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iFAST: An Intelligent Fire-Threat Assessment and Size-Up Technology for First Responders

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*i*FAST: AN INTELLIGENT FIRE-THREAT ASSESSMENT AND SIZE-UP TECHNOLOGY FOR FIRST RESPONDERS

by

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Abstract

Currently, emergency response agencies use simplified "one-size-fits-all" procedures to decide what quantity and type of resources to dispatch to each fire threat. These procedures are based on principles established decades ago, and are generally static in nature. They then rely on the judgment of the experienced officer who has arrived on-scene to make a dynamic evaluation and request additional units if appropriate. In this thesis, we propose a fuzzy expert system to enhance the assessment procedures. *i*FAST is shown to reduce the dispatch time (usually between eight to sixteen minutes) to less than 30 seconds; hence saving lives while reducing costs and property loss. The intent of the proposed system is to allow the emergency response agencies to perform the majority of the "initial-size-up" analysis in less than thirty seconds after a fire emergency report. Our system will outline the decisions in regards to the adequate resources required to be sent to the incident at the given time, as opposed to having to wait until the first experienced officer has arrived on-scene.

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Moncton Fire Department
Orillia Fire Department
Oshawa Fire Department
Pickering Fire Department
Saint John's Regional Fire Department
Saint Albert Fire Department
Sault Ste. Marie Fire Department

Much appreciation and gratitude goes to my loving family - my mom, dad, and twin sister - for their unlimited and continuous support, love, care, encouragement and understanding. I owe this work to them for giving me every possible opportunity to pursue my wildest dreams.

Dedication

To my loving mom, an angel on earth,
to my supporting dad, a true inspiration, and
to my caring twin sister, my better half.

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List of Acronyms

DSS	Decision-Support System
EMYCIN	Empty MYCIN
ENS	Emergency Notification System
ERIS	Emergency Response Information System
EWS	Effective Wind Speed
FAC-AAA	Fire and Emergency Service Organization and Deployment Career
FES	Fuzzy Expert System
FIFO	First In First Out
FRBS	Fuzzy Rule-Based System
GPM	Gallon per Minute
*i*FAST	Intelligent Fire-threat Assessment and Size-up Technology
JESS	Java Expert System Shell
KBS	Knowledge-Based System
k/h	kilometre per hour
LIFO	Last In First Out
NFF	Needed Fire Flow
NFPA	National Fire Protection Association
NRC	National Research Council of Canada
OFM	Ontario Fire Marshal
PSI	Pounds per square inch
SD	Separation Distance
TSK	Takagi-Sugeno-Kang
WCI	Worker's Compensation Insurance

Chapter 1.

Introduction

THIS thesis investigates and describes the design and development of a knowledge-based fire threat assessment fuzzy expert system for first responders. *i*FAST (Intelligent Fire-threat Assessment and Size-up Technology) is our proposed fuzzy expert system that is designed to enhance and accelerate the existing emergency resource dispatch and size-up methodologies in terms of reducing the dispatch time and improving the emergency resource management. This fuzzy expert system will be embedded in a larger call-handling and dispatch system, which is currently in use by over 125 agencies serving almost 4 million Canadians in more than 200 communities.

This introductory chapter explains the operation of fire threat assessment, followed by a description on the underlying motivations of this research. Afterwards, brief explanations on the employed methodologies are presented and the objectives of this thesis are described. Finally, a summary of the thesis contents are outlined.

1.1 Operation of Fire Threat Assessment

Presently, emergency response agencies such as the police, fire-rescue departments, ambulance services, and disaster preparedness offices perform a simplified one-size-fits-all procedure. As a result, a predefined number and type of emergency resources are sent to the incident regardless of the size and type of the constructions that they are going to face. The size-up procedure is based on a series of codes and principles that were established and standardized using existing emergency cases by experienced fire chiefs. As a result, a collective set of decisions and rules were determined decades ago. These rules now influence the core decision-making process in determining the dispatch and size-up procedures of an incident.

Additionally, these principles are static in nature and are mostly decided based on a number of events (primarily in the residential areas). Therefore, there is not enough strong reasoning behind these codes and standards. These decisions are derived from an accumulated set of evaluations made by the experienced chiefs and firefighters for a specific situation. Although these principles are derived based on a large number of events, they cannot handle specific unforeseen cases. For instance, in incidents where larger structures – such as schools, factories, warehouses, etc. – are involved, additional precautionary steps and special attention is required, yet the same fixed and predefined number of emergency machineries and equipment are dispatched. Consequently, due to lack of precision and accuracy of such procedure, an experienced officer is sent to the scene to make a more dynamic evaluation, in addition to the static one-size-fits-all quantity and types of resources.

Not only these standards were established decades ago, but also they are only based on residential structures. Thus, dispatching the predefined fixed number of resources to a larger structure can be dangerous and threatening to the lives of the people involved and hazardous to the properties.

More importantly, it takes four to eight minutes for the first set of resources and the fire officer to arrive on-scene. If the first officer, who is the chief officer in command, requests for more units (personnel and/or equipment), an additional four to eight minutes needs to be added. Unfortunately, the intervening eight to sixteen minutes (called the response interval) can result in loss of lives, increased injuries and suffering, as well as a considerable loss of property.

Furthermore, in some situations, scarce resources that could be engaged elsewhere can be over-committed based on the one-size-fits-all procedure.

1.2 Motivation

While means to assess and manage fire threats presently exist, a review of the existing practices as stated here indicates that an accurate assessment and size-up of resources are still lacking.

Significant attention has been made to static definition of principles and guidelines for fire threat assessment, while they have been proved to be unable to deal with all fire scenarios, especially with uncertainty of unforeseen events.

At the same time, fuzzy expert systems have a number of attributes and properties that makes them appealing for the existing problem at hand. These include their ability to deal with uncertain and incomplete information, ability to expand/shrink gradually without changing the structure of the system, as well as their transparency and explanation capabilities.

All these factors together with expressed interest from local industry provided the impetus to design and develop an intelligent fire threat assessment and size-up fuzzy expert system.

The idea for this project was established when we (Ryerson University) were approached by industry personals from CriSys Ltd. (which has been a leader in communications software since 1990), regarding a possible project that can enhance the existing size-up and dispatch methodologies.

*i*FAST, is a Precarn[1] funded research project, and is a collaborative work between Ryerson University, CriSys Ltd., York University, and the Ontario Association of Fire Chiefs (as well as fifteen Canadian Fire-Rescue services).

Ryerson was in charge of system implementation and testing, while CriSys Ltd and the Ontario Association of Fire Chiefs provided the data and required information regarding the system analysis. York University was responsible of knowledge acquisition and system modeling. However, due to a strike that happened at York University [**1**], the university was closed for months. Therefore, not much work was done regarding the system analysis and modeling. Despite our time limitations, we were forced to perform the knowledge acquisition and the system modeling within a very short period of time.

It is important to further discuss and explore the need for an intelligent fuzzy expert system in addition to highlighting a number of existing problems and limitations in the fire emergency resource dispatch and size-up procedures.

[1] Precarn funds and coordinates collaborative research conducted by industry, university and government researchers. [**2**]

1.2.1 Need for fire threat assessment fuzzy expert systems

CriSys Ltd. is currently developing an emergency call handling and dispatch system called Xpert^{Fire}. In order to enhance their current system, and to overcome the existing problems, CriSys approached us to develop an intelligent fire threat assessment system in order to embed in their existing dispatch and size-up system.

According to a recent statistical report produced by CriSys Ltd., more than 20% of the fire emergencies requested additional equipment and personnel. This statistics were produced for both cities of Brantford and Sault Ste Marie, Ontario, Canada. Considering the number of people (injuries, trapped or fatalities) and the millions of dollars in property damage involved in each situation, these statistics indicate an alarming number of potential lives and property that could be in dire jeopardy.

Moreover, in situations where there are fatalities and/or injuries, or where considerable property damage has occurred, emergency response agencies are being sued for those losses and damages (particularly in the litigation-prone United States).

Therefore, using a one-size-fits-all procedure is to be replaced by a knowledge-driven size-up procedure based on the available factors. A knowledge-based fuzzy expert system can be argued to be the most promising solution to solve this issue. These systems can represent and handle different types of information, such as numerical, linguistic, empirical, graphical, tabular, and uncertain data. Using a KBS (Knowledge-Based System) not only provides facilities to use the available information beforehand due to its capabilities of handling linguistic values, but it also significantly reduces the dispatch and size-up time. This is accomplished by providing fast and robust decisions on the size-up and dispatch alternatives and hence saving lives and reducing costs.

1.2.2 Limitations of current dispatch systems

In this subsection, we explore the limitations of the current methodologies and procedures. These limitations and problems include one-size-fits-all procedure, high response time, direct and indirect costly outcomes, and finally inability to provide self-explanatory reasoning. In what follows, these issues are described in more detail.

1. One-size-fits-all procedure

   One of the disadvantages and problems of the current dispatch and size-up systems is the one-size-fits-all procedure. A fixed predefined set of emergency resources are sent to the incident, regardless of the size and height of the building, the distance of the incident from the surrounding exposure(s) and many more factors. This sole problem leads to many hazardous crises, which are described in the following points.

2. High response time

   A consequence of the on-scene size-up procedure is the inevitable extension of dispatch time. Depending on the number of requests made by the officer in command regarding the additional resources, the dispatch and response time increases. For instance, the final response time is 8 to 16 minutes when one additional request is made, and this time increases to 12 to 24 minutes when only two requests were sent to the closest emergency response agency.

3. Direct and indirect costly outcomes

The current dispatch and size-up systems generate a vast amount of direct and indirect costly outcomes and steps to reduce these costs were undermined. These costly outcomes are mainly the consequences of response interval. These costs are such as hundreds of lives, human resource productivity, healthcare, property damage and legal costs possibly as a result of lawsuits.

Being unable to provide decision support documents and due to the lack of reasoning behind the one-size-fits-all procedure, emergency response agencies are victims of lawsuits by the individuals who were suffered from the inappropriate response of these agencies. Annually, millions of dollars are being paid in North America by these agencies, solely because of acting upon the old and mainly based-on-previous-experience procedures and standards.

Use of a fuzzy expert system, thus, enhances these procedures and enables the emergency response agencies to not only provide systematic reasoning behind the size-up decisions that they have made, but also reduce the response time drastically. Subsequently, the massive costs caused by the mentioned direct and indirect reasons can be reduced.

4. Inability to provide self-explanatory reasoning

Fire fighters and in general the users of the dispatch and size-up systems will seldom have confidence in the results and decisions provided by the expert systems unless the expert system also provides a descriptive and well-reasoned explanation on how this system has reached its proposed solution.

One of the fundamental components of a fuzzy expert system is the explanation mechanism, by which a well-documented and satisfactory explanation is provided.

As stated earlier, emergency response agencies would benefit from this detailed and descriptive document by presenting it as a strong defence, instead of an unsatisfactory "that is our standard procedure" explanation to why a specific set of vehicles were dispatched.

1.3 Methodology

Our proposed intelligent system, called *i*FAST, is a fuzzy expert system, which attempts to enhance the emergency resource size-up methodologies. *i*FAST reduces the dispatch and size-up time significantly resulting in a vast amount of monetary savings.

Fuzzy expert systems are increasingly used these days to solve decision-making problems. These systems use fuzzy logic instead of classical Boolean logic. Most fuzzy expert systems provide parallel rule execution (rule firing) of current fireable rules [3]. This is an advantage when working with fuzzy sets. This advantage provides shorter run time and better performance, comparing with an equivalent sequential system.

The process of drawing conclusions from existing data is called inference; thus, one of the main components of a fuzzy expert system is the inference engine.

Written entirely in Oracle's Java™ language[2], by Ernest Friedman-Hill at Sandia National Laboratories, JESS (Java Expert Systems Shell) is a commonly used inference engine [**4**]. The following are a few advantages of JESS:

- JESS is small, light, and one of the fastest rule engines available,
- It has a number of features that support backward-chaining and working memory queries,
- JESS can directly manipulate and reason about Java objects,
- Its powerful scripting language offers access to all the Java APIs,
- JESS provides rule loop prevention methods,
- It uses an enhanced version of Rete[3] algorithm in order to process rules.

The proposed fuzzy expert system is developed using a combination of the Java programming language, JESS Version 7.1p2 in addition to the FuzzyJ Toolkit version 1.7. FuzzyJ Toolkit is utilized in order to implement fuzzy logic concepts and the fuzzy rules.

The NRC FuzzyJ Toolkit, introduced by the National Research Council of Canada's Institute for Information, is a set of Java classes. These classes provide the capabilities to handle the fuzzy concepts and reasoning [**5**].

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[2] Oracle acquired Sun on January 27th, 2010 [**6**].
[3] Rete is an efficient mechanism that deals with the difficult many-to-many matching problem [**7**].

1.4 Objective

The main objective of this thesis is to enhance the existing process of "on-scene size-up" and dispatch procedure while suggesting similar results to the final number and type of emergency resources by developing a knowledge-driven fuzzy expert system. Thus, by deploying such intelligent system a more efficient size-up and assessment procedure and emergency resource management can be achieved.

Moreover, the adequate amount of resources would arrive on scene after more than sixteen minutes – given the officer in command requests additional resources only once. The response time would dramatically increase if firefighters deal with disastrous fire emergencies; therefore, a further aim of this project is to decrease the emergency response time to less than 30 seconds by enhancing the dispatch and size-up methodologies.

As a result, using such intelligent system can save hundreds of lives per year. Additionally, embedding *i*FAST in the existing dispatch systems can prevent property damage caused as a result of inefficient dispatch procedures. Consequently, *i*FAST can affect economics with saving a large number of human resources and millions of dollars of property damage repairs per year. These costs include property damage, insurance issues, and lawsuits. Moreover, by mitigating injuries suffered in fires and accidents, millions of dollars are saved in healthcare costs.

Another advantage of such systems is that, for the first time, emergency response agencies are able to provide comprehensive listing of the factors and reasons that guide the decision to dispatch the resources sent. This would constitute a powerful defence in an "inadequate response" lawsuit.

1.5 Thesis Outline

This thesis is organized as follows.

Chapter 2 studies the background information on the Fuzzy Expert Systems, the advantages of such systems and a brief discussion on how these systems provide the emergency response agencies with ready-to-use and reliable information. Moreover, this chapter describes the existing emergency resource dispatch methodologies and a review of the literature related to activities to enhance and improve the existing methods.

An extensive evaluation and analysis of the system is provided in Chapter 3. Moreover, a number of points of incident assessment are explained in detail. These points are the important factors that are considered in the process of size-up and decision-making. They are used in order to mimic the thought process of the officer in command. We have proposed methodologies and algorithms in order to define, estimate, and calculate these factors.

In Chapter 4, we provide a detailed explanation on the development of the proposed Intelligent Fire-threat Assessment and Size-up Technology. Furthermore, we discuss the methodologies, technologies, and platforms that we used in developing such system. Afterwards, the underlying architecture and the process of development of *i*FAST are explained. This chapter also includes the experiments, testing procedure and the results of the proposed fuzzy expert system based on the existing data provided by the Ontario fire-rescue services and CriSys Ltd.

Finally, Chapter 5 presents the contribution of this work and directions for future work.

Chapter 2.

Background Information

IN this chapter, we first explain and provide background information on FES (Fuzzy Expert Systems). We introduce JESS (the Java Expert System Shell) and the FuzzyJ Toolkit. Afterwards we provide descriptions of fuzzy logic, fuzzy sets, fuzzy operators, fuzzy IF-THEN rule structure, inference mechanism and fuzzy rule-based models. Furthermore, the existing fire threat assessment and size-up methodologies are described. We then review and discuss the previous research on enhancing the existing methodologies. A review of the literature as related to the applications of intelligent systems for disaster and emergency response management is also presented.

2.1 Fuzzy Expert Systems

Expert systems are computer programs designed to mimic the thought process and to provide the skills of an expert to users – either experts or non-experts. It is usually preferable to consult a complicated situation with more than one human expert to be able to make the best decision. This can be done by expert systems by means of collecting and making use of the experiences and knowledge of a group of experts all at once. This represents one of many advantages of such systems. In addition, expert systems are able to make decisions as quickly as (if not faster than) a human expert, while handling and processing vast amount of knowledge and experience (Facts and Rules) [4]. Moreover, in cases where human thoughts, and mainly imprecise data, are to be modeled and being reasoned upon, using fuzzy expert system methodologies and techniques would lead to better solutions. In effect, an expert system is suitable for applications that are either too difficult to be solved using optimization methods or too complex to be solved with mathematical equations [8].

Fuzzy expert systems are expert systems that are based upon fuzzy logic, rather than the classical Boolean logic. These systems use fuzzy logic and generally fuzzy rules to reason, infer, and make decisions.

Among the many characteristics of FESs, parallel rule firing provides concurrent rule execution, which means all fireable rules will be fired effectively at one time. This gives FESs a number of advantages. A FES is not only faster, due to this characteristic, but also sequence independent. That is, unlike many sequential non-expert systems, rules are fired only if their conditions (antecedents) are met and not because of the sequential execution forces. However, there is a feature in FES which enables these systems with sequential execution where required.

Another advantage of expert systems over human experts is that unlike human experts, these systems are able to perform efficiently, 24 hours a day, 7 days a week, without any complaints. Additionally, fuzzy expert systems are proved to match or exceed the performance of the human experts in specific situations [9], [10], [11], [12] and [13].

There are two main types of FESs: Fuzzy process control and fuzzy reasoning [14]. Although both types use fuzzy sets, they are different in the methodologies that they are deploying.

1. Fuzzy process control

Fuzzy process control was first introduced by Mamdani [14] when he used a fuzzy system for controlling a cement plant [15]. As Figure 2-1 demonstrates, fuzzy process control systems consist of four main steps: Fuzzification, Inference, Combination, and Defuzzification.

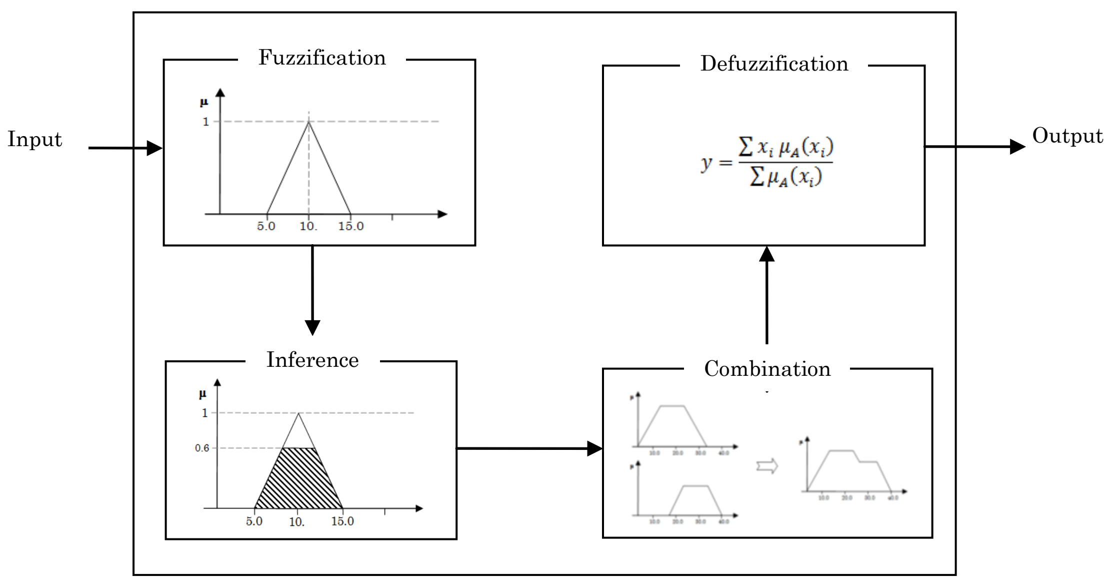


Figure 2-1 Fuzzy process control system

A brief explanation on these steps is as follows: These systems accept crisp and numeric values as their input, then convert these numeric values to fuzzy values, mostly linguistic values (e.g. near, OK, far, etc.) through the process of fuzzification. Afterwards, new fuzzy values are inferred from these fuzzy values through the rule firing process. This is performed by means of inference engines, such as JESS inference engine. Subsequently, fuzzy systems compose and combine these new values and through the combination process, produce fuzzy results. Finally, after the combination step, fuzzy values are converted to numeric values. This step is called defuzzification. Since in most real world applications only numeric values can be used, the defuzzification step is inevitable.

Therefore, fuzzy process control systems only accept numeric values as the input and produce numeric results as the output. The two steps of fuzzification and defuzzification add restrictions to fuzzy control system, since these steps are inevitable.

2. Fuzzy reasoning

Fuzzy reasoning, on the other hand, can deal with both numeric and linguistic values. The concept of linguistic variables was developed by Lotfi A. Zadeh [16].

As opposed to the fuzzy process control systems, the domain of fuzzy reasoning systems is not restricted to numeric values; hence, these systems are suitable for the human thought emulations. Moreover, the output values of these systems are not necessarily numeric, which enables these systems to perform in a similar fashion as human experts (e.g. IF the room is a little warm, THEN open the window a little).

2.1.1 JESS the Java Expert System Shell

Expert system shells are software systems that simplify the process of creating a knowledge base and provide a layer between the user interface and the computer operating system to manage the input and output data.

EMYCIN (Empty MYCIN [17], is the first expert system shell, which was designed by the developers of MYCIN [18].

Written entirely in Java by Ernest Friedman-Hill at Sandia National Laboratories in Livermore, Canada, JESS is an expert system shell, originally inspired by CLIPS expert system shell [3], but has grown into a more Java-influenced environment [4]. Similar to CLIPS, JESS has a Lisp-like syntax.

There are three different ways of knowledge representation embedded in JESS [4]:

- Rules, which are mainly designed for heuristic knowledge,
- Functions, which are designed for procedural knowledge,
- Object-oriented programming, which are also designed for procedural knowledge. Classes, encapsulations, message-handlers, abstraction, inheritance, and polymorphism, which are the features of object-oriented programming, are also supported.

2.1.2 FuzzyJ Toolkit

The NRC FuzzyJ Toolkit, introduced by the National Research Council of Canada's Institute for information, is a set of Java classes (nrc.fuzzy.* and nrc.fuzzy.jess.*) [19]. This toolkit is used for its capability of handling fuzzy concepts and reasoning abilities.

The FuzzyJ Toolkit consists of two Java packages: nrc.fuzzy and nrc.fuzzy.jess (or FuzzyJess). The first package (nrc.fuzzy) can be used alone in a pure Java environment in order to implement fuzzy concepts and to perform fuzzy reasoning. The second package (nrc.fuzzy.jess), on the other hand, consists of a number of JESS user functions and is an integration of JESS and nrc.fuzzy, while providing fuzzy reasoning in an expert system shell environment.

2.1.3 Fuzzy Logic

As opposed to the classical Boolean logic – which is based on the traditional set theory – fuzzy logic deals with vague, imprecise, and uncertain data [20]. Having this ability, fuzzy expert systems are widely used in classification, decision-making, modeling, and in general designing systems with ambiguous and uncertain data. The knowledge that the officer in command uses in the process of size-up decision making is mainly based on non-crisp and inaccurate data. Due to the linguistic information that the fire chiefs use in the process of on-scene size-up, FESs are one of the best ways to develop such system.

Fuzzy logic was first introduced in 1975 [21] and is formed based on the fuzzy set theory [22]. The idea of Fuzzy sets was established in 1964 by Professor Lotfi A. Zadeh [23] and formed the basis of fuzzy logic to solve the complex real-world problems.

