen in the lobby atrium.

(5) The water supply will be a wet standpipe located in the stairwell.

Three attack paths are indicted in Figures 14 and 15. Information related to the three paths, which is taken from the plans or is developed by making judgements about the building, fire, or fire department factors, is listed in Tables 7 through 9. The values developed for the path evaluation are shown in the upper portions of Tables 10 through 12. In addition, a distance line plot of path-2 is shown in Figure 16.

The three paths are evaluated using the equations and definitions described in chapter 5. The tables and figures in the appendix are used to determine the equivalence values and multipliers. The effective distance for each path segment listed in Tables 7 through 9 is contained in Tables 10 through 12.

Graphing the path segment distances, D_i, and the path segment effective distances, De_i, is a convenient way to show path difficulty. Figures 17 through 21 are graphs of this type. The distance shown by the graph is cumulative. The path difficulty value is the indicated by the ratio of De and D for the last feature on the graph.

Figures 17 through 19 are graphs the effective distances of the three paths to the selected fire space. By comparing the difficulty values it can be seen that path-1 is the best choice for the fire department to make. However, a look at the plans suggests path-2 will be the first choice for the fire department. Path-2 has access to the upper floor from the lobby space. It is doubtful that firefighters, without some additional direction, would travel to the stairway used by path-1.

If path-2 will be the first choice of firefighters can anything be done to make the path less difficult? When the middle stairway door is moved to the long corridor, and the alternative path is evaluated, the path difficulty value is less. The path-2 alternative is shown in Figure 20. The effective distance of the alternative is less for two reasons. The actual path is slightly shorter, and there is one less bend in the hose.

Another way to make path-2 less difficult is to make available additional manpower. Figure 21 shows path-2 effective distances with available manpower, M_a, from three to five firefighters. The effective distance lines show the influence of the additional manpower.

CHAPTER 7

FUTURE WORK

The proposed evaluation framework lacks both quantification and validation. In addition, the path selection process needs a way to assign path selection probabilities. Furthermore, the framework will require modification to address a wider range of fire situations.

The evaluation framework developed in Chapter 5 permits a comparison of various paths the fire department could take to a fire in a building. However, the question of which path would be taken remains. The path decisions are made on the basis of what is known about the location on the fire, and what is known about the building. Moreover, what is known about the fire and building will change as the fire attack is made. A path selection process needs to be integrated with the path difficulty evaluation.

The values used in the evaluation process description are illustrative. Realistic values need to be developed through experimentation and observation. When developed, the realistic values can be validated through a comparison with actual fires. Manual suppression time lines can be developed from recordings of radio transmissions from actual building fires. Then the radio transmission time line can be compared with an effective distance evaluation made on the actual attack path.

Finally, the evaluation method needs to be expanded to address larger fires. The larger fires introduce the more complex situation when water application and barriers are being used to gain control of a fire.

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APPENDIX A

FIRE SITUATION SIZE UP FACTORS

LIFE HAZARD

OCCUPANCY

CONSTRUCTION

HEIGHT

AREA

LOCATION OF FIRE

EXTENT OF FIRE

MANPOWER & EQUIPMENT

WATER SUPPLY

WEATHER CONDITIONS

TIME OF DAY

Table 1

DISTANCE LINE SYMBOL KEY

SYMBOL	FEATURE
B	SCBA Use
C	Corridor
D	Door
E	Elevator
H	Hose use
R	Room
S	Stairs
T	Turn
¦	Virtual Barrier

Table 2

ASSEMBLY MULTIPLIER FOR A ROOM, A

DESCRIPTION	A
> 50% OF FLOOR AREA OPEN	
EXIT PATH VISIBLE	
1 OPENING	1.0
> 1 OPENING	1.1
EXIT PATH NOT VISIBLE	
1 OPENING	1.2
> 1 OPENING	1.3
<= 50% OF FLOOR AREA OPEN	
EXIT PATH VISIBLE	
1 OPENING	1.4
> 1 OPENING	1.5
EXIT PATH NOT VISIBLE	
1 OPENING	1.6
> 1 OPENING	1.7

Table 3

ASSEMBLY MULTIPLIER FOR A BARRIER, A

DESCRIPTION	A
BARRIER	
OPEN	0
CLOSED	
UNLOCKED	20
LOCKED	
OPENED WITH KEY	50
FORCED	
GLASS	
IMPACT	75
PRY	150
WOOD	
IMPACT	100
PRY	
MANUAL	150
POWER	100
METAL	
IMPACT	300
PRY	
MANUAL	200
POWER	100

Table 4

ENVIRONMENT FACTOR, E

From firefighter viewpoint

SITUATION	FACTOR
SCBA in use	2
Crawling (under smoke layer)	2
Creeping (due to heat)	4
Visibility obscured	4

Sum factor values

From building viewpoint

Intact barrier	4
Failed barrier	4
Space	2

Subtract factor values from 10

Table 5

MANPOWER USED, Mu

USE	M
Water Control Point	1
100 Feet of 1 3/4-inch Hose	1
Force Entry	1
90 Degree Turn in Hose	1

Table 6