Afterwards, the first industrial fuzzy logic application was developed by Blue Circle Cement and SIRA in 1976 [**23**].

Fuzzy logic based technologies use non-crisp fuzzy sets which do not have sharp and defined boundaries. These technologies are suitable for designing and implementing systems with uncertain and inexact knowledge and concepts.

2.1.4 Fuzzy Sets

Unlike the classical set theory, a fuzzy set is a set with a smooth boundary [**23**]. A set in a classical set theory has sharp, "black-and-white" membership concept. That is, an object either belongs to a set or does not. In contrary, fuzzy set theory has included "gray" to the black-and-white membership concept. This means, fuzzy sets are defined by non-crisp and fuzzy boundaries with a membership function that defines the degree of membership of each member. These fuzzy boundaries enables these systems to better model the imprecise and uncertain human thoughts [**24**].

However, classical sets can also be defined by modifying the membership function of the fuzzy sets to values of 0.0 and 1.0 only; therefore, classical set theory is a subset of the fuzzy set theory.

In addition to the fuzzy membership function, fuzzy sets can be associated with linguistic terms. This represents two major advantages [**23**]: (1) human Experts can easily express their knowledge, using plain linguistic terms and (2) this knowledge is simply comprehensive, which reduces the design and implementation expenses. This leads to a mutual understanding of the system between the system analysts and the experts.

Membership functions usually have simple and smooth shapes [25], such as Trapezoid, Triangle, Singleton, Gaussian, etc. We introduce only the membership functions that were used in the implementation of *i*FAST.

1. Triangle Membership Function:

   Triangle membership function is one of the most commonly used membership functions in practice. It is used to build fuzzy sets that have a triangle shape. This function has three parameters (assuming that the peak of this membership function is 1.0. Additional parameter is required otherwise.).

   The syntax of the triangle membership function, provided by FuzzyJ Toolkit, is as follows:

   TriangleFuzzySet (double leftBottom,
   double middleTop,
   double rightBottom)

   where leftBottom is the start of the curve at the left with a membership value of 0.0, middleTop is the middle point with a membership value of 1.0, and rightBottom is the end of the curve with a membership value of 0.0.

   As an example, the following function is plotted in Figure 2-2:

   TriangleFuzzySet (5.0, 10.0, 15.0)

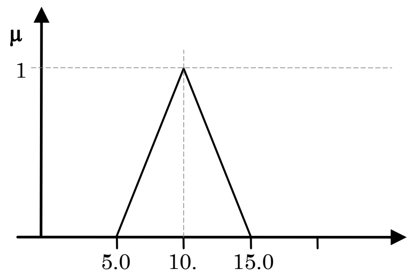


Figure 2-2 Triangle Membership Function

2. Trapezoid Membership Function:

Another most commonly used membership function is the trapezoid membership function. This function has four parameters (assuming that the peak membership function is 1.0. Additional parameter is required otherwise.), and is used to build fuzzy sets with a trapezoid shape. The main advantage of the triangle and trapezoid membership functions is their simplicity [**23**].

The syntax of the trapezoid membership function, which is provided by FuzzyJ Toolkit, is as follows:

TrapezoidFuzzySet (double zeroLeftX,
double oneLeftX,
double oneRightX,
double zeroRightX)

where zeroLeftX is the start of the curve at the left with a membership value of 0.0, oneLeftX is the end of the left upwards sloping line with a membership value of 1.0, oneRightX is the start of the right downwards sloping line with a membership value of 1.0, and zeroRightX is the end of the right downwards sloping line with a membership value of 0.0.

Figure 2-3 illustrates the following function:

TrapezoidFuzzySet (10.0, 20.0, 30.0, 40.0)

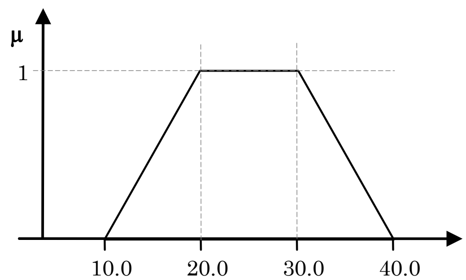


Figure 2-3 Trapezoid Membership Function

3. RFuzzySet and LFuzzySet Membership Functions:

RFuzzySet membership function is used to build specialized fuzzy sets that in general have membership values of 1.0 at the left edge and 0.0 at the right edge. The shape of the curve between the left and right values can be defined, by using a specific function such as RightLinearFunction. However, RightLinearFuzzySet, which is a subclass of this fuzzy set, is generally used when the curve between the two x values is a linear function.

LFuzzySet membership function on the other hand is used to build fuzzy sets with membership values of 1.0 at the right edge and 0.0 at the left. Similar to the RFuzzySet membership, LeftLinearFuzzySet is usually used when LeftLinearFunction is used to build the curve between the two x values.

The syntax of the RFuzzySet and LFuzzySet membership functions, which are provided by FuzzyJ Toolkit, are as follows:

RFuzzySet (double leftX,
double rightX,
nrc.fuzzy.FuzzySetFunction rightFunction)

where leftX is the x value where the membership is 1.0, rightX is the x value where the membership is 0.0, and rightFunction is the function that generates the shaped right side for the fuzzy set.

LFuzzySet (double leftX,
double rightX,
nrc.fuzzy.FuzzySetFunction leftFunction)

where leftX is the start of the curve at the left with a membership value of 0.0, rightX is the end of the curve where the membership is 1.0, and leftFunction is the function that generates the shaped left side for the fuzzy set.

The following two examples of the (a) RFuzzySet and (b) LFuzzySet membership functions are demonstrated in Figure 2-4.

(a) RFuzzySet (2.0, 4.0, new RightLinearFunction())

(b) LFuzzySet (12.0, 15.0, new LefttLinearFunction())

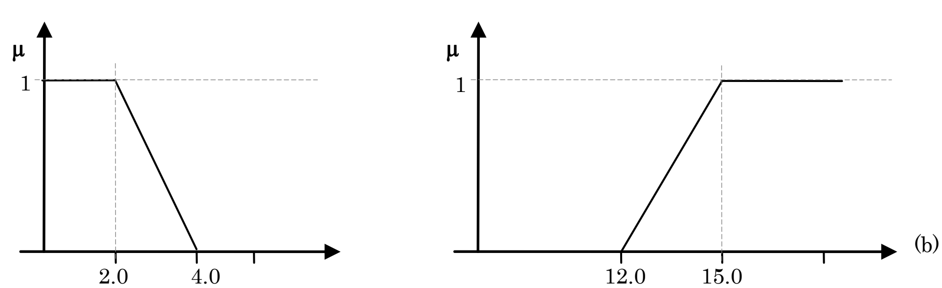


Figure 2-4 (a) RFuzzySet and (b) LFuzzySet Membership Functions

4. Singleton Membership Function:

The singleton membership function is used to build specialized fuzzy sets that have a single value with membership value of 1.0. It is a subset of triangle membership function where the left, middle, and right x values are the same. Singleton membership function is generally used when the output values are crisp. This membership function is used when implementing zero-order Takagi-Sugeno-Kang (TSK) rules. TSK rules have fuzzy inputs but constant and crisp output values.

The syntax of the singleton membership function, provided by FuzzyJ Toolkit, is as follows:

SingletonFuzzySet (double xValue)

Figure 2-5 demonstrates an example of this membership function:

SingletonFuzzySet (10.0)

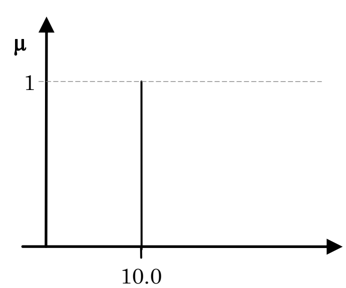


Figure 2-5 Singleton Membership Function

2.1.5 Fuzzy Operators

Union, intersection, and complement are the three basic operations in classical sets. Since objects of a fuzzy set are associated with membership degrees, these operations are generalized accordingly to consider the membership of the members as well.

The fuzzy set union, intersection, and complement operations are to some extend similar to the conjunction, disjunction, and negation in logic and the classical set theory.

1. Fuzzy set union operator

A common fuzzy union operator is defined the maximum operator; therefore, fuzzy union is the maximum membership of one object in both fuzzy sets and is defined as follows:

$$\mu_{A\cup B}(x) = \max\{\mu_A(x),\ \mu_B(x)\} \qquad \text{(Equation 1)}$$

Figure 2-6 illustrates this operation.

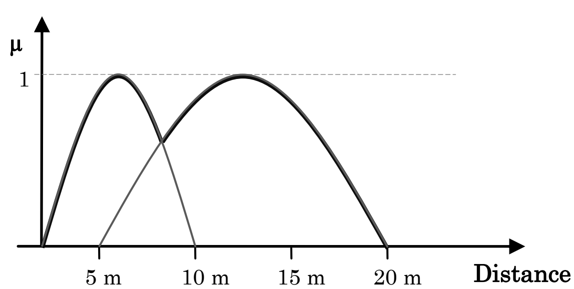


Figure 2-6 Fuzzy set union

2. Fuzzy set intersection operator

Fuzzy set intersection is defined the minimum membership value of one object in two fuzzy sets. Fuzzy intersection is defined as follows:

$$\mu_{A \cap B}(x) = \min\{\mu_A(x),\ \mu_B(x)\} \qquad \text{(Equation 2)}$$

It is illustrated in Figure 2-7.

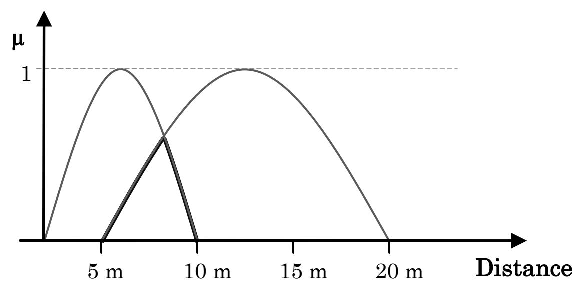


Figure 2-7 Fuzzy set intersection

3. Fuzzy set complement operator

The fuzzy set complement operator returns the difference between 1 and the membership of each member. Fuzzy set complement is defined as follows:

$$\mu_{A^c}(x) = \mu_{\bar{A}}(x) = 1 - \mu_A(x) \qquad \text{(Equation 3)}$$

This operator is demonstrated in Figure 2-8.

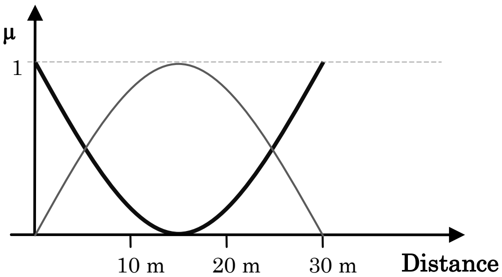


Figure 2-8 Fuzzy set complement

There are however, a few differences between the nature of these operators in classical set theory and fuzzy set theory. For instance, unlike the traditional set theory, laws of contradiction and excluded middle are not necessarily valid in fuzzy set theory.

(a) $\mu_{A \cup \bar{A}}(x) = \max\{\mu_A(x),\ \mu_{\bar{A}}(x)\} \neq U$ (Equation 4 - a)

(b) $\mu_{A \cap \bar{A}}(x) = \min\{\mu_A(x),\ \mu_{\bar{A}}(x)\} \neq \emptyset$ (Equation 4 - b)

2.1.6 Fuzzy IF-THEN Rule Structure

As Anderson indicated in [**26**], much of the human thoughts can be expressed in the form of rules; however, there are ambiguities and uncertainties when it comes to the human thoughts. In order to handle the vagueness and imprecision of human thoughts, fuzzy systems techniques are used.

Fuzzy rules are the basic elements of a fuzzy system and are used for capturing knowledge. A fuzzy rule consists of two main parts: the antecedent or the IF-part and the consequent or the THEN-part. The following is the structure of a fuzzy rule:

IF <antecedent> THEN <consequent>

The antecedent is the condition that when met, the consequent will be performed. As opposed to the non-fuzzy rules, the condition of a fuzzy rule can be satisfied to a degree rather than either satisfied or dissatisfied.

There are, on the other hand, three categories of fuzzy rule consequents [**23**]:

1. Crisp consequent (e.g. *IF <antecedent> THEN* $y = a$)
2. Fuzzy consequent (e.g. *IF <antecedent> THEN* $y = A$; where A is a fuzzy set)
3. Functional consequent (e.g. *IF* x_1 *is* A_1 *AND … * x_n *is* A_n *THEN* $y = a_0 + \sum_{i=1}^{n} x_i \times a_i$; where $a_0, a_1, \ldots, a_n$ are constants)

In general, fuzzy rules with a crisp consequent are more efficient, where fuzzy rules with fuzzy consequents are more comprehensive [**23**].

2.1.7 Fuzzy Rule-based Inference Mechanism

The mechanism of fuzzy rule-based inference consists of three main steps and two optional steps. These steps are described below.

1. Fuzzification (Optional)

   Fuzzification, which is an optional step of the fuzzy rule-based inference mechanism, is the process of mapping the crisp numeric values into fuzzy sets. To fuzzify the numeric values, there are two generally used fuzzy sets: (1) Singleton fuzzy sets and (2) Triangle fuzzy sets. Other fuzzy sets can also be deployed to fuzzify the crisp values.

2. Fuzzy matching

In the fuzzy matching step, the degree to which the input data matches the condition of the fuzzy rules is calculated. For instance, Figure 2-9 illustrates the fuzzy matching step for the case of input target distance *d = 9m*. The degree, to which this input target satisfies the following rule, is 0.6.

IF the target distance d is near, THEN <consequent>

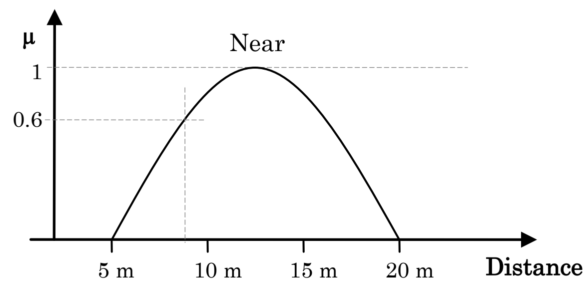


Figure 2-9 Fuzzy matching example

3. Inference

In this step the relevant rules' conclusions, based on the matching degrees, are calculated. In other words, based on the rule's matching degree, the consequent fuzzy set is either clipped or scaled. Figure 2-10 demonstrated these two methods: (1) the clipping method and (2) the scaling method. As it is displayed in this figure, the fuzzy consequent set, which is a triangle fuzzy set, is clipped and scaled according to the matching degree of 0.6.

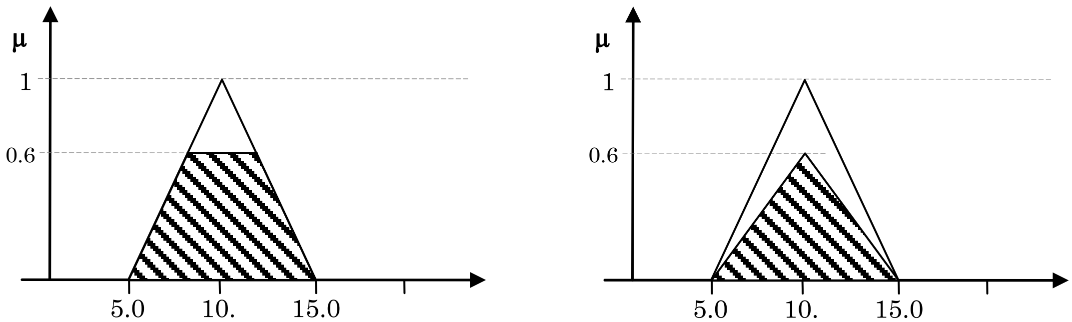


Figure 2-10 Examples of two inference methods: (a) Clipping and (b) Scaling

4. Combination

The combination step combines the conclusion fuzzy sets into a single result fuzzy set. This step is required due to the fact that often more than one fuzzy rule is triggered and fired; therefore, more than one conclusion fuzzy set is inferred for a fuzzy variable. The combination is done typically by superimposing all the conclusion fuzzy sets to form the final fuzzy set.

Figure 2-11 demonstrates the combination of two clipped trapezoid fuzzy sets.

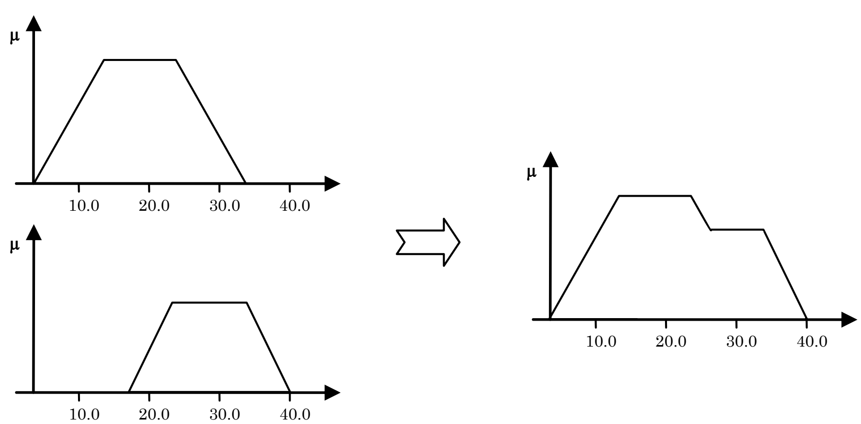


Figure 2-11 An example of fuzzy composition

5. Defuzzification (Optional)

Defuzzification step is an optional step in which a crisp output value is calculated. In many real world problems, a crisp and non-fuzzy value is required. For instance, an air conditioning device works with numeric values rather than linguistic values.

There are a number of defuzzification methods. The following is a list of a number of these methods:

- Maximum defuzzification
- Weighted average defuzzification
- Center of area defuzzification
- Bisector of area defuzzification
- Smallest of maximum defuzzification
- Largest of maximum defuzzification

2.1.8 Fuzzy Rule-based Models

A FRBS (Fuzzy Rule-Based System) is a rule-based system to which fuzzy logic is applied. According to [27] there are mainly two FRBS models: the Mamdani model [28] and the Takagi-Sugeno-Kang model [29]. Mamdani implemented a control fuzzy rule-based system [28] for the first time using Zadeh's fuzzy logic concept. About a decade after the introduction of Mamdani model, the TSK model was introduced by Takagi and Sugeno in 1984 [23]. Figure 2-12 demonstrates the basic structures of the TSK and Mamdani models.

The Mamdani model accepts numeric values and generates numeric results through the processes of fuzzification, inference, combination, and defuzzification.

The TSK model illustrated in Figure 2-12, on the other hand, accepts both numeric and fuzzy values as the input and calculates the output values using one of the defuzzification methods after the inference step. The weighted average and the maximum defuzzification methods are commonly used to defuzzify the output values.

The weighted average defuzzification, finds the weighted average of the x values, using the points that identify fuzzy sets and the membership values of these points. The following formula demonstrates the weighted average defuzzification calculations:

$$y = \frac{\sum x_i \, \mu_A(x_i)}{\sum \mu_A(x_i)} \qquad \text{(Equation 5)}$$

where x_i are the x values that define the fuzzy set A and $\mu_A(x_i)$ are the membership values of the relating points.

This defuzzification method is mainly used when the fuzzy set is a series of singleton values. The weighted average defuzzification method is therefore functional for TSK method.

Maximum defuzzification, on the other hand, finds the mean of the x values with maximum membership values. This is especially used when the goal is to find the x value at which the membership function value is the maximum.

Comparing the Mamdani and TSK methods, systems designed using Mamdani method are more interpretable and integration of the expert's thoughts and knowledge are easily done by means of its mechanisms, while systems deploying TSK method are more accurate and derive a set of more compact rules [30].

One of the advantages of TSK models over Mamdani models is that the TSK models require less number of rules to function. This is due to the replacement of the fuzzy sets in the right-hand side of the rules (the consequent part) with a linear equation of the input variables. This advantage is especially important for high-dimensional and complex problems, since as a result the knowledge base is reduced in size.

In general, a TSK rule has a form of the following:

$$\text{IF } x_1 \text{ is } A_{i1} \text{ AND } x_2 \text{ is } A_{i2} \text{ AND } \dots \text{ AND } x_n \text{ is } A_{in}$$

$$\text{THEN } y = f_i(x_1,\, x_2,\, x_n\,) = b_{i0} + b_{i1}x_1 + \dots + b_{in}x_n$$

where f_i is the linear equation and b_{ij} (j = 0, 1, …, n) are real-valued parameters.

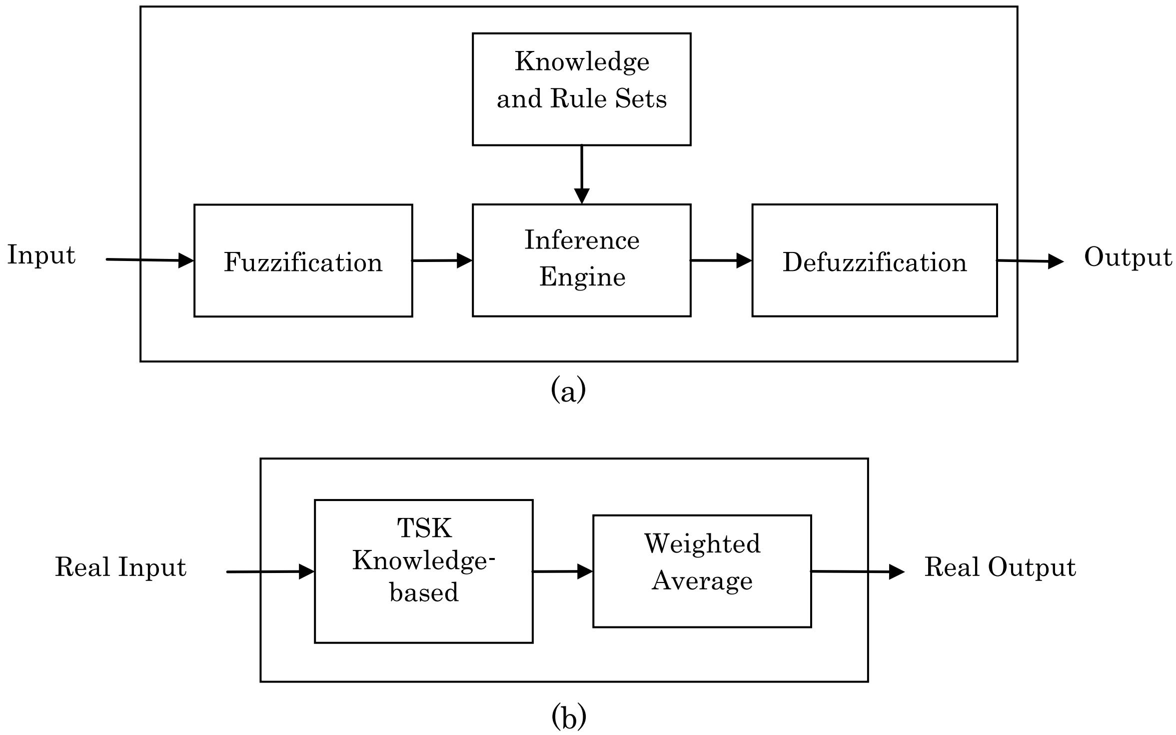


Figure 2-12 (a) Mamdani Model and (b) TSK Model [1]

2.2 Existing size-up methodologies

In this section, we introduce the current methodologies employed in the size-up process.

Emergency response agencies are required to react to a report of an emergency as quickly as possible. A series of procedures have been performed including selecting an appropriate quantity of resources of a given type of what they currently have available, and dispatching them to the incident as quickly as possible. The factors that involve in the process of size-up decision making are many, and mostly available. These factors are described in detail in Chapter 3.

Although the number and the types of the emergency resources depend on the mentioned factors, this information usually is not in a form that is amenable to rapid decision support to humans. Consequently, in spite of having these factors available, yet not in a proper form, a standardized one-size-fits-all procedure is being performed, by which a fixed number of resources are sent to the incident. An experienced officer is sent to the scene accompanying the first predefined default set of emergency resources, which remains the same regardless of the magnitude of the incident. Afterwards, based on the on-scene decision-making procedures, the chief officer in command, who is the first officer on the scene, will determine whether they require additional resources or if they should send the scarce units and personnel back.

This decision is made by observing and quantifying the same factors on-scene, which were available at the very first seconds of receiving the emergency phone call at the emergency response agency.

In addition, it usually takes more than four to eight minutes for the first set of emergency resources to arrive on scene. Requesting additional resources will add another four to eight minutes to this time. Within these eight to sixteen minutes and more, lives are in danger and millions of dollars are lost as a result of the damage that could have been prevented only if the right amount and types of resources were dispatched to the disaster at the first time.

As previously mentioned, the current size-up and dispatch methodologies are based on a one-size-fits-all on-scene procedure. The on-scene size-up methodology is mainly a consequence of the fixed and predefined number and type of resources that are sent to the event as a response to any emergency call. This default set of resources, which has now become a standard, is based on the previous experiences of a number of fire chiefs and lacks strong reasoning behind in a number of cases.

These standards are gathered by National Fire Protection Association and are established in a large number of documents such as NFPA 1710 [**31**] and NFPA 1720 [**32**].

NFPA 1710 is established for the organization and deployment of fire suppression operations, emergency medical operations, and special operations to the public by career fire departments. NFPA 1720 is a similar standard but is established for the volunteer fire departments.

The limited and insubstantial reasoning behind the rules and regulations is noticeable. These codes and standards are based on a response to a "standard" 1500 sq ft home – as stated by one of the editors and committee members of Fire and Emergency Service Organization and Deployment Career (FAC-AAA). FAC-AAA committee members are responsible for standardizing procedures.

Additionally, the existing dispatch systems are sequential software systems connected to static databases. Xpert^{Fire} is an example of a widely used and well-designed sequential software system that is being deployed since1990.

2.3 Literature review

Expert systems have been quite successful in the area of decision making and diagnosis. Fuzzy systems have widely been applied to control, classification, and modeling problems [33] and [34].

However, there are a few published works on the applications of expert systems in the field of emergency management.

Hernández and Serrano [35] considered emergency situations caused by flood and Tufekci [36] proposed a framework for a modular DSS (Decision-Support System) for hurricane emergency management. Jotshi et al. [37] developed a dispatching and routing emergency vehicle system in an earthquake scenario using data fusion.

Lemelson and Pedersen [38] investigated danger detection by surveillance platforms and explorations related to the field of emergency response systems. They used neural networks and fuzzy logic in order to detect danger and to transform danger signals to a control center.

Imriyas [39] proposed a fuzzy expert system based WCI (Worker's Compensation Insurance) premium-rating model in addition to establishment of risk control strategies for contractors and clients. They claimed that the implementation of such system in the insurance industry would curtail accidents in the construction industry.

Malizia et al. [40] proposed an ontology for risk management and emergency notification transmission to vulnerable groups of people in order to reduce the number of victims of emergency situations. In addition to this ontology EMS (Emergency

Notification System), there are a number of emergency notification systems which are included within ERIS (Emergency Response Information Systems). However, not many of these emergency notification systems consider accessibility principles [40]. Sahana, AlertFind, Arce, Command Caller, Rapid Reach, Sigame, and SWN are a few examples of emergency notification systems [40].

Michalowski et al. [41] proposed a decision-support framework for disaster managerial decision making based on the NEGOPLAN approach [42] and [43].

Kacprzyk and Yagek [44] presented a fuzzy expert system that responds to inquiries concerning emergency-like situations in the fashion of safety-first.

Hushon [45] investigated the need for expert systems to assist first responders in chemical emergencies. Additionally, a comparative study was presented on a number of existing expert systems that provide support in chemical emergencies.

Doheny and Fraser [46] described a decision modeling tool for the behaviours of victims of emergency situations in offshore environments. MOBEDIC, which is their proposed software tool, is designed to predict the movements and behaviours of different groups of people in emergency situations.

Barr et al. [47] investigated the ergonomics of firefighting. They studied effectiveness of different recovery methods and the safety of the firefighters.

Liu [48] introduced an agent-based environmental emergency management framework. It contains a resource discovery architecture in order to search and find the proper resources.

Uddin and Engi [49] demonstrated a prototype natural disaster management system for southwestern Indiana. However, they lack extensive data repositories for their applied tool to perform satisfactorily in a fully integrated disaster management system.

Chu et al. [50] proposed a DSS for natural disaster management and resource allocation in urban areas such as Hanoi in Vietnam. They developed a simulation platform in order to build an agent-based environment to be able to verify their disaster management model. They provided an example on the behaviours of ambulances during the simulated disaster.

As reviewed, there are many works done on disaster management and modeling, especially in the fields of natural disasters and routing; however, according to my knowledge, no work has been published to date, neither relating to the man-made fire emergency response systems nor regarding the enhancement of the existing resource size-up and dispatch procedures.

Chapter 3.

System Analysis

IN this chapter, we present and explain the points of incident assessment that build the basis of *i*FAST decision making model along with the solutions we obtained to gather, calculate and estimate these factors.

There are a number of main factors, based on which the experienced officer on-scene decides whether the resources are insufficient or excessive. These factors are the main focus when the officer is attempting to perform the incident assessment and size-up procedures.

A large number of these factors are retrievable and accessible by specifying the incident location (latitude and longitude), which may not necessarily be the location of the caller. Therefore, it is crucial to distinguish between the location of the caller and the incident while receiving the call. These factors include the size and the type of the incident building, the number and the type of the hydrants around it, its distance from the nearest exposure(s) such as a gas station, etc. Although a few of these factors are not highly accurate (e.g. the distance from the closest lake or swimming pool, or the weather conditions), these factors would provide sufficient information in order to make the closest decision to that of an expert officer on-scene.

The following subsections discuss a number of these factors in the approximate order in which the system would subsequently be aware of, while receiving an emergency call. Classifying and modeling these factors enables us with immense understanding of the architecture of the system that we are developing. These factors are described in detail in the following subsections.

3.1 Time and Date

This includes the "Time of day", "Day of week" and "Date or Time of year – holiday". The information regarding the time and date is all known as soon as the first ring of the phone.

1. Time of Day:

   This piece of information would aid the system to make reasonable inferences on the expected occupancy of the building, even when the detailed occupancy profiles are unknown (occupancy profile provides the number and age distribution of occupants by time-of-day and day-of-week, with optional date-based overrides). This inference is mainly based on the occupancy type of the building (i.e., Residential, Commercial, Industrial, etc.). An example for this is the difference between a fire incident at a school at 1:00 pm and 1:00 am. This can also give an indication of traffic levels, which will affect response time.

2. Day-of-Week:

   To make a more reasonable inference on the occupancy, it is important to know on what day of week the fire incident is happening. An example would be a fire incident at a school at 1:00 pm on a Tuesday and 1:00 pm on a Sunday.

3. Date (Time of year):

Some dates have special significance (holidays, for instance), some of which are universal (i.e. they apply to all types of occupancies) and some of which can be related to specific types of occupancies. In addition, the general date can be used to infer "typical" weather conditions. As an example, snow storms most often happen in winters and with a low probability in summers.

3.2 Approximate Weather

Weather information can play an important role in the process of size-up decision making. This can be accessible through weather forecast websites. The term "approximate" weather was used due to the fact that the weather is usually measured for a general geometric area, rather than the specific "at-the-scene" measurements. In addition, the weather might be unstable in the sense that it might change within the time of the emergency call and the time when the crew arrives on scene. However, approximate weather information can be used immediately to plan for the need for backup crew on-site. Fatigue becomes an issue when the emergency personnel operate in poor weather conditions. Therefore, extra number of personnel is typically required to compensate for the overall performance. Three main factors relating to the approximate weather are:

- Temperature (important for backup crew)
- Wind speed, wind direction (important for exposure factors)
- Humidity (important for backup crew)

3.3 Location

Location is an important factor from which a large number of facts can be inferred. These facts include the size of the building, occupancy data, construction type, the availability of the sprinkler systems, on-site resources such as pool or water tankers, etc. The caller location is retrieved between the first and the second phone ring through Ani/Ali[4] system.

There are a few problems relating to the incident location:

- The caller location is not always the incident location. However, since the caller location and the incident location are usually the same or close to each other, this location is still worth to begin with until changed.
- According to a retrieved statistic by CriSys Ltd., more than half of 911 calls are from cellular phones. Normally cellular phones are registered to a billing address, hence when a call is made from a cellular phone, it is difficult to locate the individual based on their billing address. However, there are two different methods that can be performed in order to retrieve the caller's location. Method one returns the address of the cellular phone tower that the caller's cellular phone is connected to. Method two, which has been used in the recent months, finds the closest three cellular phone towers and after calculating a triangular formula, it returns the co-ordinates of the caller and the strength of the signal that indicates the accuracy of the co-ordinates. This process can be considered to be difficult.

[4] Automatic Number Identifier / Automatic Location Identifier

Having the location of the incident allows us to be able to identify the street address. Knowing the street address of the incident enables us to gain a better understanding of the building in terms of the following information:

1. A number of the building data, which may include none, any, or all of:
    1) Occupancy profile,
    2) Occupancy type,
    3) Construction type,
    4) Size: area, height/number of floors,
    5) On-site resources, which include the detection or alarm systems, zoned or un-zoned heat/smoke/flame systems, and in-building suppression systems,
    6) Sprinkler systems,
    7) Standpipe systems,
    8) Specialized extinguishing systems (Halon, etc).
2. Knowing the latitude and longitude co-ordinates makes the following factors available:
    1) Water supply including the hydrant information such as location and the rated flow and other sources such as lakes, rivers, swimming pools, etc.),
    2) Exposures. The distance from the incident building and the exposure(s) can be calculated in two ways: (1) Implicit, which is the distance from the incident's latitude and longitude point to that of the nearest exposure(s). (2) Explicit, only if we have an understanding of the actual relationship between the incident and the exposure(s) building, in terms of their actual distances using explicit maps. This information is not yet available, but

attempts have been made to build such plans by which the exact distances between the incident and the surrounding exposure(s) can be retrieved.

The occupancy type, construction type, and size of the building can be derived from the tax records. The other factors can be gathered from the fire inspectors. CriSys Ltd. has supplied this information within a database.

3.4 Hydrant Type

One of the important factors in the process of size-up decision-making is the number and the type of the hydrants close to the incident building. There are four main types of hydrants: Type AA, Type A, Type B, and Type C [**51**].

Hydrants have different water flow (gallon per minute) depending on the type of the hydrant. Table 3-1 demonstrates the water flow of each type. It is common to consider only the effective flow (as opposed to the low flow and high flow) in the calculations of the required number of hydrants.

Using the latitude and longitude co-ordinates of the surrounding hydrants, we are able to locate and calculate the distance between these hydrants and the incident building. In cases where no hydrants are close enough to the incident, more than two pumper trucks are used to perform the relay pump task. Relay pump is a process in which one pumper truck is connected to the distant hydrant and another pumper truck is connected to the auxiliary pumper truck. In scenarios where relay pump is not feasible, tanker trucks are used.

Table 3-1 Hydrant types

Class	Colour	Flow Lo (gpm)	Flow Hi (gpm)	Effective Flow (gpm)
C	red	0	499	250
B	orange	500	999	750
A	green	1,000	1,499	1,250
AA	blue	1,500	> 1,500	1,500

3.5 Occupancy Profile

Buildings can be referenced as residential, commercial, mixed (combination of residential and commercial), institutional, educational, health care, industrial, manufacturing, etc. Each of these buildings has its own specification, limitations and concerns, when facing a fire emergency.

One of the major attributes of the buildings is the occupancy profile. Occupancy profile provides information regarding the number of people occupying the building. Furthermore, it offers certain attributes regarding the occupants, such as age distribution. These values can vary depending on the given time and date.

Occupancy profile can be used as an estimation of the number of people trapped and/or injured in fire emergencies, when no accurate information is available.

Table 3-2 contains a number of examples of the occupancy profiles.

Table 3-2 Examples of occupancy profile

Occupancy type	Sat, Sun & 5pm Fri - 8am Mon	Mon-Fri 8am-5pm	Mon-Fri 5pm-8am
School	0	200	0
Residential	4	1	4
Industrial	0	50	2
Commercial	0	50	0

3.6 Occupancy Type Factor

Occupancy type factor (O_i) is a factor relating to the occupancy type of the building. This factor is used in the NFF (Needed Fire Flow) calculation (NFF is a terminology used to denote the required water flow in order to extinguish fire). According to the building occupancy type, which is based on the combustibility of the construction, a factor (O_i) is determined. These factors are shown in Table 3-3.

Table 3-3 Occupancy types

Class	Description	Factor (O_i)	Occupancy Type examples
C-1	non-combustible	0.75	storage of stone, metal, marble, etc
C-2	limited combustible	0.85	airport, schools, hospitals, banks, libraries, etc
C-3	combustible	1.00	dry cleaner, casino, bakery, pet shop, etc.
C-4	free-burning	1.15	grocery stores, retail, warehouses, etc.
C-5	rapid burning	1.25	refineries/chemicals, rag stores, fireworks, etc

For more information on the occupancy combustibility classifications please refer to [52].

3.7 Construction Type

Another important factor in the process of emergency resource size-up is the construction type of the building.

This factor plays an important role in the required water flow calculation. Each construction type has a coefficient F which is used in the NNF calculations. The construction type, not only influences the water flow needed for the incident building, but also is necessary in the calculation of the NFF for the exposure(s) around the incident.

A few years ago, there were only five construction types: Fire-resistive, non-combustible, ordinary brick and joist, heavy timber, and wood frame constructions. However, at present, newer, lighter, and hybrid construction methods and materials have been introduced [53]. This new type of construction is referred to as the hybrid or type6 construction. Table 3-4 demonstrates the different construction type coefficients (F).

Table 3-4 Construction type coefficient

Type/Class	Description	Coefficient (F)
Type1	wood frame	1.5
Type2	joisted masonry	1.0
Type3	non-combustible	0.8
Type4	masonry non-combustible	0.8
Type5	modified fire-resistive	0.6
Type6	fire-resistive	0.6

A set of independent rules are created for these construction types; therefore, it is crucial to understand the construction types in order to be able to make a decision on which set of rules to fire. These construction types are briefly introduced below (for more information on these construction types please refer to [53]).

1. Type1: Fire-Resistive Construction

   Type1 construction type is known to be the most resistant to the fire spread and significant collapse. Fire-resistive construction, as the name implies, is a building with components that are designed and protected to resist the maximum severity of fire. An example of this construction type is the large commercial office high-rise buildings.

   The main characteristic of type1 construction is that the components of this type of construction do not add to the fire spread. Masonry and steel, which is protected by encasement or other coverings, are the two main components of this type of construction; therefore, the key structural components of this construction type are protected.

   There are, however, negative characteristics of this type of construction. These characteristics include heat, forcible entry, large open spaces, and ventilation.

2. Type2: Non-combustible/Limited Combustible Construction

   Non-combustible or limited combustible constructions consist of masonry blocks and/or steel exterior walls, with a steel-supported roof system. Type2 construction is generally a one or two storey building. These constructions are known as high-ceiling occupancy by many firefighters. The main difference between type1 and type2 constructions is that the steel used as one of the main components of this type is exposed and unprotected, which causes the building to collapse.

The sole favourable characteristic of this construction type is that masonry and steel do not contribute to the fire spread; hence, type2 constructions are called non-combustible.

In contrary, type2 constructions have a large number of negative characteristics that are listed in [**53**]

3. Type3: Ordinary Construction/Brick and Joist Construction

Type3 constructions are referred to the structures with the exteriors constructed of non-combustible materials such as concrete blocks, brick, or clay tile and the interiors (floor, wall, and ceiling) built of wood. Firefighters refer to this type of construction as brick and joist construction. These constructions have one to seven (most commonly two to four) storeys.

Positive characteristics of ordinary construction types consist of the non-combustible exterior walls, which do not contribute to the fire load. Moreover, these constructions are generally smaller than constructions of type1 and type2.

One of the main destructive characteristic of type3 construction is alteration, since these buildings are generally old, which creates struggling situations for the firefighters.

4. Type4: Heavy Timber Construction

This type of construction is built using either brick, block, or stone on the exterior and large wooden timberwork on the interior. Type4 constructions are usually six or seven storey buildings and are referred to as mill construction.

Out of several positive characteristics, the following two factors are considered to be the most predominant. First, the ratio of surface to mass is low in these types of constructions. This feature provides excellent resistance to the early fire involvements in addition to another feature of type4 constructions, which is non-combustibility of the components of these structures. Second, lack of void spaces is another important characteristic of these constructions. This feature leads to less building collapses.

On the other hand, the wooden interior of these constructions is a massive challenge for the firefighters by reason of the tremendous amount of heat. In addition, due to the combustible interior components, these types of buildings often cause severe exposure problems and fire can spread extremely fast, once the large timberwork is ignited.

5. Type5: Wood Frame Construction

Type5 constructions are referred to the structures built primarily of wood. Having said that, these types of construction have the most fire activities; hence, require faster response than the previous construction types.

One of the negative characteristics of wood frame construction is the open interior stair construction, which causes the uncontrollable movements of fire to the upper-levels of the construction. Since the main component of these structures is wood, these construction types are extremely combustible. Moreover, the key structures are sometimes no larger than 4×9 cm; therefore, collapse effortlessly.

6. Type6: Hybrid Construction

Hybrid constructions are made of pre-engineered or light-weighted components, which are generally combined with the previous five types of construction. These construction types are such as light-weighted wood trusses, unprotected steel, and wooden I-beams, etc. This type of construction has been introduced recently; hence, firefighters are becoming more and more concerned about the new construction techniques and materials. The use of new light-weighted materials makes it difficult to estimate the building collapse time; therefore, requires much more concern and precautions.

3.8 Separation Distance

Having the latitude and longitude co-ordinates of the buildings in addition to the building areas, we are able to estimate the distance between the incident building and the surrounding exposure(s).

A simple way of estimating the distance is to use the distance formula:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \qquad \text{(Equation 6)}$$

Line (2) in Figure 3-1demonstrates the distance calculated using this formula.

However, as it is shown, the explicit distance between these two constructions is graphed with line (1). Due to the fact that presently there is no information available on the building footprints, the exact shape of the constructions is not defined.

In order to have a better estimation of the distance between two constructions, we made an assumption that all the constructions have a square shape. Therefore, we can estimate the side of these squares by calculating the square root of the area of these buildings. The squares with dashed lines in Figure 3-1 represent the assumed building footprints. Thus, line (3) in the figure demonstrates a better distance estimation comparing with line (2).

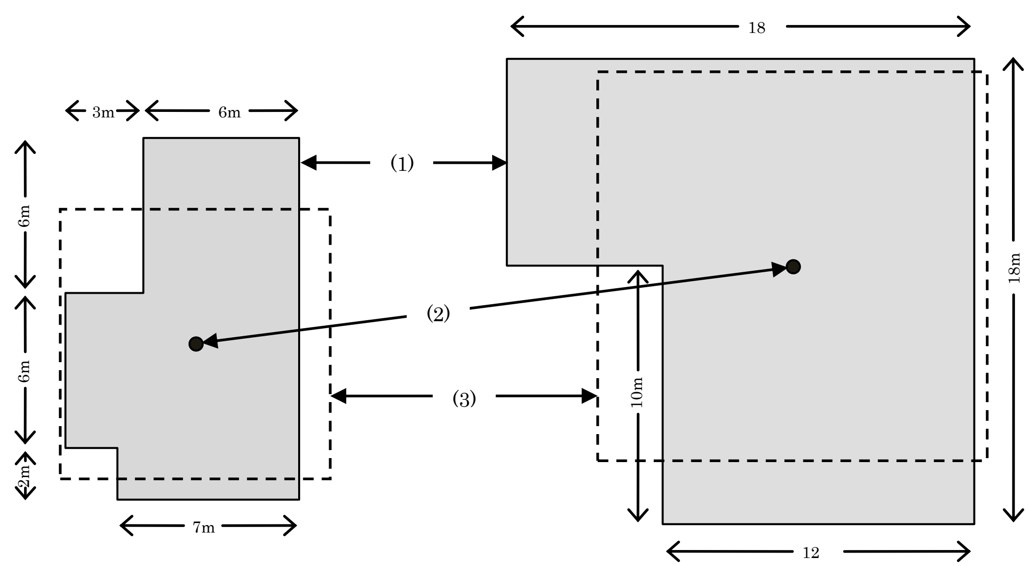


Figure 3-1 Separation Distance

However, the positioning of the exposure building should be defined in relation to the incident building. There are eight possible scenarios that these buildings might be positioned. These scenarios are shown in Table 3-5.

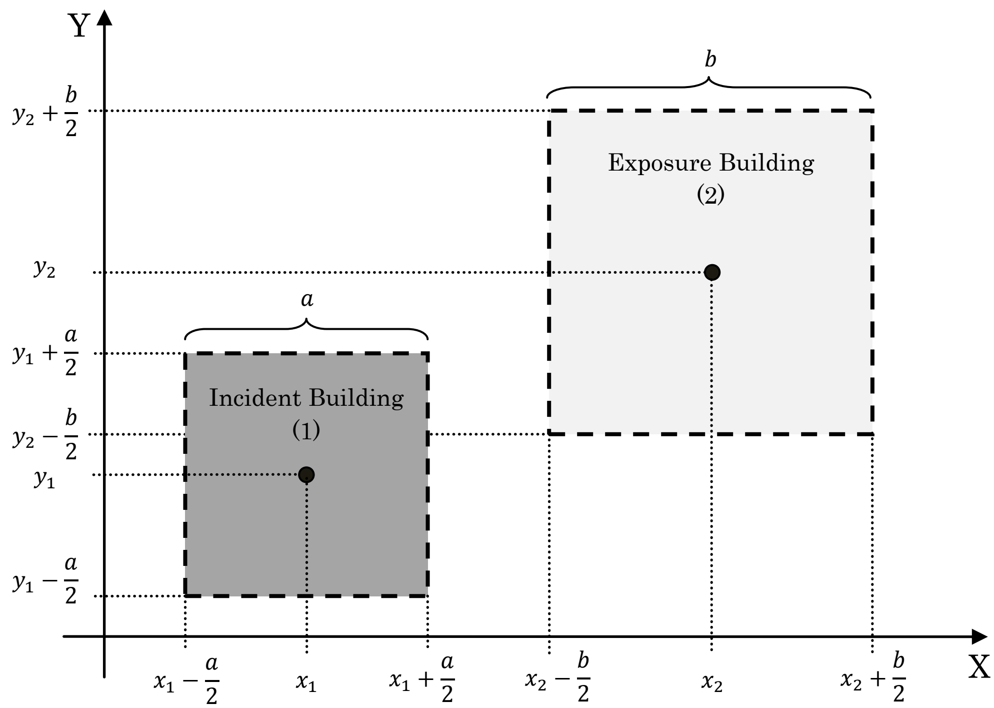


Figure 3-2 x-y Points used in separation distance estimation

The separation distance is estimated using the algorithm below.

$$
\begin{aligned}
&IF\ \ |x_2 - x_1| \le \frac{a}{2} + \frac{b}{2}\ \ THEN \\
&\qquad IF\ y_2 > y_1\ THEN\ d = y_2 - \tfrac{b}{2} - y_1 - \tfrac{a}{2} \\
&\qquad ELSE\ \ d = y_1 - \tfrac{a}{2} - y_2 - \tfrac{b}{2} \\
&ELSE\ IF\ \ x_2 > x_1\ \ THEN \\
&\qquad IF\ \ |y_2 - y_1| \le \tfrac{a}{2} + \tfrac{b}{2}\ \ THEN\ d = x_2 - \tfrac{b}{2} - x_1 - \tfrac{a}{2} \\
&\qquad ELSE\ IF\ y_2 > y_1\ THEN\ \ d = \sqrt{(x_1 + \tfrac{a}{2} - x_2 + \tfrac{b}{2})^2 + (y_1 + \tfrac{a}{2} - y_2 + \tfrac{b}{2})^2} \\
&\qquad ELSE\ \ d = \sqrt{(x_1 + \tfrac{a}{2} - x_2 + \tfrac{b}{2})^2 + (y_1 - \tfrac{a}{2} - y_2 - \tfrac{b}{2})^2} \\
&ELSE \\
&\qquad IF\ \ |y_2 - y_1| \le \tfrac{a}{2} + \tfrac{b}{2}\ \ THEN\ d = x_1 - \tfrac{a}{2} - x_2 - \tfrac{b}{2} \\
&\qquad ELSE\ IF\ y_2 > y_1\ THEN\ \ d = \sqrt{(x_1 - \tfrac{a}{2} - x_2 - \tfrac{b}{2})^2 + (y_1 + \tfrac{a}{2} - y_2 + \tfrac{b}{2})^2} \\
&\qquad ELSE\ \ d = \sqrt{(x_1 - \tfrac{a}{2} - x_2 - \tfrac{b}{2})^2 + (y_1 - \tfrac{a}{2} - y_2 - \tfrac{b}{2})^2}
\end{aligned}
\qquad \text{(Equation 7)}
$$

where:

x_1 = *the incident building's latitude,*

y_1 = *the incident building's longitude,*

x_2 = *the exposure's latitude,*

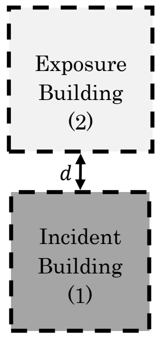
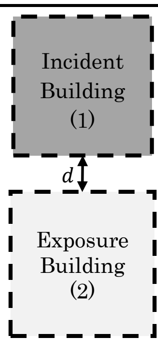
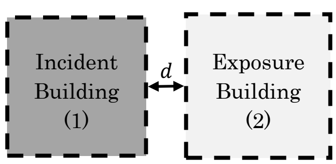
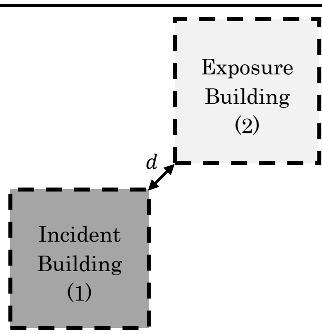
y_2 = *the exposure's longitude,*

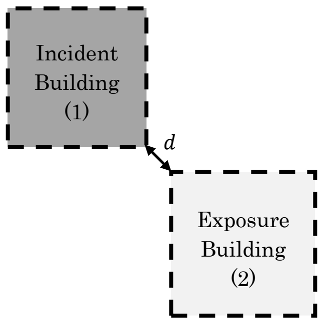
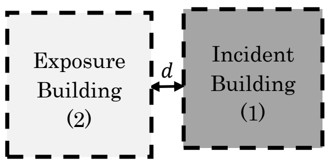
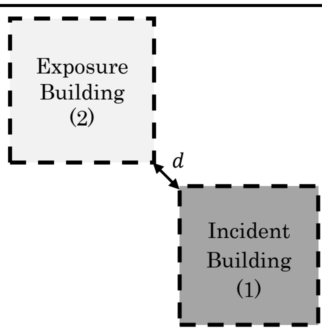
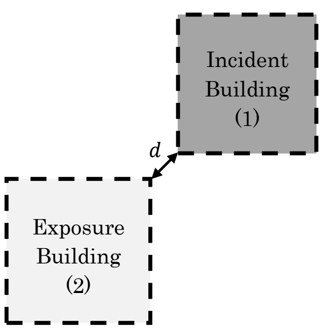
a = *each side of the assumed incident building footprint (*$a = \sqrt{Area_{Incident\ Building}}$*),*

b = *each side of the assumed exposure building footprint (*$b = \sqrt{Area_{Exposure\ Building}}$*).*

These parameters are demonstrated in Figure 3-2, which is one of the eight possible scenarios.

Table 3-5 Eight possible positioning scenarios

	Scenario	Description	Separation Distance
North		The exposure building is on the north side of the incident building	$d = y_2 - \frac{b}{2} - y_1 - \frac{a}{2}$
South		The exposure building is on the south side of the incident building	$d = y_1 - \frac{a}{2} - y_2 - \frac{b}{2}$
East		The exposure building is on the east side of the incident building	$d = x_2 - \frac{b}{2} - x_1 - \frac{a}{2}$
North-East		The exposure building is on the north-east side of the incident building	$d = \sqrt{\left(x_1 + \frac{a}{2} - x_2 + \frac{b}{2}\right)^2 + \left(y_1 + \frac{a}{2} - y_2 + \frac{b}{2}\right)^2}$

<table>
<tr><th></th><th>Scenario</th><th>Description</th><th>Separation Distance</th></tr>
<tr><td>South-East</td><td></td><td>The exposure building is on the south-east side of the incident building</td><td>$d = \sqrt{\left(x_1 + \frac{a}{2} - x_2 + \frac{b}{2}\right)^2 + \left(y_1 - \frac{a}{2} - y_2 - \frac{b}{2}\right)^2}$</td></tr>
<tr><td>West</td><td></td><td>The exposure building is on the west side of the incident building</td><td>$d = x_1 - \frac{a}{2} - x_2 - \frac{b}{2}$</td></tr>
<tr><td>North-West</td><td></td><td>The exposure building is on the north-west side of the incident building</td><td>$d = \sqrt{\left(x_1 - \frac{a}{2} - x_2 - \frac{b}{2}\right)^2 + \left(y_1 + \frac{a}{2} - y_2 + \frac{b}{2}\right)^2}$</td></tr>
<tr><td>South-West</td><td></td><td>The exposure building is on the south-west side of the incident building</td><td>$d = \sqrt{\left(x_1 - \frac{a}{2} - x_2 - \frac{b}{2}\right)^2 + \left(y_1 - \frac{a}{2} - y_2 - \frac{b}{2}\right)^2}$</td></tr>
</table>

After being fuzzified, the separation distance is used in the calculations of the exposure factor.

3.9 Effective Wind Speed

The positioning of the exposure building in relation to the incident building is not only an important factor in the calculations of the separation distance, but also the main attribute by which the effective wind speed is calculated.

To further clarify this point, an example would be a scenario where the exposure is placed on the north side of the incident building. A wind speed of 50 k/h to the south is not as effective as a wind speed of 10 k/h directly to the north.

One of the solutions to this problem is to calculate an estimation of the effective wind speed. Based on the 16-point compass rose (shown in Figure 3-3), there are seven effective wind directions from the incident building towards the exposure construction. In the mentioned example the following wind directions are effective: North, North-northeast, North-northwest, Northeast, Northwest, East-northeast, and West-northwest.

By multiplying a factor with the wind speed, the effective wind speed is calculated. This factor is defined based on the location of the exposure and the direction of the wind in conjunction with the rule of thumb. Table 3-6 demonstrates these factors. The effective wind speed formula is as follows:

$$EWS = windSpeed \times factor_{wind\ direction} \qquad \text{(Equation 8)}$$

As an example, the effective wind speed is calculated for a scenario where the exposure building is on the north side of the incident building and the wind speed is 50 k/h. Different wind directions are calculated below.

- North: $EWS = 50 \times 1.0 = 50.0\ k/h$
- North-northeast: $EWS = 50 \times 0.9 = 45.0\ k/h$
- North-northwest: $EWS = 50 \times 0.9 = 45.0\ k/h$
- Northeast: $EWS = 50 \times 0.75 = 37.5\ k/h$
- Northwest: $EWS = 50 \times 0.75 = 37.5\ k/h$
- East-northeast: $EWS = 50 \times 0.5 = 25.0\ k/h$
- West-northwest: $EWS = 50 \times 0.5 = 25.0\ k/h$
- Other wind directions: $EWS = 50 \times 0.0 = 0.0\ k/h$

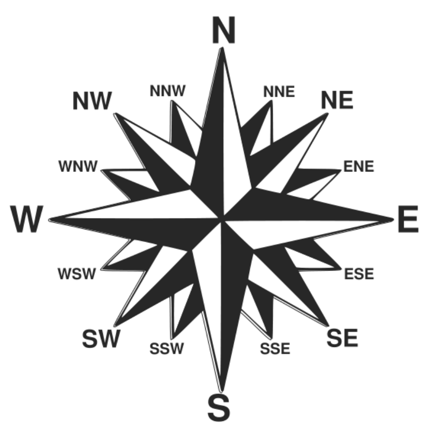
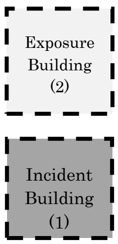
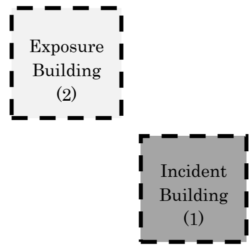
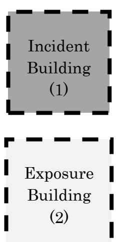
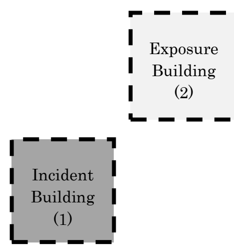
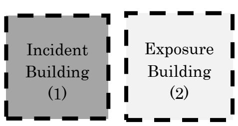
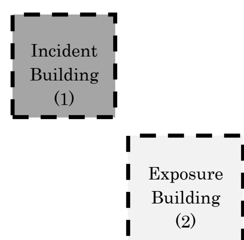
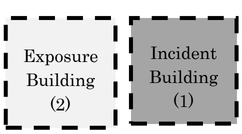
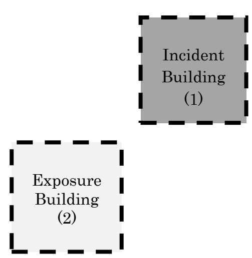


Figure 3-3 16-point compass rose

The effective wind speed is also used in the calculations of the exposure factor after being fuzzified. This is described in depth in the following subsection.

Table 3-6 Wind speed effectiveness factor

Scenario	Effectiveness factor	Scenario	Effectiveness factor
North 	- $factor_N = 1.0$ - $factor_{NNE} = 0.9$ - $factor_{NNW} = 0.9$ - $factor_{NE} = 0.75$ - $factor_{NW} = 0.75$ - $factor_{ENE} = 0.5$ - $factor_{WNW} = 0.5$ - $factor_{the\ rest} = 0.0$	North-West 	- $\mathrm{factor}_{\mathrm{NW}} = 1.0$ - $factor_{NNW} = 0.9$ - $factor_{WNW} = 0.9$ - $factor_N = 0.75$ - $factor_W = 0.75$ - $factor_{NNE} = 0.5$ - $factor_{WSW} = 0.5$ - $factor_{the\ rest} = 0.0$
South 	- $factor_S = 1.0$ - $factor_{SSE} = 0.9$ - $factor_{SSW} = 0.9$ - $factor_{SE} = 0.75$ - $factor_{SW} = 0.75$ - $factor_{ESE} = 0.5$ - $factor_{WSW} = 0.5$ - $factor_{the\ rest} = 0.0$	North-East 	- $\mathrm{factor}_{\mathrm{NE}} = 1.0$ - $factor_{ENE} = 0.9$ - $factor_{NNE} = 0.9$ - $factor_N = 0.75$ - $factor_E = 0.75$ - $factor_{ESE} = 0.5$ - $factor_{NNW} = 0.5$ - $factor_{the\ rest} = 0.0$
East 	- $factor_E = 1.0$ - $factor_{ENE} = 0.9$ - $factor_{ESE} = 0.9$ - $factor_{NE} = 0.75$ - $factor_{SE} = 0.75$ - $factor_{NNE} = 0.5$ - $factor_{SSE} = 0.5$ - $factor_{the\ rest} = 0.0$	South-East 	- $\mathrm{factor}_{\mathrm{SE}} = 1.0$ - $factor_{SSE} = 0.9$ - $factor_{ESE} = 0.9$ - $factor_S = 0.75$ - $factor_E = 0.75$ - $factor_{ENE} = 0.5$ - $factor_{SSW} = 0.5$ - $factor_{the\ rest} = 0.0$
West 	- $\mathrm{factor}_{\mathrm{W}} = 1.0$ - $factor_{WNW} = 0.9$ - $factor_{WSW} = 0.9$ - $factor_{NW} = 0.75$ - $factor_{SW} = 0.75$ - $factor_{NNW} = 0.5$ - $factor_{SSW} = 0.5$ - $factor_{the\ rest} = 0.0$	South-West 	- $\mathrm{factor}_{\mathrm{SW}} = 1.0$ - $factor_{WSW} = 0.9$ - $factor_{SSW} = 0.9$ - $factor_W = 0.75$ - $factor_S = 0.75$ - $factor_{WNW} = 0.5$ - $factor_{SSE} = 0.5$ - $factor_{the\ rest} = 0.0$

3.10 Exposures Factor

Another important factor to be considered is the condition of the exposure(s) close to the incident. It is crucial to take into account the number, type, and size of the exposure(s) around the construction before sending the first crew. For instance, a tragedy would occur, if the incident was close to a daycare, or even worse, a gas station. Therefore, it is important to consider not only the information of the incident construction, but also the previously mentioned factors of the exposure(s) around the construction, such as the distance between the exposure(s) and the incident along with the size of the exposure(s).

In order to be able to make a decision on the conditions of the exposures, two main factors are to be calculated and measured. These factors include the separation distance (between the incident building and the exposure) and the effective wind speed (which is dependent on the wind speed and the direction of the wind).

Due to the unpredictable and variable nature of wind speed and direction, there is a high chance that the values of these two variables are changed when the rescue crew arrive on the scene. Fuzzy logic enables us to overcome the variability issue of these values and also the fact that the officer in command uses linguistic values (e.g. wind speed is fast) during the process of on-scene size-up.

We generated Table 3-7 to 3-12 based on the interviews, discussions, and experiences of a number of Ontario fire chiefs and also a statistical document provided by CriSys Ltd. These tables contain empirical information relating to the exposure factors for each construction type.

As a matter of fact, the stronger the effective wind speed blows in the direction of the exposure and the closer the exposure is located to the incident building, the higher the exposure factor is. We have graphed these values in order to provide a better understanding of the impacts of the separation distance and the effective wind speed on the exposure factors. These graphs are shown in Figure 3-4 to 3-9.

Table 3-7 Exposure Factor - Construction Type 1 - Wood Frame

		Separation Distance									
		0-5m	**5-10m**	**10-15m**	**15-20m**	**20-25m**	**25-30m**	**30-35m**	**35-40m**	**40-45m**	**> 45m**
Effective Wind Speed	> 75 k/h	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45
	70-75 k/h	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40
	65-70 k/h	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35
	60-65 k/h	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30
	55-60 k/h	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25
	50-55 k/h	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20
	45-50 k/h	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15
	40-45 k/h	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10
	35-40 k/h	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
	30-35 k/h	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.05
	25-30 k/h	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.05	0.05
	20-25 k/h	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.05	0.05	0.05
	15-20 k/h	0.30	0.25	0.20	0.15	0.10	0.05	0.05	0.05	0.05	0.05
	10-15 k/h	0.25	0.20	0.15	0.10	0.05	0.05	0.05	0.05	0.05	0.05
	5-10 k/h	0.20	0.15	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	0-5 k/h	0.15	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table 3-8 Exposure Factor - Construction Type 2 - Jointed Masonry

		Separation Distance									
		0-5m	**5-10m**	**10-15m**	**15-20m**	**20-25m**	**25-30m**	**30-35m**	**35-40m**	**40-45m**	**> 45m**
Effective Wind Speed	> 70 k/h	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30
	65-70 k/h	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25
	60-65 k/h	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20
	55-60 k/h	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15
	50-55 k/h	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10
	45-50 k/h	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
	40-45 k/h	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.05
	35-40 k/h	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.05	0.05
	30-35 k/h	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.05	0.05	0.05
	25-30 k/h	0.30	0.25	0.20	0.15	0.10	0.05	0.05	0.05	0.05	0.05
	20-25 k/h	0.25	0.20	0.15	0.10	0.05	0.05	0.05	0.05	0.05	0.05
	15-20 k/h	0.20	0.15	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	10-15 k/h	0.15	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	5-10 k/h	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	0-5 k/h	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table 3-9 Exposure Factor - Construction Type 3 - Non-Combustible

		Separation Distance									
		0-5m	**5-10m**	**10-15m**	**15-20m**	**20-25m**	**25-30m**	**30-35m**	**35-40m**	**40-45m**	**> 45m**
Effective Wind Speed	> 60 k/h	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15
	55-60 k/h	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10
	50-55 k/h	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
	45-50 k/h	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.05
	40-45 k/h	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.05	0.05
	35-40 k/h	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.05	0.05	0.05
	30-35 k/h	0.30	0.25	0.20	0.15	0.10	0.05	0.05	0.05	0.05	0.05
	25-30 k/h	0.25	0.20	0.15	0.10	0.05	0.05	0.05	0.05	0.05	0.05
	20-25 k/h	0.20	0.15	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	15-20 k/h	0.15	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	10-15 k/h	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	5-10 k/h	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	0-5 k/h	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table 3-10 Exposure Factor - Construction Type 4 - Masonry Non-Combustible

		Separation Distance								
		0-5m	5-10m	10-15m	15-20m	20-25m	25-30m	30-35m	35-40m	> 40m
Effective Wind Speed	> 40 k/h	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
	35-40 k/h	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.05
	30-35 k/h	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.05	0.05
	25-30 k/h	0.30	0.25	0.20	0.15	0.10	0.05	0.05	0.05	0.05
	20-25 k/h	0.25	0.20	0.15	0.10	0.05	0.05	0.05	0.05	0.05
	15-20 k/h	0.20	0.15	0.10	0.05	0.05	0.05	0.05	0.05	0.05
	10-15 k/h	0.15	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	5-10 k/h	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	0-5 k/h	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table 3-11 Exposure Factor - Construction Type 5 - Modified Fire-Resistive

		Separation Distance					
		0-5m	5-10m	10-15m	15-20m	20-25m	> 25m
EWS	> 25 k/h	0.30	0.25	0.20	0.15	0.10	0.05
	20-25 k/h	0.25	0.20	0.15	0.10	0.05	0.05
	15-20 k/h	0.20	0.15	0.10	0.05	0.05	0.05
	10-15 k/h	0.15	0.10	0.05	0.05	0.05	0.05
	5-10 k/h	0.10	0.05	0.05	0.05	0.05	0.05
	0-5 k/h	0.05	0.05	0.05	0.05	0.05	0.05

Table 3-12 Exposure Factor - Construction Type 6 - Fire-Resistive

		Separation Distance		
		0-5m	5-10m	> 10m
EWS	> 10 k/h	0.15	0.10	0.05
	5-10 k/h	0.10	0.05	0.05
	0-5 k/h	0.05	0.05	0.05

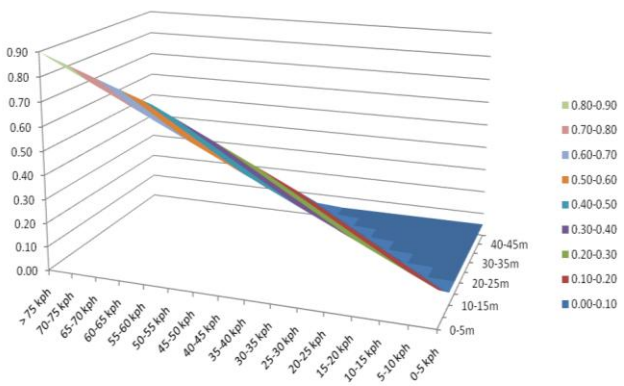


Figure 3-4 Construction Type 1 - Wood Frame

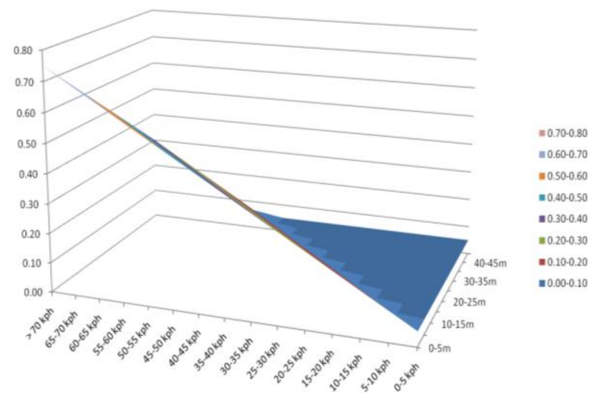


Figure 3-5 Construction Type 2 - Jointed Masonry

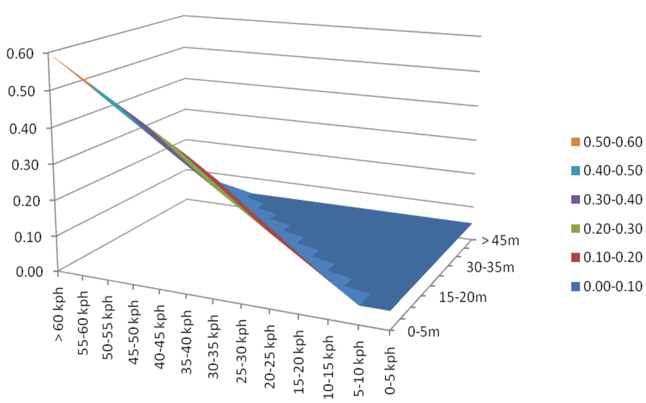


Figure 3-6 Construction Type 3 - Non-Combustible

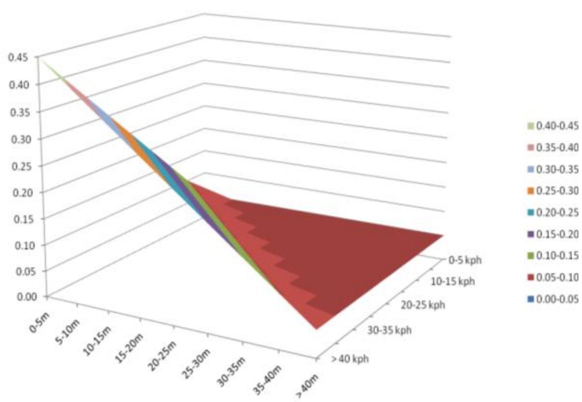


Figure 3-7 Construction Type 4 - Masonry Non-Combustible

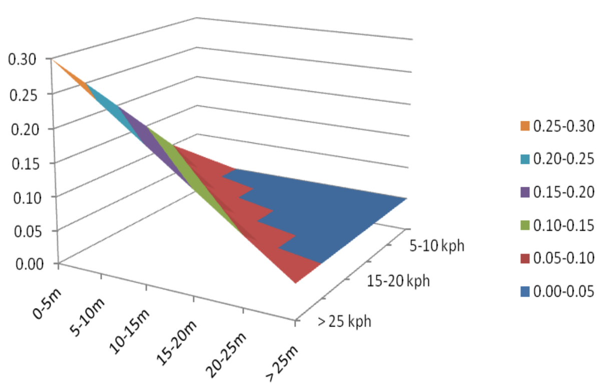


Figure 3-8 Construction Type 5 - Modified Fire-Resistive

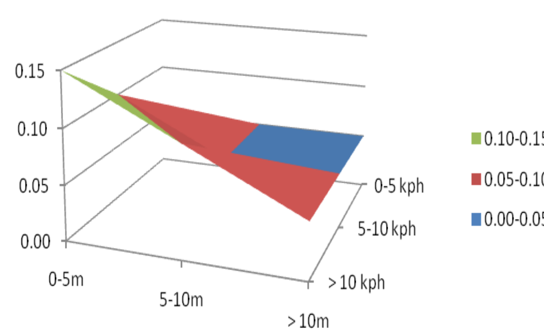


Figure 3-9 Construction Type 6 - Fire-Resistive

3.11 Needed Fire Flow Calculation

Fire Suppression Rating Schedule (FSRS) [54] is a manual that ISO uses to describe decisive factors used in the evaluation of a community's fire defence. It describes a methodology to calculate the amount of water necessary to provide fire protection at selected locations [52]. However, the water flow needed is typically estimated on-scene by observing different fire assessment factors. We have combined the on-scene thought process of the experienced fire chiefs in addition to the NFF calculation.

The following formula is used by ISO to estimate the amount of water needed (Needed Fire Flow) to fight fire in a non-sprinklered building, [52]:

$$NFF_i = C_i \times O_i \times [1.0 + (X + P)_i] \qquad \text{(Equation 9)}$$

where

NFF_i = the needed fire flow in gallons per minute (gpm),
C_i = a factor related to the type of construction,
O_i = a factor related to the type of occupancy,
X = a factor related to the exposure buildings,
P = a factor related to the communication between buildings.

In order to calculate the needed fire flow of a building, we need to determine a number of factors such as the predominant type or class of construction (C_i), size (effective area) of the building (A_i), predominant type of occupancy (O_i), exposure(s) close to the property (X), and the factor for communication to another building (P).

The exposure factors (X) can be determined after identifying the construction type, the area and the height (number of floors) of the exposure(s) near the construction and also the distance (in feet) between these exposures and the building. This factor is defined using fuzzy rules.

The construction factor (C_i) is estimated knowing the effective area and a factor associated to the predominant construction type. Substituting these two values into the following formula, the construction type can be calculated:

$$C_i = 18 \times F \times (A_i)^{0.5} \qquad \text{(Equation 10)}$$

where:

A_i *= the effective area,*
F *= a factor associated to the predominant construction type.*

The value of (C_i) is rounded off to the nearest 250 gpm after calculation.

The factor related to the communications between buildings (P) is determined if there is a communication charge between the constructions. This factor is determined by identifying the combustibility of the passageway – whether or not the passageway is open, the dimensions of the passageway, and a description of the passageway openings, indicating if any protection is provided in the passageway openings or not. However, due to lack of adequate information and resources regarding this factor, we were unable to determine the value of this factor in the NFF calculations.

Chapter 4.

Intelligent Fire-threat Assessment and Size-up Technology Framework

THIS chapter describes the actual implementation and development of the proposed intelligent fire threat assessment and size-up fuzzy expert system. After discussing the methodologies that were deployed in the implementation of *i*FAST and the platforms and toolkits we used, we elaborate the fuzzy concepts and the knowledge base of the system. Next, we present and explain the developing procedure of *i*FAST followed by a description of the underlying architecture of our fuzzy expert system. Finally, a discussion on the experiments and results of the system is provided.

4.1 Intelligent Fire-threat Assessment and Size-up Technology

*i*FAST is a fuzzy expert system that is designed to enhance the emergency resource size-up and dispatch methodologies; hence, reduce the emergency response time significantly which results in a vast amount of monetary savings, while saving many lives.

Since *i*FAST is an emulation of the officer in command's thought process for the procedure of on-scene size-up and dispatch decision-making, we have decided to implement the fuzzy reasoning methodologies.

In order to model and build a system based on linguistic information, such as “near”, “far”, “fast”, etc., a fuzzy logic based expert system deems to be a good choice for the size-up and dispatch procedures, since these terminologies can be easily handled.

Our proposed system contains over 600 fuzzy and non-fuzzy rules. These rules are listed in Appendix B. We followed the standard fuzzy operations [55] for the AND, OR and NOT operations of our fuzzy rules.

We have chosen JESS version 7.1p2, which is a powerful inference engine, to be our system’s reasoning core. Moreover, in order to implement our fuzzy rules, FuzzyJ Toolkit version 1.7, which is a set of Java classes, was employed. This version of FuzzyJ Toolkit is compatible with JESS version 6.0a5 or later. Currently the licence for educational and research use for both JESS and FuzzyJ Toolkit is free of charge.

4.1.1 Fuzzy Concepts

Fuzzy concepts are represented using fuzzy variables, fuzzy sets and fuzzy values. These concepts are implemented using the FuzzyJ Toolkit.

Fuzzy variables define the basic components that are used to describe a fuzzy concept, such as distance, or wind speed. Each fuzzy variable consists of a name (e.g. distance), a range of valid values (e.g. 0.0 to 100.0), the unit of the variable (e.g. meter), and a set of fuzzy terms (e.g. near, OK, and far). The following is an example of representing a fuzzy value in FuzzyJ Toolkit.

```
FuzzyVariable distanceType6 = new FuzzyVariable("Distance", 0.0, 100.0, "meter");
distanceType6.addTerm("near", new RFuzzySet(4.0, 7.0, new RightLinearFunction()));
distanceType6.addTerm("OK", new TrapezoidFuzzySet(3.0, 6.0, 9.0, 12.0));
distanceType6.addTerm("far", new LFuzzySet(8.0, 11.0, new LeftLinearFunction()));
```

We have two main fuzzy variables for each of the six construction types (i.e. separation distance and effective wind speed). Additionally, a fuzzy variable containing singleton fuzzy sets is also implemented for the exposure factors as the result of the fuzzy component of our system. The fuzzy variables that are used in the implementation of *i*FAST fuzzy component and their relating fuzzy sets are illustrated in Figure 4-1 to Figure 4-11.

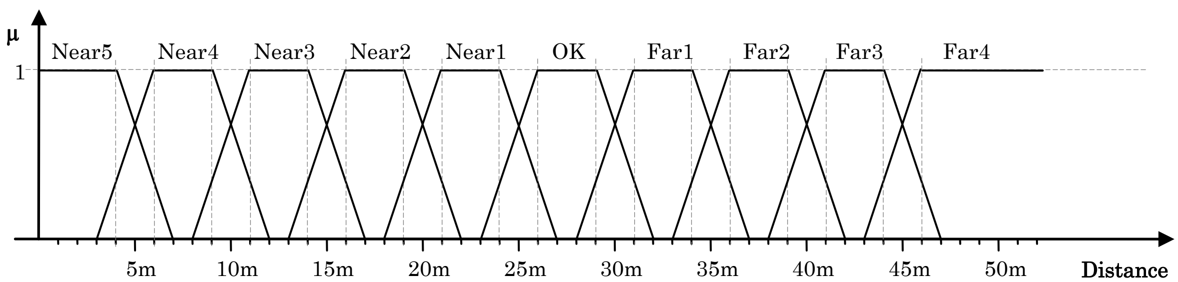


Figure 4-1 Fuzzy Variable Distance for Construction Classes 1, 2 and 3

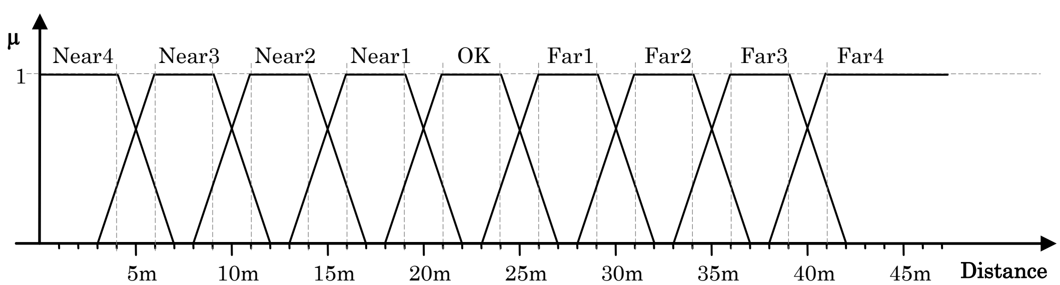


Figure 4-2 Fuzzy Variable Distance for Construction Class 4

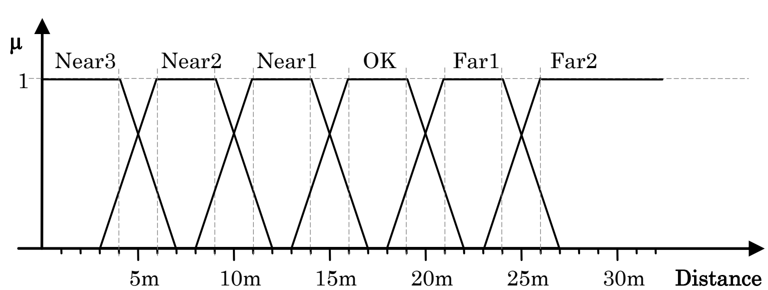


Figure 4-3 Fuzzy Variable Distance for Construction Class 5

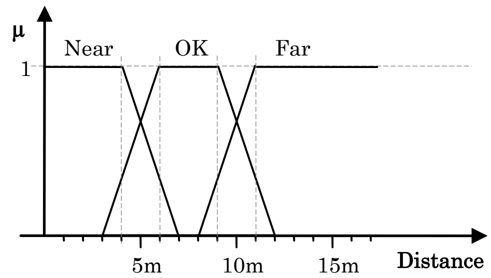


Figure 4-4 Fuzzy Variable Distance for Construction Class 6

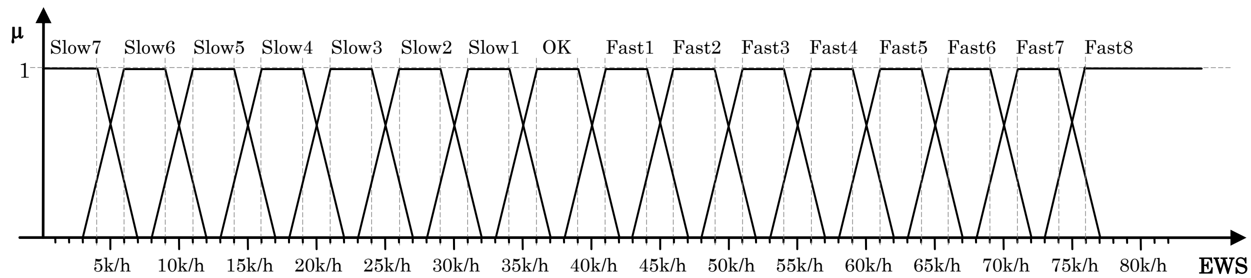


Figure 4-5 Fuzzy Variable Effective Wind Speed for Construction Class 1

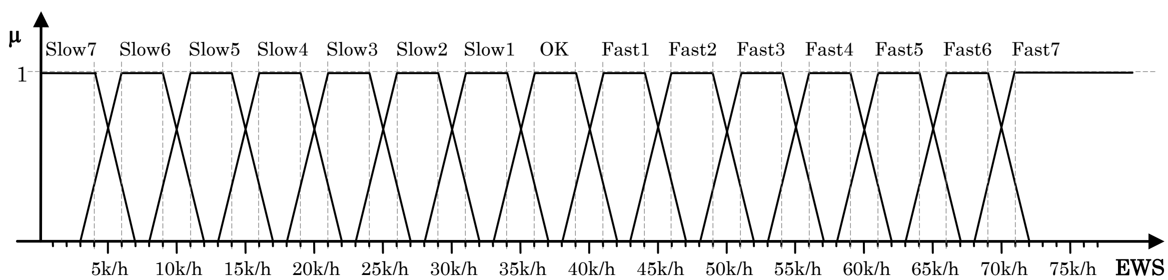


Figure 4-6 Fuzzy Variable Effective Wind Speed for Construction Class 2

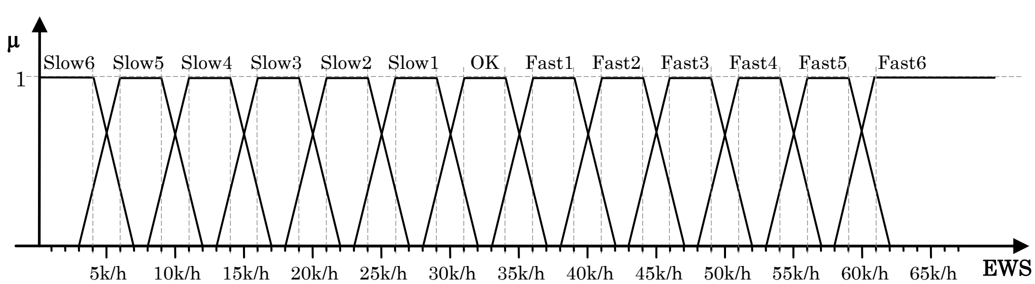


Figure 4-7 Fuzzy Variable Effective Wind Speed for Construction Class 3

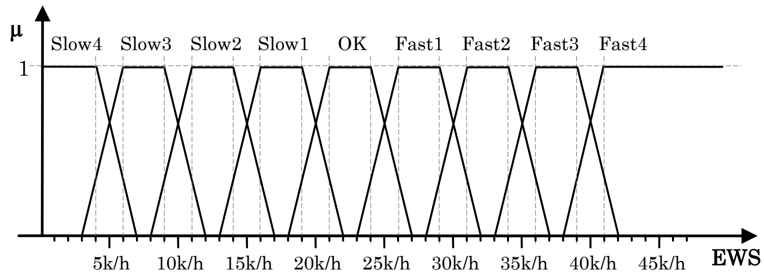


Figure 4-8Fuzzy Variable Effective Wind Speed for Construction Class 4

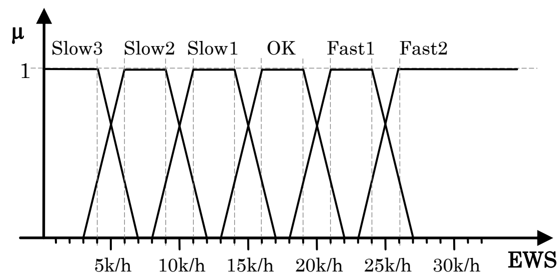


Figure 4-9 Fuzzy Variable Effective Wind Speed for Construction Class 5

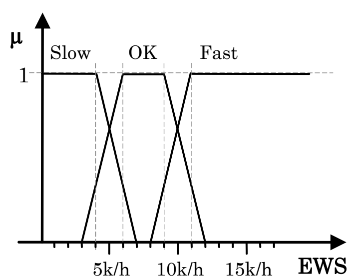


Figure 4-10 Fuzzy Variable Effective Wind Speed for Construction Class 6

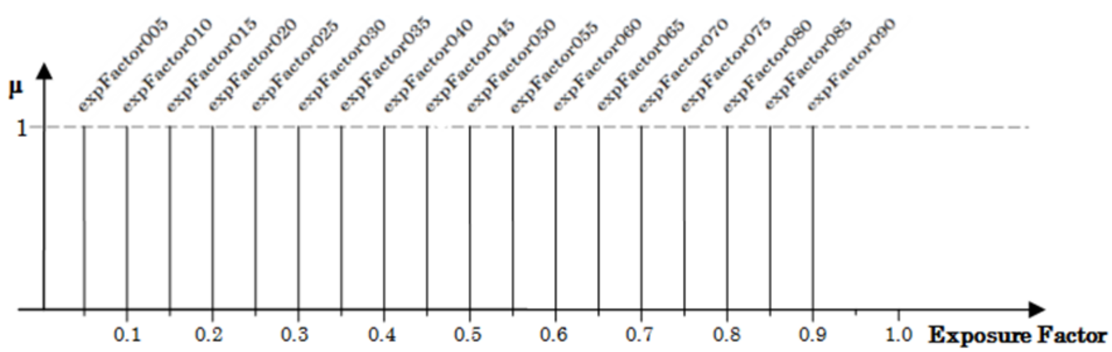


Figure 4-11 Fuzzy Variable Exposure Factor with Singleton Fuzzy Sets

In addition to the trapezoid-shape fuzzy sets, we used other fuzzy sets such as triangle-shape fuzzy sets and calculated the impact of such changes. The results showed that the final solution is not sensitive to the type of the fuzzy sets.

4.1.2 *i*FAST Knowledge Base

*i*FAST includes over 600 fuzzy and non-fuzzy rules. A list of the rule names of our system is provided in Appendix B. A description of these rules is provided below.

1. *i*FAST Non-Fuzzy Rules

Our non-fuzzy rules are stored in a separate file named JessFireRules.clp. This file is batched to our Java source code, in order to assert the non-fuzzy rules to the knowledge base. Table 4-1 contains a few examples of our non-fuzzy rules accompanying a brief description.

Facts and rules are created and being deployed using JESS constructs, such as deftemplates, deffacts, defmodules, etc. These constructs are explained in detail in [4]. We have implemented our expert system using the JESS Java library (jess.*) constructs.

JESS library provides three types of facts [4]:

- Unordered facts: These facts resemble a row in a relational database. The data fields correspond to the columns of the database table. These data fields are defined as slots and multislots. When asserting an unordered fact, there is no need to follow a specific order in regards to the slot names; hence these facts are called unordered facts.

- Ordered facts: These facts are simple lists and do not have predefined slots associated with them.
- Shadow facts: These facts are unordered facts linked to Java objects. For more detail, please refer to [**4**].

In order to create the unordered facts, a template is to be created first. Deftemplates are used to define a template for the unordered facts. A number of deftemplates of our system are described below.

The "hydrant" deftemplate is created using the following Java source code:

```
Deftemplate d = new Deftemplate ("hydrant", "Defines a template for the
                                          hydrant attributes.", engine);

d.addSlot("hydrantIndex", v0, "INTEGER");
d.addSlot("x_lon", v0, "FLOAT");
d.addSlot("y_lat", v0, "FLOAT");
d.addSlot("flow", v0, "FLOAT");
d.addSlot("is_candidate", vF, "ATOM");
d.addSlot("distance", v_1, "FLOAT");
```

The deftemplate is called "hydrant", and is one of the elements of the JESS Rete instance, *engine*. This deftemplate has six slots. Slot "hydrantIndex", indicates the index of the hydrant. "x_lon" and "y_lat" are the latitude and longitude co-ordinates of the hydrant. "flow" indicates the water flow capacity of the hydrant. "is-candidate" is a flag used by our expert system indicating whether or not this hydrant is in use. Lastly, the slot "distance" specifies the hydrant distance from the incident building. The default value of this slot is set to -1. Our expert system has a specific rule to calculate the distance of the hydrants with the "distance" value of -1. This prevents excessive calculations (i.e. distance is calculated only for the hydrants with slot "(distance -1)").

In order to categorize different types of personnel involved and their attributes in an emergency event, we created the "personnel" deftemplate. The following is the Java source code that was written to build this deftemplate:

```
Deftemplate d = new Deftemplate ("personnel", "Defines a template for
                              the personnel type and attributes", engine);

d.addSlot("perIndex", Funcall.NIL, "INTEGER");
d.addSlot("perType", Funcall.NIL, "STRING");
d.addSlot("perDescription", Funcall.NIL, "STRING");
d.addMultiSlot("perAttributes", Funcall.NILLIST);
```

This deftemplate has three slots and a multislot. The "perIndex" slot is an index that is used by CriSys Ltd. referencing codes. The "perType" slot is the name of the personnel (such as FF1, CAPT, PARA-II, etc.). The "perDescription" slot is used to provide a brief description about the personnel (such as Firefighter First class, Captain, ALSParamedic, etc.). Finally, the multislot is used to determine the list of attributes that the personnel are capable of. These attributes are such as search and rescue, first aid, hose and stream, entry, technical rescue, ALS, BLS, ventilation, salvage and etc.

Usually all personnel are trained to become skilled at as many of these attributes as possible; thus, these personnel can be sent to the events interchangeably. Therefore we decided to focus mainly on the attributes that each task requires to perform.

Later on, we determine the combination of personnel that should be sent to the event.

Same approach applies to the units (emergency machinery). The more advanced the units are, the more attributes they have. Thus, these units can also be used in emergency situations interchangeably. However, there are still some unique attributes that are specifically being considered in designing these units that in some cases, it is important to send the right unit to be able to perform a specific task.

The following is the Java source code that was used to create a deftemplate for the emergency units:

```
Deftemplate d = new Deftemplate ("unitType", "Defines a template for the
                                  units type and attributes.", engine);

d.addSlot("unitTypeIndex", Funcall.NIL, "INTEGER");
d.addSlot("unitTypeName", Funcall.NIL, "STRING");
d.addSlot("unitTypeMinPers", Funcall.NIL, "INTEGER");
d.addSlot("unitTypeMaxPers", Funcall.NIL, "INTEGER");
d.addSlot("unitTypeNumbPers", Funcall.NIL, "INTEGER");
d.addSlot("unitTypePersIndex", Funcall.NIL, "INTEGER");
d.addSlot("unitTypePersType", Funcall.NIL, "STRING");
d.addMultiSlot("unitTypeAttributes", Funcall.NILLIST);
d.addSlot("unitTypeAvailable", Funcall.NIL, "INTEGER");
```

This deftemplate is called “unitType” and contains eight slots and a multislot. The “unitTypeIndex” slot is used as an index, following the CriSys code system. The “unitTypeName” slot stores the name of the unit (such as pumper and rescue trucks). The “unitTypeMinPers” and “unitTypeMaxPers” slots define the minimum and maximum number of personnel that each unit can accommodate. The “unitTypeNumbPers” slot, on the other hand, is used for the final number of personnel that would be sent to the incident. This slot is modified when the system is dealing with deciding on the final combination that is to be sent to the event. The “unitTypePersIndex” and “unitTypePersType” slots define the index and name of the personnel that a specific unit carries and requires in order to function. The “unitTypeAvailable” is a counter determining the number of available units of a specific type. And the “unitTypeAttributes” multislot holds a list of attributes that the unit is capable of performing.

2. *i*FAST Fuzzy Rules

We have used fuzzy rule partitioning in order to reduce the size of our fuzzy knowledge base. *i*FAST contains six partitions. These partitions are based on the six construction types.

Based on the construction type of the surrounding exposure(s), our system determines which set of rules in which partition to be fired. These groups of rules are designed to calculate the exposure factor of the surrounding exposure(s) in order to be used in the Needed Fire Flow calculation.

As an example, Table 4-2 provides the set of fuzzy rules that are implemented for construction type6. Type6 fuzzy sets are demonstrated in Figure 4-4 and Figure 4-10. These rules are designed based on the empirical exposure factors described in Section 3.10.

Table 4-3 demonstrates the fuzzy set inputs and output diagrams of the mentioned rules. As these diagrams show, two trapezoid-shaped fuzzy sets are considered as the rule antecedents, and the conclusion fuzzy set is a singleton function.

Table 4-1 Examples of non-fuzzy rules

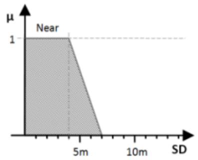
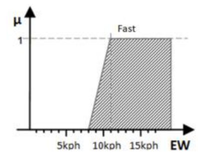
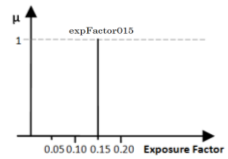
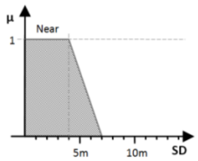
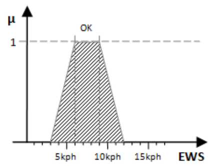
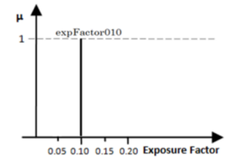
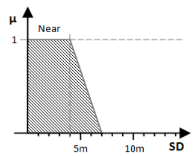
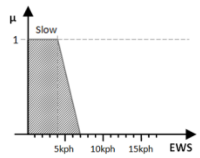
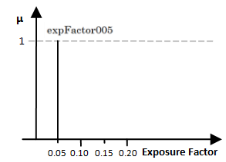
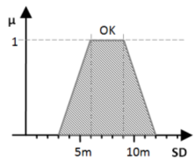
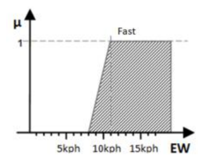
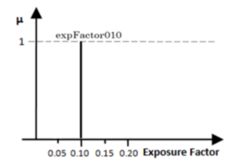
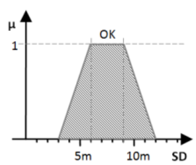
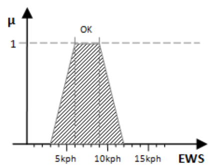
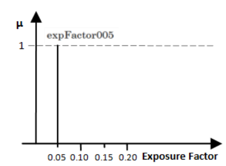
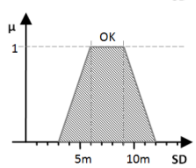
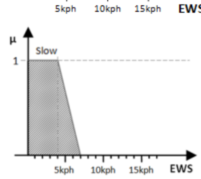
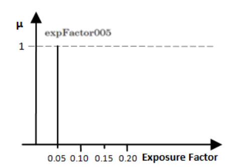
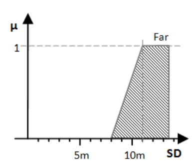
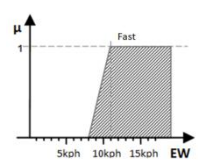
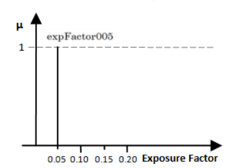
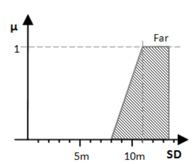
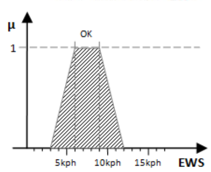
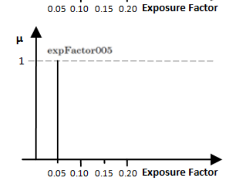
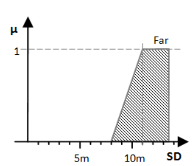
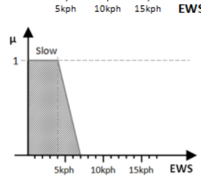
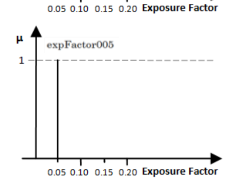
Rule #	Non-Fuzzy Rule	Description
Rule 1	(defrule Number_of_500gpmPumpers "This rule will calculate the number of PUMPERS that carry 5 personnel and can perform 200, 350, or 500 gpm water flow. It is based on NFPA FIRE ATTACK page 51" ?nff <- (NeedFireFlow_forPumpers ?ffn&:(>= ?ffn 350)) ?pum <- (unittype (unitTypeName "ENGINE") (unitTypeAvailable ?uAv&:(> ?uAv 0))) ?pAtt <- (persAttributes (HoseStream ?pa)) ?uAtt <- (unitAttributes (Pump ?ua)) => (retract ?nff) (assert (NeedFireFlow_forPumpers (format nil "%.2f" (- ?ffn 500)))) (modify ?pAtt (HoseStream (+ ?pa 5))) (modify ?uAtt (Pump (+ 1 ?ua))) (modify ?pum (unitTypeAvailable (- ?uAv 1))))	This rule modifies the persAttributes fact and unitAttributes fact if the conditions are met.
Rule 2	(defrule find_numberOf_hydrants "This rule will find the best combination of hydrants according to the FireFlowNeeded" (declare (salience 60) (auto-focus TRUE)) ?nff <- (NeedFireFlow_forHydrants ?ffn&:(> ?ffn 0)) ?numh <- (NumHydrants ?nh) ?h1 <- (hydrant (hydrantIndex ?HI1) (x_lon ?Hx1) (y_lat ?Hy1) (flow ?hff1) (distance ?d1) (is_candidate FALSE)) (not (hydrant {distance < ?d1} (is_candidate FALSE))) => (retract ?numh) (retract ?nff) (assert (NeedFireFlow_forHydrants (- ?ffn ?hff1))) (assert (NumHydrants (+ ?nh 1))) (modify ?h1 (is_candidate TRUE)))	This rule determines the number of fire hydrants based on the amount of fire flow needed.
Rule 3	(defrule Task300Rule "Establish Water Supply" ?t <- (task 300) (NumHydrants ?hyd) ?pAtt <- (persAttributes (HoseStream ?pa)) ?uAtt <- (unitAttributes (Pump ?ua)) => (modify ?pAtt (HoseStream (+ ?pa (* 2 ?hyd)))) (modify ?uAtt (Pump (+ ?ua 1))) (retract ?t))	This rule determines how many pumper trucks and personnel with the attribute of hose/stream is required to perform Task300

Rule #	Non-Fuzzy Rule	Description
Rule 4	(defrule calculate_exposures_implicit_distance "This rule will calculate the implicit separation distance." (declare (salience 80) (auto-focus TRUE)) ?e1 <- (exposureInfo (x_lon ?x2) (y_lat ?y2) (size_sqft ?ESize) (distance 1000.0)) (buildingInfo (x_lon ?x1) (y_lat ?y1) (size_sqft ?ASize)) => (if (<= (abs (- ?x2 ?x1)) (+ (halfSide ?ASize) (halfSide ?ESize))) then (if (> ?y2 ?y1) then (modify ?e1 (distance (format nil "%.2f" (- (- ?y2 ?y1) (+ (halfSide ?ASize) (halfSide ?ESize)))))) else (modify ?e1 (distance (format nil "%.2f" (- (- ?y1 ?y2) (+ (halfSide ?ASize) (halfSide ?ESize))))))) else (if (> ?x2 ?x1) then (if (<= (abs (- ?y2 ?y1)) (+ (halfSide ?ASize) (halfSide ?ESize))) then (modify ?e1 (distance (format nil "%.2f" (- (- ?x2 ?x1) (+ (halfSide ?ASize) (halfSide ?ESize)))))) else (if (> ?y2 ?y1) then (modify ?e1 (distance (format nil "%.2f" (distance (+ ?x1 (halfSide ?ASize)) (+ ?y1 (halfSide ?ASize)) (- ?x2 (halfSide ?ESize)) (- ?y2 (halfSide ?ESize)))))) else (modify ?e1 (distance (format nil "%.2f" (distance (+ ?x1 (halfSide ?ASize)) (- ?y1 (halfSide ?ASize)) (- ?x2 (halfSide ?ESize)) (+ ?y2 (halfSide ?ESize)))))))) else (if (<= (abs (- ?y2 ?y1)) (+ (halfSide ?ASize) (halfSide ?ESize))) then (modify ?e1 (distance (format nil "%.2f" (- (- ?x1 ?x2) (+ (halfSide ?ASize) (halfSide ?ESize)))))) else (if (> ?y2 ?y1) then (modify ?e1 (distance (format nil "%.2f" (distance (- ?x1 (halfSide ?ASize)) (+ ?y1 (halfSide ?ASize)) (+ ?x2 (halfSide ?ESize)) (- ?y2 (halfSide ?ESize)))))) else (modify ?e1 (distance (format nil "%.2f" (distance (- ?x1 (halfSide ?ASize)) (- ?y1 (halfSide ?ASize)) (+ ?x2 (halfSide ?ESize)) (+ ?y2 (halfSide ?ESize)))))))))))	This rule calculates the separation distance. For further information refer to 3.8
Rule 5	(defrule fetch-store_closest_ExpDistances "This rule will store the closest exposure to the incident and the Java code will fetch this value later" (declare (salience 85) (auto-focus TRUE)) (exposureInfo (distance ?d1&:(<> ?d1 1000.0))) (not (exposureInfo (distance ?d2&:(< ?d2 ?d1)))) => (store ExpDISTANCE ?d1))	This rule finds the closest exposure to the incident building and stores its distance in ExpDISTANCE, which is later fetched by the Java code.

Table 4-2 Description of Fuzzy Rules for the Construction Type6 Exposure Factor Calculations

Rule #	Fuzzy Rule for the Construction Type6 Exposure Factor Calculation	Description
Rule 1	private FuzzyRule Type6NearFastRule = new FuzzyRule(); Type6NearFastRule.addAntecedent(distType6NearFVal); Type6NearFastRule.addAntecedent(windSpdType6FastFVal); Type6NearFastRule.addConclusion(expfactor015FVal);	This rule is fired if: - The exposure is Near and - The wind speed is Fast => Exposure factor = 0.15
Rule 2	private FuzzyRule Type6NearOKRule = new FuzzyRule(); Type6NearOKRule.addAntecedent(distType6NearFVal); Type6NearOKRule.addAntecedent(windSpdType6OKFVal); Type6NearOKRule.addConclusion(expfactor010FVal);	This rule is fired if: - The exposure is Near and - The wind speed is OK => Exposure factor = 0.10
Rule 3	private FuzzyRule Type6NearSlowRule = new FuzzyRule(); Type6NearSlowRule.addAntecedent(distType6NearFVal); Type6NearSlowRule.addAntecedent(windSpdType6SlowFVal); Type6NearSlowRule.addConclusion(expfactor005FVal);	This rule is fired if: - The exposure is Near and - The wind speed is Slow => Exposure factor = 0.05
Rule 4	private FuzzyRule Type6OKFastRule = new FuzzyRule(); Type6OKFastRule.addAntecedent(distType6OKFVal); Type6OKFastRule.addAntecedent(windSpdType6FastFVal); Type6OKFastRule.addConclusion(expfactor010FVal);	This rule is fired if: - The exposure is OK and - The wind speed is Fast => Exposure factor = 0.10
Rule 5	private FuzzyRule Type6OKOKRule = new FuzzyRule(); Type6OKOKRule.addAntecedent(distType6OKFVal); Type6OKOKRule.addAntecedent(windSpdType6OKFVal); Type6OKOKRule.addConclusion(expfactor005FVal);	This rule is fired if: - The exposure is OK and - The wind speed is OK => Exposure factor = 0.05
Rule 6	private FuzzyRule Type6OKSlowRule = new FuzzyRule(); Type6OKSlowRule.addAntecedent(distType6OKFVal); Type6OKSlowRule.addAntecedent(windSpdType6SlowFVal); Type6OKSlowRule.addConclusion(expfactor005FVal);	This rule is fired if: - The exposure is OK and - The wind speed is Slow => Exposure factor = 0.05
Rule 7	private FuzzyRule Type6FarFastRule = new FuzzyRule(); Type6FarFastRule.addAntecedent(distType6FarFVal); Type6FarFastRule.addAntecedent(windSpdType6FastFVal); Type6FarFastRule.addConclusion(expfactor005FVal);	This rule is fired if: - The exposure is Far and - The wind speed is Fast => Exposure factor = 0.05
Rule 8	private FuzzyRule Type6FarOKRule = new FuzzyRule(); Type6FarOKRule.addAntecedent(distType6FarFVal); Type6FarOKRule.addAntecedent(windSpdType6OKFVal); Type6FarOKRule.addConclusion(expfactor005FVal);	This rule is fired if: - The exposure is Far and - The wind speed is OK => Exposure factor = 0.05
Rule 9	private FuzzyRule Type6FarSlowRule = new FuzzyRule(); Type6FarSlowRule.addAntecedent(distType6FarFVal); Type6FarSlowRule.addAntecedent(windSpdType6SlowFVal); Type6FarSlowRule.addConclusion(expfactor005FVal);	This rule is fired if: - The exposure is Far and - The wind speed is Slow => Exposure factor = 0.05

Table 4-3 Construction Type6 Input/Output Fuzzy Rule Diagrams

Rule #	Input Fuzzy Sets		Output Fuzzy Set
	Separation Distance Fuzzy Set	Effective Wind Speed Fuzzy Set	Exposure Factor Fuzzy Set
Rule 1			
Rule 2			
Rule 3			
Rule 4			
Rule 5			
Rule 6			
Rule 7			
Rule 8			
Rule 9			

4.2 Underlying Architecture of *i*FAST

The structure of our system model is designed based on the points of incident assessment, which were described in Chapter 3. In addition to these points, we categorized the duties of firefighters into 20 main tasks. These tasks are listed in Table 4-4.

Table 4-4 Tasks performed by firefighters on-scene

#	Task	#	Task
1	Establish Incident Command, size-up	300	Establish Water Supply from Tanker
100	Enter Structure – rescue	300	Establish Water Supply from Static Source such as pool, river, lake, etc
101	Search and Rescue Operations – Interior	301	Apply 250 gpm stream – Exterior
110	Stabilize Patient	303	Enter Structure – suppress/extinguish fire
120	Perform Extrication	305	Ventilation Operations – Basic, no roof operations
130	Evacuate Structure	306	Ventilation Operations – Full
140	Administer ALS and Transport patient	311	Apply 250 gpm fog – Exterior
150	Administer BLS and Transport patient	321	Overhaul and Salvage – Basic
160	Administer 1st Aid to Patient	321	Overhaul and Salvage – Full
300	Establish Water Supply from Hydrant	330	External Rescue Operations – including with ladders

A series of our system main rules are developed based on these tasks. These rules are amongst the first rules to be executed after inserting the necessary information to the working memory in the form of facts. The output of these rules influences the size-up mechanism of our system.

Figure 4-12 illustrates the underlying architecture of our fuzzy expert system. This architecture consists of three main components: Input, which is in fact the gate to our fuzzy expert system, FuzzyJess Engine that handles the fuzzy concepts, and JESS Engine that deals with non-fuzzy materials.

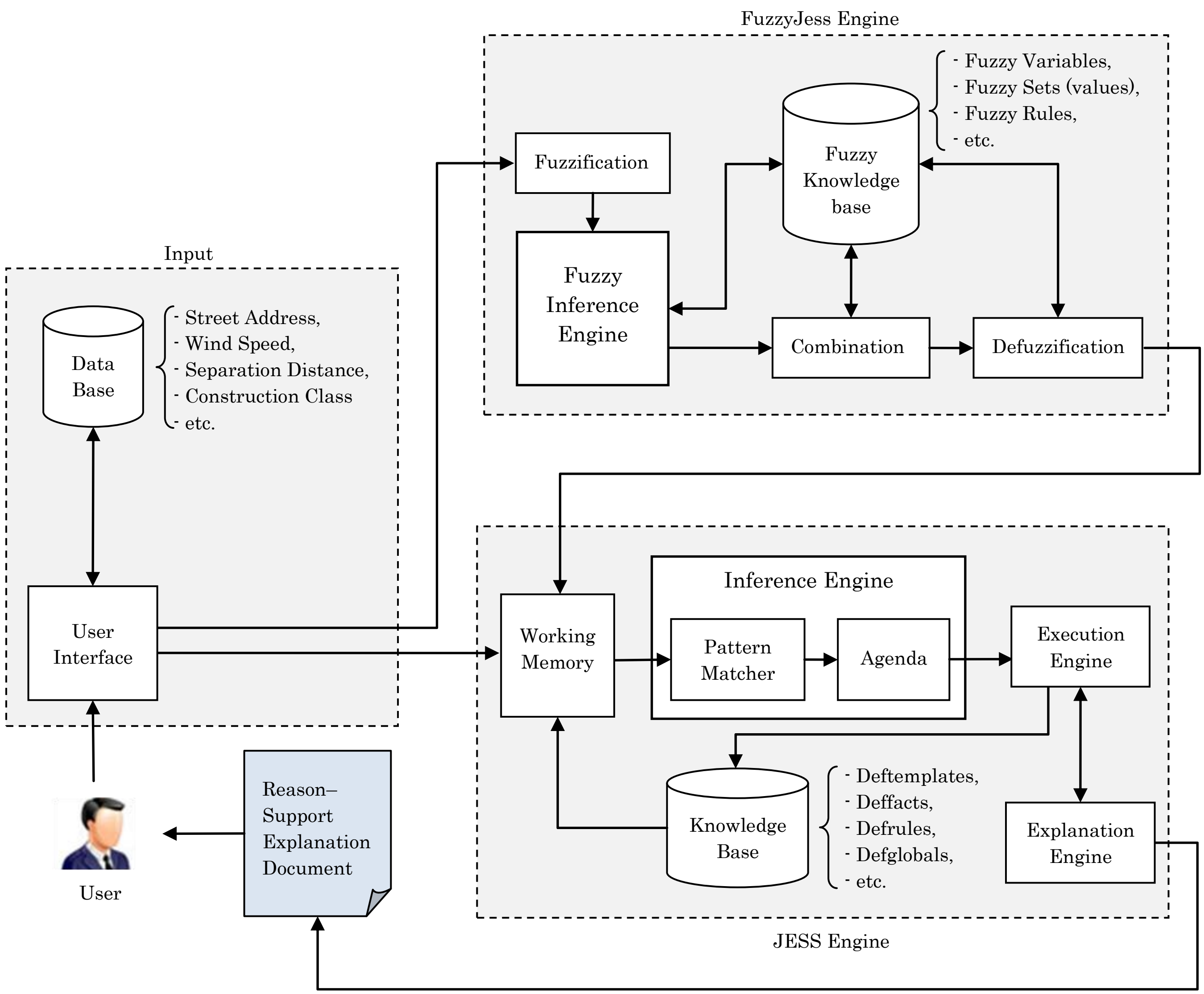


Figure 4-12 The underlying architecture

4.2.1 Input component

The Input component consists of a user interface and a database. As Figure 4-12 demonstrates, the user interacts with the system through a user interface. Through the user interface the addresses of the incident and the exposure(s) accompanying other data are fed to the system. The input for these components is provided by user inputs and data retrieval from the database. The database is provided by CriSys Ltd and contains information regarding the street addresses, building construction types, occupancy types and much more. These factors are described in Chapter 3.

The input data to the FuzzyJess Engine component, which is received from the user interface, is in the form of both numerical crisp data, and linguistic and fuzzy values. However, the input information to the JESS Engine component is only in the form of numerical data.

4.2.2 FuzzyJess Engine component

The FuzzyJess Engine component contains four elements and a fuzzy knowledge base. These four components are fuzzification, fuzzy inference engine, combination, and defuzzification and are all in close relation with the fuzzy knowledge base.

Our fuzzy knowledge base consists of fuzzy variables, fuzzy sets, fuzzy rules and other fuzzy components of our system.

We used triangle fuzzy sets in order to fuzzify the crisp inputs such as wind speed or distance when required. Since Takagi-Sugeno-Kang was chosen to be used as our inference mechanism, the fuzzification step can be skipped for linguistic fuzzy values. 2.1.8 describes the TSK model. The following are two examples of fuzzification in our fuzzy expert system:

FuzzyValue (distanceType1, new TriangleFuzzySet (distance-1.0, distance, distance+1.0));
FuzzyValue (windSpdType1, new TriangleFuzzySet (windSpd-1.0, windSpd, windSpd+1.0));

After the fuzzification step, the fuzzy inference engine component draws conclusions based on the fuzzified values. In this step, the executable fuzzy rules are chosen to be fired. The FuzzyJess function *fuzzy-match* compares two fuzzy values to determine whether or not they match [**5**]. For instance, the above fuzzified distance value, which is in a triangle-shape, is compared to each trapezoid-shape distance fuzzy set – such as near, OK, or far – to find the best match. Afterwards, the related fuzzy rules are fired, which result in one or more output fuzzy sets. This is mainly because of the fact that the input triangle-shaped distance fuzzy set, for instance, can belong to more than one fuzzy set, with different membership values and met more than one relating rule's condition; therefore, more than one fuzzy rule are to be fired.

The next step is the combination step. In the step of combination, all the fuzzy subsets assigned to the output variable are combined together to form a single fuzzy subset.

After the combination step, fuzzy values are transferred to crisp values using defuzzification techniques. Since the output fuzzy sets of *i*FAST are in the form of singleton fuzzy set, the most proper defuzzification mechanism is maximum defuzzification. More information on the foundation of fuzzy systems are provided in 2.1 and [**56**].

4.2.3 JESS Engine component

The output of the FuzzyJess Engine accompanying the information gathered from the user are then being fed to our second main component, JESS Engine, in the form of facts. The JESS Engine component contains three elements and a knowledge base. These components are the working memory, the inference engine, and the explanation engine. The inference engine, in turn, consists of a pattern matcher, an agenda, and an execution engine.

The working memory, sometimes called the fact base, contains all the information the expert system is working with. Facts are asserted in the working memory from three different sources.

- A number of facts, which contain information about the incident building, weather conditions, fire hydrants and such are asserted from the user interface (from both the input values inserted by the user and the consequent data retrieved from the database).
- Another series of facts are asserted in the working memory from the knowledge base. These facts are implemented in the form of deffacts and are asserted to the working memory as soon as the JESS engine is invoked. Facts relating to the personnel types, emergency resource (unit) types and hydrant types are a few examples of the mentioned facts.
- The last group of facts are added to the working memory from the fuzzyJess engine component. As mentioned earlier, the fuzzyJess engine component outputs are in the form of crisp values. The fact representing the exposure

factors, which are used in the Needed Fire Flow calculation is an example of this group of facts.

The central part of an expert system is its inference engine. The inference engine controls the process of applying rules to the facts in the working memory to draw inclusions based on these facts. This component consists of three elements: pattern matcher, agenda, and execution engine.

The pattern matcher component decides on what rules to be fired and when. The process of pattern matching is being dealt with the optimized pattern matching algorithms provided by JESS expert system shell.

Once the inference engine decides on the rules that are to be fired, an ordered list of the fireable rules is stored in the agenda. Agenda uses a specific conflict strategy in order to label the priority of each rule and defines which rule has the highest priority. Rules may also have priorities attached to them. This is possible by setting the salience of the rule to a number. The larger the salience value, the higher the rule priory. For instance, looking at Table 4-1, rule fetch-store_closest_ExpDistances has a higher priority than rule find_numberOf_hydrants.

JESS has two conflict strategies: depth (LIFO), and breadth (FIFO). By following the depth strategy, which is the default conflict strategy of JESS, the most recently activated rules are fired before the least recently activated ones with the same salience.

On the other hand, by activating the breadth strategy, rules with the same salience are fired in the order that they are activated. We calculated the impact of both conflict strategies and it was evident that the final results were independent of the type of the deployed conflict strategy.

The execution engine component fires the executable rules in the same order as the agenda. In older rule engines, such as MYCIN, rules could only add, retract, and modify the facts, where in more modern engines, such as JESS, programmers are offered with complete programming language effects in addition to the basic add, remove and modify effects.

The explanation engine component is capable of providing a human readable, plain-language explanation of the reasoning and factors behind a given decision. This component is basically the output gate of the JESS Engine main component and is in charge of producing the reason-support explanation document, which is being presented either to the dispatch center personnel or as the liability defence in a lawsuit.

The knowledge base contains all the non-fuzzy rules of our expert system. A number of examples are provided in Table 4-1.

The rule compiler of JESS builds complex and independent data structure called a Rete network, which speeds up the rule processing. For more information about Rete network please refer to chapter 8 of [**4**].

The last component of *i*FAST model is the report generated by our fuzzy expert system. This report is generated in addition to the suggested decision on the number and the types of the emergency resources and is a well-defined, explanatory document that provides evidence and strong reasoning behind the recommended size-up results.

4.3 Developing *i*FAST

There are usually two groups of people involved in the development of an expert system. These groups include: the domain experts and the knowledge engineers.

The domain experts have a vast amount of information and knowledge about the domain of the problem and have the capability to handle and solve these problems. Although the domain experts are fully experienced and knowledgeable about the detailed aspects of the problem, they lack computer programming abilities and the knowledge involving the implementation of a system with all the necessary features.

The knowledge engineers, on the other hand, are a group that contains individuals who are thoroughly familiar with programming concepts and technologies. Despite being experienced in designing expert systems and employing computer technologies involved, the knowledge engineers have little or no knowledge about the problems at hand.

The process of obtaining and gathering proper knowledge and transforming it to appropriate rules is called knowledge acquisition [**57**].

One of the great advantages of using fuzzy expert systems is that the communication between the domain experts and the knowledge engineers is made easier. This is due to the fact that the rules can be written in the language that the domain experts speak.

In order to perform the knowledge acquisition phase, we conducted months of interviews with a large number of experienced fire captains and firefighters. We studied and analysed the process of on-scene size-up of a large number of scenarios, in addition to the factors that the fire chiefs consider on scene. A number of fire departments committed to contributing domain expertise by making experienced staff available for interviews. These fire departments are categorized by size and characteristics in Table 4-5.

		Population			
		Small Town (< 50K)	Small City/Region (50K-100K)	Medium-Sized City/Region (100K-200K)	Large City/Region (> 200K)
Characteristics	Rural/Agricultural	Hawkesbury Fire Department	Clarington Fire Department	Brantford Fire Department	–
	Residential	Orillia Fire Department	Saint Albert Fire Department	Pickering Fire Department	–
	Light Industrial base	Belleville Fire Department	Moncton Fire Department	Saint John's Regional Fire Department	Kitchener Fire Department
	Residential	Grande Prairie Fire Department	Sault Ste. Marie Fire Department	Cambridge Fire Department	Oshawa Fire Department

Table 4-5 List of the collaborative fire departments

Since facts and rules are written in a language similar to English, the communications between the knowledge engineers and the domain experts is facilitated. The knowledge engineers are able to get verifications from the domain experts simply by showing them the facts and the rules of the fuzzy expert system. However, one of the disadvantages of FESs is that the knowledge acquisition phase is usually difficult. Distinguishing between a firefighter's mind process and the standard tasks that they are to perform is not an easy job. Additionally, firefighting tasks can hardly be modeled and categorized, since firefighters follow their senses and they usually decide on their actions based on what they observe on scene. As one of the experienced officers stated, firefighting is like fighting a dragon. Firefighters are to be proactive, since this dragon tries to run away from them. As a result, despite having all the available factors amenable, the shape and movement of fire itself is a decisive factor.

In addition, there are mainly two types of fire departments: volunteer and career. As the names imply, firefighters are volunteered to be at a volunteer fire department at undetermined times, while in a career fire department, firefighters are employed to be there at specific times. Therefore, the availability of the personnel is dependent on the type of the fire department.

Thus, another concern is that depending on the fire department rules and regulations, and whether it is a career or a volunteer fire department, the availability of the personnel and units is limited; hence different sets of considerations are required.

After the implementation of the system, we tuned the accuracy using a tuning data set similar to the training set of a neural network. This training data is usually much smaller than the training set that is required to train the neural networks [**14**]. This is one of the advantages of using FESs over neural networks. In order to tune *i*FAST's accuracy, we used a portion of the data provided by CriSys Ltd. These data have been collected from the Brantford fire department since December 22nd, 1999 to date.

After tuning our proposed fuzzy expert system, we validated *i*FAST with the test and validation data provided by CriSys Ltd. Note that the tuning data is different from the test and validation data. Furthermore, the test and the validation process are similar to the neural networks.

4.4 Experiment and Results

We have carried out an extensive experiment and numerous tests to investigate the performance and accuracy of the proposed fuzzy expert system. These series of tests showed increase in the dispatch time to less than thirty seconds, while maintaining similar yet better results in regards to the emergency resource management.

As previously stated, to test and validate *i*FAST, we used the information that is collected by CriSys Ltd of different fire departments. One of these departments is located in Brantford city, which is on the Grand River in Southern Ontario, Canada. Brantford Fire Department started using XpertFire on December 22nd, 1999. However, the available data date-range is from January 1st, 2000 to June 30th, 2010.

Since December 22nd, 1999 to date, there have been 39,337 emergency responses in Brantford city where a vehicle has been dispatched (i.e. these did not involve false-alarms). Of these 39,337 fire emergencies, 4,771 have requested multiple resource dispatch resources.

Due to the fact that the OFM (Ontario Fire Marshal) changed their reporting requirements on January 1st, 2009, there is insufficient data prior to this date; therefore, not much of the information between January 1st, 2000 and December 31st, 2008 is of use. As a consequence, two data reports were provided by CriSys Ltd. (1) OFM Incident Report 2000-2008 and (2) OFM Incident Report 2009-2010.

The two OFM Incident Reports contain information regarding the following:

- Location which includes x and y co-ordinates (latitude and longitude), street number, street name, unit number, name of the city (which in this case is Brantford city, Ontario, Canada) and postal code of the incident and exposure buildings.

- Date and time of five main events. These five events are the alarm date and time, time on scene, application time, under control date, and different dispatch times. The alarm date and time indicates the time when the emergency call was received. The time on scene specifies the arrival time of the first dispatch resources on the scene. The application time denotes the time when the firefighters started the process of fire suppression. The under control date represents the time when the fire was completely extinguished. And the different dispatch times denote the different times when the resources were dispatched. This may contain more than one date and time, since in a number of cases, additional requests of resources have been made by the officer in command.

- Incident information such as number of dispatches, the alarm source (e.g. 911, telephone from civilian, etc.), the response type (e.g. fire), the event status on arrival (whether or not the smoke and/or flames were visible, etc.), the area and source of origin, the estimation of loss and value at risk, number of exposure(s) around the incident building, the initial detection method (e.g. the fire alarm system, the smoke alarm system, person reporting, etc.), the level of origin (which floor), number of evacuated people,

- Building information includes the property type (e.g. detached, semi-detached, multi-unit dwelling, etc.), the complex type (e.g. apartment, educational institution, manufacturing/storage complex, etc.), the occupancy status and type, the number of storeys, the structure age (i.e. how old the building is), the availability and functionality of the smoke alarm system, the presence and functionality of the fire alarm system and the existence and operation of the sprinkler system.

- Exposure information includes similar information as of the incident building such as x and y co-ordinates (latitude and longitude), number of storeys, property and complex types, occupancy type and status, the availability and functionality of the alarm systems, etc.

- Water supply information including the number of hydrants within 600 meters of the incident, the x and y co-ordinates (latitude and longitude) and the type of the hydrants, minimum, maximum and mean flow of the hydrants, the hydrant pressure and the information regarding the existing open waters close to the incident such as swimming pools or lakes.

- The information regarding the dispatched personnel and units including the number of dispatches, time and date of each dispatch, the total number of personnel on scene, and the number and the types of units for each dispatch.

It is important to mention that not all of the incidents contain the full details on all the mentioned attributes. Furthermore, unfortunately, the data gathered from Brantford fire department do not contain information regarding the weather conditions at the incident time. However, we have estimated the weather conditions via looking through the history of a number of weather forecast websites. In addition, the data regarding the size of the incident and exposure(s) buildings were not collected by the fire department staff. We estimated the construction sizes using Google map [58] and an application provided by View of House website [59].

Table 4-6 demonstrates a number of test cases in order to provide verification of the accuracy of our proposed system.

The following are few reasons why the suggested number and types of units and personnel by *i*FAST do not exactly match the actual dispatched resources to these cases.

One of the main reasons is that the information provided by the fire departments is usually submitted by officers and staff, who were not necessarily on scene; thus lacks accuracy and validity. On the other hand, not all the data are provided by the fire departments and in many cases a large number of data are missing. Therefore, there is not always enough information on hand in order to be fed to the system to get the best possible results. For instance, size of the buildings and the surrounding exposure(s) were not being recorded and also the occupancy profile and type in addition to the construction type of the buildings were not defined.

Another main reason is the time of the dispatch. It is an obvious fact that if sufficient number and proper types of resources were sent to the incident on the first attempt, the under control time would be less; hence, there would be no need for the additional resource requests. In other words, if the adequate number and types of resources were available all at the same time on seen, the firefighters could have extinguished the fire before it would grow larger and travel to other buildings. Therefore, with less number of resources than is recorded on each incident's profile, the situation could be taken over.

One more reason for the difference between the numbers of resources of each type would be the fact that units and personnel with similar attributes can be used interchangeably.

A theoretical analysis of the cases presented in Table 4-6 is as follows:

Incident 2009-182:

A phone call was received from a civilian on January 20th, 2009 at 7:33 A.M. reporting a fire emergency at a secondary/senior high school. The smoke alarm was present but did not operate. However, the fire alarm system functioned, resulting in evacuation of people in the building. The incident building is a three storey construction with an approximate size of 4600 ft^2. The value at risk was estimated more than two million dollars. No request for additional resources was recorded. The time between the alarm and the resource dispatch was 33 seconds.

This case is provided in order to evaluate the accuracy of *i*FAST compared with a one-time-dispatch event. The dispatch time provided by *i*FAST is still a few seconds less than this incident's dispatch time. According to the results, the accuracy of the system in this case is extremely high. However, an extra Pumper truck was suggested by *i*FAST due to the size and the attributes of the incident building and the fact that the occupancy profile of such construction in the morning demonstrates a high number of occupancy.

Incident 2009-1478:

On May 17th 2009, at 4:41 A.M. a fire emergency was reported. An exposure (a recently constructed two-storey building) was involved in addition to the old one-storey structure. Both the incident and the exposure constructions were detached dwellings, located close to each other. It is recorded that the fire was initiated on the porch or the balcony and had spread and traveled to the whole building.

The value at risk was estimated to be $200,000 to $499,999. As the time and occupancy profiles imply, there was a high chance that both buildings were occupied and the occupants were almost certainly asleep.

There are thirteen dispatch events recorded for this event. This is doubtlessly a consequence of the lack of knowledge about the existence of the exposure.

The number of resources that *i*FAST suggests is less than the number of resources that were sent to the incident. This is simply as a result of not sending adequate number of resources to the event at the first time; therefore, fire was spread due to the delay and insufficient emergency equipments. *i*FAST suggests a total of nine Pumper and Rescue trucks. Five Pumper Trucks are responsible for the incident building while four other trucks are used to take control over the exposure building. These four trucks are in charge of performing the cooling process in order to reduce the combustibility of the exposure building. Moreover, since *i*FAST suggests a proper number of personnel before dispatching the resources, only two Utility Vehicles are required accompanied with other units to transfer all the personnel to the incident.

The number of personnel that *i*FAST recommends is larger than the recorded number of personnel used. Sending seventeen personnel on seventeen units does not seem to make sense. This number of personnel might be due to the lack of accuracy of the recorded data or insufficient available personnel at the time of the emergency.

Incident 2009-3121:

A report of a fire emergency was received on September 14th, 2009 at 1:01 A.M. It is recorded that flames were visible from a small area of the structure. The incident building was an old two-storey detached dwelling with an estimated value of $50,000 to $99,999. There was no smoke alarm, fire alarm and sprinkler systems available.

There were a total of seven dispatch events recorded on this incident's profile. The last request was dispatched after more than eight hours. Due to the delay and lack of all the required resources on scene, the entire structure was destroyed.

Since the structure was a two-storey construction, an Arial truck (Ladder truck) is suggested instead of a Pumper truck. All the required personnel can be sent to the incident on the recommended units; hence no Utility Vehicle is required.

Incident 2010-124:

This incident was reported on January 13th, 2010 at 7:12 A.M. As described, flames were showing from more than one storeys initiated from the kitchen. The incident building is an old Attached Dwelling (constructed prior to 1946) and not equipped with a sprinkler system. The value of the building is estimated to be 1 million to 1.9 million dollars.

As results illustrate, *i*FAST recommends two Arial units for this incident rather than one. This is mainly due to the size and the number of storeys of the construction. According to the occupancy profile of this building, there is a high probability of people being trapped and/or injured.

Additionally, Arial and Pumper trucks can be used interchangeably. As suggested by our system, only one Chief or Command unit is necessary and the required personnel can easily be transported to the incident using only three Training or Utility Vehicles rather than four. Using one extra vehicle for sending additional personnel to the incident might be a result of delayed recognition that more personnel are required on-scene.

Thirteen dispatch events were reported for this incident and the time between the alarm and last dispatch time is more than seven hours. Considering the outstanding time difference, there is no need to further underline the enormous positive impact of deploying *i*FAST to this incident.

Incident 2010-199:

A fire emergency was reported on January 20th, 2010 at 6:56:45 P.M. The fire was initiated in the bathroom of the first floor of a four-storey attached dwelling. There was a report indicating the existence of a number of occupants which were evacuated as a result of hearing the fire alarm.

The incident building, which is a newly constructed structure, was estimated to be worth 1 million to 1.9 million dollars.

There is a report of two dispatches to this incident and the time between the alarm and the last dispatch was two minutes and thirty eight seconds.

The proposed resources by *i*FAST are similar to the actual dispatched units in this case. However, an Arial truck is suggested instead of a Pumper truck. This is due to the number of the storeys of the incident building and the presence of the sprinkler system. We would again like to mention that these two trucks can be used interchangeably.

Incident 2010-805:

On March 25th, 2010 at 7:46 P.M. a report was received indicating that the individual's fence had caught on fire. The fire eventually spread to the main building structure, which is a two-storey construction.

A report of two dispatches is on file. Only one Pumper truck was dispatched to the incident at first, regardless of the fact that the fire would have quickly spread to the actual building. Thus an additional resource request was obligatory.

*i*FAST recommends one less emergency unit than was actually dispatched to the incident. This one extra truck may be a result of the delay in dispatching the adequate amount of resources to the event.

Incident 2010-1807:

This incident happened only two months prior to the completion of this thesis, on June 12th, 2010 at 4:30 A.M. Unfortunately, there is a report of one fatality. As the caller described, flames were showing from a small part of an attached dwelling. There were ten other similar structures involved as exposures. Considering the time of this disaster, a significant number of occupants were involved and presumably asleep. A number of occupants were evacuated but some were unable to exit due the heavy smoke and fire that blocked the exits.

The construction and the surrounding exposures were recently built but lacked smoke alarm, fire alarm, and sprinkler systems.

A total number of eight dispatches were recorded and the total value at risk was estimated to be $750,000 to $999,999.

*i*FAST suggests seven Pumper and Rescue trucks accompanying one Command truck, while the resources that were dispatched to the actual event include four Pumper and rescue trucks, three Command and two Utility Vehicles.

Considering the situation, there were ten attached dwellings to the incident construction, which could have been less if the adequate number of resources were dispatched at the first time. These constructions were two-storey small/medium attached structures. The main tasks that are essentially required in these situations are search and rescue, evacuation, salvage, first aid, and establishing water supplies; thus Pumper trucks were more useful than Chief and Command units. On the other hand, all the required personnel can be transported to the event using the suggested units; therefore, no Utility Vehicles were required.

Incident 2010-1841:

Only less than two month prior to the completion of this document, on June 14th, 2010 at 5:16:48 P.M. a fire emergency was reported shortly after witnessing smoke coming out of a detached dwelling. The incident building was an old two-storey structure equipped with smoke alarm system. The occupants evacuated the construction immediately after hearing the smoke alarm. The value at risk was estimated to be $100,000 to $199,999.

A total number of eight dispatch events were recorded. The time between the alarm and the last dispatch is two hours and thirteen minutes. *i*FAST recommends an Arial and a Pumper truck instead of two Command units. This is due to the reason that an Arial truck is required to perform the ventilation, salvage, and rescue tasks. Additionally, all the required personnel can be easily transported to the incident location using the recommended units; thus, no further Utility Vehicles are required.

Table 4-6 Comparison of results

Incident number	Number of Dispatch Events	Alarm date/time	Last dispatch time	Time between the alarm and the last dispatch time	Under Control Date	Full Property Type	Full Value at Risk	Building Size / Area (ft²)	Total number of Exposures	Full Occupancy Type or Status	Full Building Height (Storeys)	Sprinkler Presence	Num of Hydrants within 600m	Existing Results: Total Personnel	Existing Results Units: Areal	Existing Results Units: Pumper/Rescue	Existing Results Units: Chief/ICU/command	Existing Results Units: Prevention/Training/ Utility Vehicle	Existing Results Units: Total Units	*i*FAST Results: Total Personnel	*i*FAST Results Units: Areal	*i*FAST Results Units: Pumper/Rescue	*i*FAST Results Units: Chief /ICU/Command	*i*FAST Results Units: Prevention/Training/ Utility Vehicle	*i*FAST Results Units: Total Units
2009-182	1	20/01/2009 07:33:01	20/01/2009 07:33:34	0:00:33	20/01/2009 07:43:17	School Secondary/Senior High (Gr. 9+)	$2Million+	4600	0	Seasonal (In Use) Person(s) Present	3	YES	57	17	1	3	1	0	5	17	2	3	1	0	6
2009-1478	13	17/05/2009 04:41:40	17/05/2009 10:37:03	6:55:23	17/05/2009 11:05:00	Detached Dwelling	$200,000 to $499,999	3700	1	Permanent Person(s) Present	1	NO	54	17	1	11	1	4	17	31	1	9	1	2	13
Exposure close to incident 2009-1478					17/05/2009 9:05:00	Detached Dwelling	$10,000 to $49,999	2500	0	Permanent - Person(s) Present	2	NO													
2009-3121	7	14/09/2009 01:01:26	14/09/2009 09:14:48	8:13:22	14/09/2009 09:53:00	Detached Dwelling	$50,000 to $99,999	2800	0	Undetermined	2	NO	54	15	0	7	1	1	9	22	1	6	1	0	8
2010-124	13	13/01/2010 07:12:32	13/01/2010 14:19:36	7:07:04	13 Jan 2010 14:39:00	Attached Dwelling with Business	$1Million to $1.9Million	3300	0	Renter(s) only (business or residential, exc. students)	2	NO	94	42	1	9	2	4	16	58	2	8	1	3	16

Incident number	Number of Dispatch Events	Alarm date/time	Last dispatch time	Time between the alarm and the last dispatch time	Under Control Date	Full Property Type	Full Value at Risk	Building Size / Area (ft²)	Total number of Exposures	Full Occupancy Type or Status	Full Building Height (Storeys)	Sprinkler Presence	Num of Hydrants within 600m	Existing Results						*i*FAST Results					
															Units						Units				
														Total Personnel	Areal	Pumper/Rescue	Chief/ICU/command	Prevention/Training/ Utility Vehicle	Total Units	Total Personnel	Areal	Pumper/Rescue	Chief /ICU/Command	Prevention/Training/ Utility Vehicle	Total Units
2010-199	2	20/01/2010 18:56:45	20/01/2010 18:59:13	0:02:38	20/01/2010 19:08:15	Attached Dwelling with Business	$1Million to $1.9Million	2700	0	Renter(s) only (business or residential, exc. students)	4	YES	100	17	0	4	1	0	5	16	1	3	1	0	5
2010-805	2	25/03/2010 19:46:29	25/03/2010 19:48:47	0:02:18	25/03/2010 19:55:43	Fence	$100,000 to $199,999	N/A	1	Owner(s) occupied (business or residential)	N/A	N/A	71	13	0	3	1	0	4	12	0	3	0	0	3
Exposure close to incident 2010-805					25/03/2010 19:45:43	Detached Dwelling	$100,000 to $199,999	1100	0	Owner(s) occupied (business or residential)	2	NO													
2010-1807	8	12/06/2010 04:30:45	12/06/2010 08:57:58	4:27:13	Unknown	Attached Dwelling (e.g. rowhouse, townhouse, etc.)	$750,000 to $999,999	1300	10	Owner(s) occupied (business or residential)	2	NO	53	20	2	4	3	2	11	28	2	7	1	0	10
2010-1841	8	14/06/2010 17:16:48	14/06/2010 19:29:56	2:13:08	14/06/2010 19:34:33	Detached Dwelling	$100,000 to $199,999	2900	0	Owner(s) occupied (business or residential)	2	NO	65	21	0	5	3	3	11	25	1	6	1	0	8

Chapter 5.

Contribution and Future Work

THIS chapter provides a conclusion of the development of *i*FAST together with a list of contributions made by implementing such system. Afterwards, a number of suggestions for future work is made in order to enrich our proposed fuzzy expert system and to enhance the dispatch and size-up methodologies.

5.1 Conclusion and Contributions

In this thesis, we proposed and implemented an intelligent fire threat assessment and size-up fuzzy expert system to enhance the existing fire emergency dispatch and size-up methodologies. *i*FAST is a fuzzy expert system that at this time is in the process of being embedded into a currently in-use emergency response system (Xpert^{Fire}).

Implementing such intelligent system reduces the size-up and dispatch response interval, which is usually between 8 to 16 minutes, to less than 30 seconds, while suggesting a valid and rational number of personnel and resources of proper types. *i*FAST has been proved to provide adequate resources considering a number of available decisive size-up factors in less than 30 seconds. A comprehensive analysis of the given system has shown improvement in reducing the dispatch and size-up time [60] and [61].

Consequently, embedding *i*FAST in the existing dispatch and emergency response systems can result in saving hundreds of lives and millions of dollars annually. The direct and indirect costs that could be saved by using such intelligent system contains the real and potential human resource productivity of those lost, healthcare, property damages and repairs, insurance issues and lawsuits.

The contributions of this work are as follows:

- Our main contribution is the enhancement of the current size-up and dispatch procedures by adding the fuzzy expert system concept to the traditional emergency response systems for the first time.

- As previously stated, the dispatch and size-up procedure time is reduced to less than 30 seconds due to considering the available points of incident assessment.

- Consequently, the use of the enhanced emergency response systems can result in reducing the number of injuries, trapped and fatalities.

- Additionally, the direct and indirect costs, which are the consequences of the time-consuming and belated dispatch and emergency response procedures, can be drastically reduced; thus, millions of dollars are saved annually.

- An explanation engine was designed to provide reasoning behind the suggested number and types of resources. The output of this component is a human-readable decision-support report that provides strong reasoning and factors behind the given decision.

5.2 Limitation and Future Work

One of our suggestions for the future work is to add adaptability feature to the system in order to provide learning ability. By adding case-based reasoning features to the system, *i*FAST is enabled to learn from the existing cases in order to provide more accurate results. However, due to lack of accuracy of the cases that have been recorded by the staff at different fire departments, adding this feature can be challenging.

Moreover, the exposure factors based on which we designed our fuzzy concepts, are empirical data determined and generated using the experiences of a number of fire chiefs. As a future work, we suggest research to be conducted in order to improve these factors based on the actual effects of the separation distance and effective wind speed.

Due to time limitations, we were only able to test and verify *i*FAST using the existing data, which were provided by CriSys Ltd. One of the future works that is currently in progress is performing field trials in order to verify the accuracy of our system on-line. CriSys proposes to install a single PC at each of the Canadian fire departments, listed in Table 4-5. The PCs will run the knowledge base and reasoning engine and will be connected to the main system of events. *i*FAST will then fire in response to real-world events, determine its recommendation, and compare its suggestion with the final and actual officers' on-scene assessment.

Appendix A. List of publications

Journal Papers

- A. Sadeghian, H. Mohammadi, and J. D. Lavers, "Prediction of dynamic characteristics of electric arc furnaces using two classes of adaptive neuro-fuzzy based predictors," under review, IEEE Transactions on Industrial Electronics, 2010.

- H. Mohammadi, and A. Sadeghian, "*i*FAST: An Intelligence Fire-threat Assessment and Size-up Technology for First Responders," to be submitted, 2010.

Conference Papers

- N. P. A. Browne, H. Mohammadi, A. Abhari and M. V. dos Santos, "An Artificial Immune System Based Sensor Network for Frost Warning and Prevention," in *Proceedings of Spring Simulation Multiconference (SpringSim'09)*, San Diego, CA 2009.

- H. Mohammadi and A. Sadeghian, "An Intelligent Fire Threat Assessment and Size-up Fuzzy Expert System for first Responders," to be submitted, 2010.

- H. Mohammadi and A. Sadeghian, "An Expert System for Homeopathic Anxiety Treatment", to be submitted, 2010.

Appendix B. List of the rules in the knowledge base

Index	Rule	Index	Rule
1	Task1Rule	30	peopleSeriousInjured
2	Task100Rule	31	peopleMinorInjured
3	Task101Rule	32	Binding_defglobal_fireFlow
4	Task110Rule	33	calculate_hydrants_distance
5	Task120Rule	34	Type1Near5Fast8Rule
6	Task130Rule	35	Type1Near5Fast7Rule
7	Task140Rule	36	Type1Near5Fast6Rule
8	Task150Rule	37	Type1Near5Fast5Rule
9	Task160Rule	38	Type1Near5Fast4Rule
10	Task300Rule	39	Type1Near5Fast3Rule
11	Task301Rule	40	Type1Near5Fast2Rule
12	Task303Rule	41	Type1Near5Fast1Rule
13	Task305Rule	42	Type1Near5OKRule
14	Task306Rule	43	Type1Near5Slow1Rule
15	Task311Rule	44	Type1Near5Slow2Rule
16	Task321Rule	45	Type1Near5Slow3Rule
17	Task330Rule	46	Type1Near5Slow4Rule
18	find_numberOf_hydrants	47	Type1Near5Slow5Rule
19	Number_of_500gpmPumpers	48	Type1Near5Slow6Rule
20	Number_of_350gpmPumpers	49	Type1Near5Slow7Rule
21	Number_of_100gpmPumpers	50	Type1Near4Fast8Rule
22	calculate_exposures_implicit_distance	51	Type1Near4Fast7Rule
23	fetch-store_closest_ExpDistances	52	Type1Near4Fast6Rule
24	combine-number-of-injured-and-trapped	53	Type1Near4Fast5Rule
25	combine-persAtts	54	Type1Near4Fast4Rule
26	combine-unitAtts	55	Type1Near4Fast3Rule
27	peopleTrapped	56	Type1Near4Fast2Rule
28	Injured	57	Type1Near4Fast1Rule
29	peopleCriticalInjured	58	Type1Near4OKRule

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60	Type1Near4Slow2Rule	93	Type1Near2Slow3Rule
61	Type1Near4Slow3Rule	94	Type1Near2Slow4Rule
62	Type1Near4Slow4Rule	95	Type1Near2Slow5Rule
63	Type1Near4Slow5Rule	96	Type1Near2Slow6Rule
64	Type1Near4Slow6Rule	97	Type1Near2Slow7Rule
65	Type1Near4Slow7Rule	98	Type1Near1Fast8Rule
66	Type1Near3Fast8Rule	99	Type1Near1Fast7Rule
67	Type1Near3Fast7Rule	100	Type1Near1Fast6Rule
68	Type1Near3Fast6Rule	101	Type1Near1Fast5Rule
69	Type1Near3Fast5Rule	102	Type1Near1Fast4Rule
70	Type1Near3Fast4Rule	103	Type1Near1Fast3Rule
71	Type1Near3Fast3Rule	104	Type1Near1Fast2Rule
72	Type1Near3Fast2Rule	105	Type1Near1Fast1Rule
73	Type1Near3Fast1Rule	106	Type1Near1OKRule
74	Type1Near3OKRule	107	Type1Near1Slow1Rule
75	Type1Near3Slow1Rule	108	Type1Near1Slow2Rule
76	Type1Near3Slow2Rule	109	Type1Near1Slow3Rule
77	Type1Near3Slow3Rule	110	Type1Near1Slow4Rule
78	Type1Near3Slow4Rule	111	Type1Near1Slow5Rule
79	Type1Near3Slow5Rule	112	Type1Near1Slow6Rule
80	Type1Near3Slow6Rule	113	Type1Near1Slow7Rule
81	Type1Near3Slow7Rule	114	Type1OKFast8Rule
82	Type1Near2Fast8Rule	115	Type1OKFast7Rule
83	Type1Near2Fast7Rule	116	Type1OKFast6Rule
84	Type1Near2Fast6Rule	117	Type1OKFast5Rule
85	Type1Near2Fast5Rule	118	Type1OKFast4Rule
86	Type1Near2Fast4Rule	119	Type1OKFast3Rule
87	Type1Near2Fast3Rule	120	Type1OKFast2Rule
88	Type1Near2Fast2Rule	121	Type1OKFast1Rule
89	Type1Near2Fast1Rule	122	Type1OKOKRule
90	Type1Near2OKRule	123	Type1OKSlow1Rule
91	Type1Near2Slow1Rule	124	Type1OKSlow2Rule

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125	Type1OKSlow3Rule	158	Type1Far2Slow4Rule
126	Type1OKSlow4Rule	159	Type1Far2Slow5Rule
127	Type1OKSlow5Rule	160	Type1Far2Slow6Rule
128	Type1OKSlow6Rule	161	Type1Far2Slow7Rule
129	Type1OKSlow7Rule	162	Type1Far3Fast8Rule
130	Type1Far1Fast8Rule	163	Type1Far3Fast7Rule
131	Type1Far1Fast7Rule	164	Type1Far3Fast6Rule
132	Type1Far1Fast6Rule	165	Type1Far3Fast5Rule
133	Type1Far1Fast5Rule	166	Type1Far3Fast4Rule
134	Type1Far1Fast4Rule	167	Type1Far3Fast3Rule
135	Type1Far1Fast3Rule	168	Type1Far3Fast2Rule
136	Type1Far1Fast2Rule	169	Type1Far3Fast1Rule
137	Type1Far1Fast1Rule	170	Type1Far3OKRule
138	Type1Far1OKRule	171	Type1Far3Slow1Rule
139	Type1Far1Slow1Rule	172	Type1Far3Slow2Rule
140	Type1Far1Slow2Rule	173	Type1Far3Slow3Rule
141	Type1Far1Slow3Rule	174	Type1Far3Slow4Rule
142	Type1Far1Slow4Rule	175	Type1Far3Slow5Rule
143	Type1Far1Slow5Rule	176	Type1Far3Slow6Rule
144	Type1Far1Slow6Rule	177	Type1Far3Slow7Rule
145	Type1Far1Slow7Rule	178	Type1Far4Fast8Rule
146	Type1Far2Fast8Rule	179	Type1Far4Fast7Rule
147	Type1Far2Fast7Rule	180	Type1Far4Fast6Rule
148	Type1Far2Fast6Rule	181	Type1Far4Fast5Rule
149	Type1Far2Fast5Rule	182	Type1Far4Fast4Rule
150	Type1Far2Fast4Rule	183	Type1Far4Fast3Rule
151	Type1Far2Fast3Rule	184	Type1Far4Fast2Rule
152	Type1Far2Fast2Rule	185	Type1Far4Fast1Rule
153	Type1Far2Fast1Rule	186	Type1Far4OKRule
154	Type1Far2OKRule	187	Type1Far4Slow1Rule
155	Type1Far2Slow1Rule	188	Type1Far4Slow2Rule
156	Type1Far2Slow2Rule	189	Type1Far4Slow3Rule
157	Type1Far2Slow3Rule	190	Type1Far4Slow4Rule

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192	Type1Far4Slow6Rule	225	Type2Near3Fast6Rule
193	Type1Far4Slow7Rule	226	Type2Near3Fast5Rule
194	Type2Near5Fast7Rule	227	Type2Near3Fast4Rule
195	Type2Near5Fast6Rule	228	Type2Near3Fast3Rule
196	Type2Near5Fast5Rule	229	Type2Near3Fast2Rule
197	Type2Near5Fast4Rule	230	Type2Near3Fast1Rule
198	Type2Near5Fast3Rule	231	Type2Near3OKRule
199	Type2Near5Fast2Rule	232	Type2Near3Slow1Rule
200	Type2Near5Fast1Rule	233	Type2Near3Slow2Rule
201	Type2Near5OKRule	234	Type2Near3Slow3Rule
202	Type2Near5Slow1Rule	235	Type2Near3Slow4Rule
203	Type2Near5Slow2Rule	236	Type2Near3Slow5Rule
204	Type2Near5Slow3Rule	237	Type2Near3Slow6Rule
205	Type2Near5Slow4Rule	238	Type2Near3Slow7Rule
206	Type2Near5Slow5Rule	239	Type2Near2Fast7Rule
207	Type2Near5Slow6Rule	240	Type2Near2Fast6Rule
208	Type2Near5Slow7Rule	241	Type2Near2Fast5Rule
209	Type2Near4Fast7Rule	242	Type2Near2Fast4Rule
210	Type2Near4Fast6Rule	243	Type2Near2Fast3Rule
211	Type2Near4Fast5Rule	244	Type2Near2Fast2Rule
212	Type2Near4Fast4Rule	245	Type2Near2Fast1Rule
213	Type2Near4Fast3Rule	246	Type2Near2OKRule
214	Type2Near4Fast2Rule	247	Type2Near2Slow1Rule
215	Type2Near4Fast1Rule	248	Type2Near2Slow2Rule
216	Type2Near4OKRule	249	Type2Near2Slow3Rule
217	Type2Near4Slow1Rule	250	Type2Near2Slow4Rule
218	Type2Near4Slow2Rule	251	Type2Near2Slow5Rule
219	Type2Near4Slow3Rule	252	Type2Near2Slow6Rule
220	Type2Near4Slow4Rule	253	Type2Near2Slow7Rule
221	Type2Near4Slow5Rule	254	Type2Near1Fast7Rule
222	Type2Near4Slow6Rule	255	Type2Near1Fast6Rule
223	Type2Near4Slow7Rule	256	Type2Near1Fast5Rule

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257	Type2Near1Fast4Rule	290	Type2Far1Fast1Rule
258	Type2Near1Fast3Rule	291	Type2Far1OKRule
259	Type2Near1Fast2Rule	292	Type2Far1Slow1Rule
260	Type2Near1Fast1Rule	293	Type2Far1Slow2Rule
261	Type2Near1OKRule	294	Type2Far1Slow3Rule
262	Type2Near1Slow1Rule	295	Type2Far1Slow4Rule
263	Type2Near1Slow2Rule	296	Type2Far1Slow5Rule
264	Type2Near1Slow3Rule	297	Type2Far1Slow6Rule
265	Type2Near1Slow4Rule	298	Type2Far1Slow7Rule
266	Type2Near1Slow5Rule	299	Type2Far2Fast7Rule
267	Type2Near1Slow6Rule	300	Type2Far2Fast6Rule
268	Type2Near1Slow7Rule	301	Type2Far2Fast5Rule
269	Type2OKFast7Rule	302	Type2Far2Fast4Rule
270	Type2OKFast6Rule	303	Type2Far2Fast3Rule
271	Type2OKFast5Rule	304	Type2Far2Fast2Rule
272	Type2OKFast4Rule	305	Type2Far2Fast1Rule
273	Type2OKFast3Rule	306	Type2Far2OKRule
274	Type2OKFast2Rule	307	Type2Far2Slow1Rule
275	Type2OKFast1Rule	308	Type2Far2Slow2Rule
276	Type2OKOKRule	309	Type2Far2Slow3Rule
277	Type2OKSlow1Rule	310	Type2Far2Slow4Rule
278	Type2OKSlow2Rule	311	Type2Far2Slow5Rule
279	Type2OKSlow3Rule	312	Type2Far2Slow6Rule
280	Type2OKSlow4Rule	313	Type2Far2Slow7Rule
281	Type2OKSlow5Rule	314	Type2Far3Fast7Rule
282	Type2OKSlow6Rule	315	Type2Far3Fast6Rule
283	Type2OKSlow7Rule	316	Type2Far3Fast5Rule
284	Type2Far1Fast7Rule	317	Type2Far3Fast4Rule
285	Type2Far1Fast6Rule	318	Type2Far3Fast3Rule
286	Type2Far1Fast5Rule	319	Type2Far3Fast2Rule
287	Type2Far1Fast4Rule	320	Type2Far3Fast1Rule
288	Type2Far1Fast3Rule	321	Type2Far3OKRule
289	Type2Far1Fast2Rule	322	Type2Far3Slow1Rule

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323	Type2Far3Slow2Rule	356	Type3Near5Slow6Rule
324	Type2Far3Slow3Rule	357	Type3Near4Fast6Rule
325	Type2Far3Slow4Rule	358	Type3Near4Fast5Rule
326	Type2Far3Slow5Rule	359	Type3Near4Fast4Rule
327	Type2Far3Slow6Rule	360	Type3Near4Fast3Rule
328	Type2Far3Slow7Rule	361	Type3Near4Fast2Rule
329	Type2Far4Fast7Rule	362	Type3Near4Fast1Rule
330	Type2Far4Fast6Rule	363	Type3Near4OKRule
331	Type2Far4Fast5Rule	364	Type3Near4Slow1Rule
332	Type2Far4Fast4Rule	365	Type3Near4Slow2Rule
333	Type2Far4Fast3Rule	366	Type3Near4Slow3Rule
334	Type2Far4Fast2Rule	367	Type3Near4Slow4Rule
335	Type2Far4Fast1Rule	368	Type3Near4Slow5Rule
336	Type2Far4OKRule	369	Type3Near4Slow6Rule
337	Type2Far4Slow1Rule	370	Type3Near3Fast6Rule
338	Type2Far4Slow2Rule	371	Type3Near3Fast5Rule
339	Type2Far4Slow3Rule	372	Type3Near3Fast4Rule
340	Type2Far4Slow4Rule	373	Type3Near3Fast3Rule
341	Type2Far4Slow5Rule	374	Type3Near3Fast2Rule
342	Type2Far4Slow6Rule	375	Type3Near3Fast1Rule
343	Type2Far4Slow7Rule	376	Type3Near3OKRule
344	Type3Near5Fast6Rule	377	Type3Near3Slow1Rule
345	Type3Near5Fast5Rule	378	Type3Near3Slow2Rule
346	Type3Near5Fast4Rule	379	Type3Near3Slow3Rule
347	Type3Near5Fast3Rule	380	Type3Near3Slow4Rule
348	Type3Near5Fast2Rule	381	Type3Near3Slow5Rule
349	Type3Near5Fast1Rule	382	Type3Near3Slow6Rule
350	Type3Near5OKRule	383	Type3Near2Fast6Rule
351	Type3Near5Slow1Rule	384	Type3Near2Fast5Rule
352	Type3Near5Slow2Rule	385	Type3Near2Fast4Rule
353	Type3Near5Slow3Rule	386	Type3Near2Fast3Rule
354	Type3Near5Slow4Rule	387	Type3Near2Fast2Rule
355	Type3Near5Slow5Rule	388	Type3Near2Fast1Rule

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390	Type3Near2Slow1Rule	423	Type3Far1Fast5Rule
391	Type3Near2Slow2Rule	424	Type3Far1Fast4Rule
392	Type3Near2Slow3Rule	425	Type3Far1Fast3Rule
393	Type3Near2Slow4Rule	426	Type3Far1Fast2Rule
394	Type3Near2Slow5Rule	427	Type3Far1Fast1Rule
395	Type3Near2Slow6Rule	428	Type3Far1OKRule
396	Type3Near1Fast6Rule	429	Type3Far1Slow1Rule
397	Type3Near1Fast5Rule	430	Type3Far1Slow2Rule
398	Type3Near1Fast4Rule	431	Type3Far1Slow3Rule
399	Type3Near1Fast3Rule	432	Type3Far1Slow4Rule
400	Type3Near1Fast2Rule	433	Type3Far1Slow5Rule
401	Type3Near1Fast1Rule	434	Type3Far1Slow6Rule
402	Type3Near1OKRule	435	Type3Far2Fast6Rule
403	Type3Near1Slow1Rule	436	Type3Far2Fast5Rule
404	Type3Near1Slow2Rule	437	Type3Far2Fast4Rule
405	Type3Near1Slow3Rule	438	Type3Far2Fast3Rule
406	Type3Near1Slow4Rule	439	Type3Far2Fast2Rule
407	Type3Near1Slow5Rule	440	Type3Far2Fast1Rule
408	Type3Near1Slow6Rule	441	Type3Far2OKRule
409	Type3OKFast6Rule	442	Type3Far2Slow1Rule
410	Type3OKFast5Rule	443	Type3Far2Slow2Rule
411	Type3OKFast4Rule	444	Type3Far2Slow3Rule
412	Type3OKFast3Rule	445	Type3Far2Slow4Rule
413	Type3OKFast2Rule	446	Type3Far2Slow5Rule
414	Type3OKFast1Rule	447	Type3Far2Slow6Rule
415	Type3OKOKRule	448	Type3Far3Fast6Rule
416	Type3OKSlow1Rule	449	Type3Far3Fast5Rule
417	Type3OKSlow2Rule	540	Type3Far3Fast4Rule
418	Type3OKSlow3Rule	451	Type3Far3Fast3Rule
419	Type3OKSlow4Rule	452	Type3Far3Fast2Rule
420	Type3OKSlow5Rule	453	Type3Far3Fast1Rule
421	Type3OKSlow6Rule	454	Type3Far3OKRule

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455	Type3Far3Slow1Rule	488	Type4Near3Slow1Rule
456	Type3Far3Slow2Rule	489	Type4Near3Slow2Rule
457	Type3Far3Slow3Rule	490	Type4Near3Slow3Rule
458	Type3Far3Slow4Rule	491	Type4Near3Slow4Rule
459	Type3Far3Slow5Rule	492	Type4Near2Fast4Rule
460	Type3Far3Slow6Rule	493	Type4Near2Fast3Rule
461	Type3Far4Fast6Rule	494	Type4Near2Fast2Rule
462	Type3Far4Fast5Rule	495	Type4Near2Fast1Rule
463	Type3Far4Fast4Rule	496	Type4Near2OKRule
464	Type3Far4Fast3Rule	497	Type4Near2Slow1Rule
465	Type3Far4Fast2Rule	498	Type4Near2Slow2Rule
466	Type3Far4Fast1Rule	499	Type4Near2Slow3Rule
467	Type3Far4OKRule	500	Type4Near2Slow4Rule
468	Type3Far4Slow1Rule	501	Type4Near1Fast4Rule
469	Type3Far4Slow2Rule	502	Type4Near1Fast3Rule
470	Type3Far4Slow3Rule	503	Type4Near1Fast2Rule
471	Type3Far4Slow4Rule	504	Type4Near1Fast1Rule
472	Type3Far4Slow5Rule	505	Type4Near1OKRule
473	Type3Far4Slow6Rule	506	Type4Near1Slow1Rule
474	Type4Near4Fast4Rule	507	Type4Near1Slow2Rule
475	Type4Near4Fast3Rule	508	Type4Near1Slow3Rule
476	Type4Near4Fast2Rule	509	Type4Near1Slow4Rule
477	Type4Near4Fast1Rule	510	Type4OKFast4Rule
478	Type4Near4OKRule	511	Type4OKFast3Rule
479	Type4Near4Slow1Rule	512	Type4OKFast2Rule
480	Type4Near4Slow2Rule	513	Type4OKFast1Rule
481	Type4Near4Slow3Rule	514	Type4OKOKRule
482	Type4Near4Slow4Rule	515	Type4OKSlow1Rule
483	Type4Near3Fast4Rule	516	Type4OKSlow2Rule
484	Type4Near3Fast3Rule	517	Type4OKSlow3Rule
485	Type4Near3Fast2Rule	518	Type4OKSlow4Rule
486	Type4Near3Fast1Rule	519	Type4Far1Fast4Rule
487	Type4Near3OKRule	520	Type4Far1Fast3Rule

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521	Type4Far1Fast2Rule	554	Type4Far4Slow4Rule
522	Type4Far1Fast1Rule	555	Type5Near3Fast2Rule
523	Type4Far1OKRule	556	Type5Near3Fast1Rule
524	Type4Far1Slow1Rule	557	Type5Near3OKRule
525	Type4Far1Slow2Rule	558	Type5Near3Slow1Rule
526	Type4Far1Slow3Rule	559	Type5Near3Slow2Rule
527	Type4Far1Slow4Rule	560	Type5Near3Slow3Rule
528	Type4Far2Fast4Rule	561	Type5Near2Fast2Rule
529	Type4Far2Fast3Rule	562	Type5Near2Fast1Rule
530	Type4Far2Fast2Rule	563	Type5Near2OKRule
531	Type4Far2Fast1Rule	564	Type5Near2Slow1Rule
532	Type4Far2OKRule	565	Type5Near2Slow2Rule
533	Type4Far2Slow1Rule	566	Type5Near2Slow3Rule
534	Type4Far2Slow2Rule	567	Type5Near1Fast2Rule
535	Type4Far2Slow3Rule	568	Type5Near1Fast1Rule
536	Type4Far2Slow4Rule	569	Type5Near1OKRule
537	Type4Far3Fast4Rule	570	Type5Near1Slow1Rule
538	Type4Far3Fast3Rule	571	Type5Near1Slow2Rule
539	Type4Far3Fast2Rule	572	Type5Near1Slow3Rule
540	Type4Far3Fast1Rule	573	Type5OKFast2Rule
541	Type4Far3OKRule	574	Type5OKFast1Rule
542	Type4Far3Slow1Rule	575	Type5OKOKRule
543	Type4Far3Slow2Rule	576	Type5OKSlow1Rule
544	Type4Far3Slow3Rule	577	Type5OKSlow2Rule
545	Type4Far3Slow4Rule	578	Type5OKSlow3Rule
546	Type4Far4Fast4Rule	579	Type5Far1Fast2Rule
547	Type4Far4Fast3Rule	580	Type5Far1Fast1Rule
548	Type4Far4Fast2Rule	581	Type5Far1OKRule
549	Type4Far4Fast1Rule	582	Type5Far1Slow1Rule
550	Type4Far4OKRule	583	Type5Far1Slow2Rule
551	Type4Far4Slow1Rule	584	Type5Far1Slow3Rule
552	Type4Far4Slow2Rule	855	Type5Far2Fast2Rule
553	Type4Far4Slow3Rule	586	Type5Far2Fast1Rule

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587	Type5Far2OKRule	600	ladderArialRescue
588	Type5Far2Slow1Rule	601	pumperVsHydrant
589	Type5Far2Slow2Rule	602	negative-distance
590	Type5Far2Slow3Rule	603	effective-wind-speed
591	Type6NearFastRule	604	ladder_high-rise
592	Type6NearOKRule	605	ladder_short-buildings
593	Type6NearSlowRule	606	EventFire
594	Type6OKFastRule	607	ExposedBuildings
595	Type6OKOKRule	608	has-sprinkler-system
596	Type6OKSlowRule	609	relay-pump
597	Type6FarFastRule		
598	Type6FarOKRule		
599	Type6FarSlowRule		

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