Fire Department Response Model (FDRM) and Fire Department Effectiveness Model (FDEM) theory report

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Fire Risk Management Program
Institute for Research in Construction
National Research Council Canada

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Nomenclature

FDRM Model

$t_{dispatch}$	Dispatch time
r_{calls}	Ratio of number of phone concurrent calls over total number of calls
$t_{preparation}$	Preparation time
D	Travel distance, km
$t(D)$	The time to travel the distance D, s
t_b	Time spent on the distance from building to public road, s
d_b	The distance from building to public road, km
v_b	The average speed on the road from building to public road, km/hr
P	The probability of the primary route not being available
t_s	The time spent on the alternative route, s
t_p	The time spent on the primary route, s

FDEM Model

W(t)	Available water supply flow rate with time, kW L / s
η	Efficiency of application of water
n_{fire}	Number of fires
$Q_{f,i}(t)$	Heat release rate of each fire, i, with time kW
$Q_f(t)$	Total heat release rate of all fires with time kW
$Q_{ff}(t)$	Modified total heat release rate of all fires with time kW
$Q_{ff,i}(t)$	Modified heat release rate for each fire
$\theta(t)$	*S*uppression ratio
$q_o(t,r)$	Heat flux at radius, r, and time, t, for each fire
$q_m^{"}(t,r)$	Modified heat flux at radius, r, and time, t, for each fire, kW/m^2
$T_{p\text{-}o}(t)$	Ceiling impingement temperature at time, t, for each fire, K
$T_{p\text{-}m}(t)$	Modified ceiling impingement temperature at time, t, for each fire
$T_{eq\text{-}o}(t)$	Equivalent fire temperature at time, t, for each fire, K
$T_{eq\text{-}m}(t)$	Modified equivalent fire temperature at time, t, for each fire
T_{amb}	Compartment ambient temperature, K
$t_{intervention}$	Time of fire department intervention, s
D_m	The modified diameter of the fire source
D_o	The diameter of the fire source

1. INTRODUCTION

As Canada and other countries move from prescriptive-based building codes to performance/objective-based codes, new design tools are needed to demonstrate that compliance with these new codes has been achieved. One such tool is the computer model FiRECAM™, which has been developed over the past decade by the Fire Risk Management Program of the Institute for Research in Construction at the National Research Council of Canada (NRC). FiRECAM™ is a computer model for evaluating fire protection systems in residential and office buildings that can be used to compare the relative expected safety and cost of candidate fire protection options.

To evaluate fire protection systems in light industrial buildings, a new computer model is being developed. This model, whose current focus is aircraft hangars and warehouses, is based on a framework that allows designers to establish objectives, select fire scenarios that may occur in the building and evaluate the impact of each of the selected scenarios on life safety, property protection and business interruption. The new computer model is called FIERAsystem, which stands for **Fi**re **E**valuation and **R**isk **A**ssessment **system**. FIERAsystem uses time-dependent deterministic and probabilistic models to evaluate the impact of selected fire scenarios on life, property and business interruption. The main FIERAsystem sub-models calculate fire development, smoke movement through a building, time of failure of building elements and occupant response and evacuation. In addition, there are sub-models dealing with the effectiveness of fire suppression systems and the response of fire departments.

The purpose of this document is to describe two sub-models of FIERAsystem, namely, the Fire Department Response Model (FDRM) and the Fire Department Effectiveness Model (FDEM). These two sub-models, though can be used as stand-alone models, are strongly interconnected. The time of intervention of a fire department that is calculated by the FDRM is used in the calculations of the FDEM.

1.1 Fire Department Response Model (FDRM)

The FDRM model is an optional computer model developed to evaluate the fire department response characteristics to a design building if the fire department is not considered to be a typical one where normal response statistics can be applied. The main objectives of this model are to determine the response time of fire departments, and to evaluate the various factors influencing the response time.

Many researchers have carried out fire department studies. Most of them focused on fire department deployment analysis [1,2], or fundamental analysis of fire suppression [3,4,5,6,7,8,9], which are very important issues for fire department operations. This model focuses on calculating fire department response time to a fire call. The fire department response time is the sum of the dispatch time, preparation time, and travel time.

1.2 Fire Department Effectiveness Model (FDEM)

The Fire Department Effectiveness Model (FDEM) is developed to calculate the revised fire heat release rates, heat fluxes, ceiling impingement temperatures, equivalent fire temperatures, and source diameters due to the intervention of the fire department. The FDEM model can be used as an integrated part of the FIERAsystem model as well as a stand-alone module so as to enable the user to input new data, view the results of calculations, and open runs created at an earlier time.

The following sections describe the procedure used for the calculations involved in these two models.

2. DESCRIPTION OF THE MODELS

2.1 FDRM Model

There are a number of publications that describe how a typical fire department is organized and how it operates, especially dealing with firefighting operations since fire department deployment issues revolve around these activities. More information on these aspects of a fire department's operations can be found in [1,2]. In order to provide a framework for describing a fire department's suppression activities, we consider the events that occur from the start of a fire until it is extinguished. The sequence of events, which is shown in Figure 2.1, begins with ignition. After some time the fire is detected (by a person or by an automatic device) and it is reported to the fire department. One or more dispatchers at the fire department process the alarm and then fire services are notified to respond. Equipped firefighters respond to the fire scene where they operate to extinguish the fire. The effectiveness of the fire department in minimizing loss of life and property depends in part on the elapsed time between ignition and intervention by the fire department.

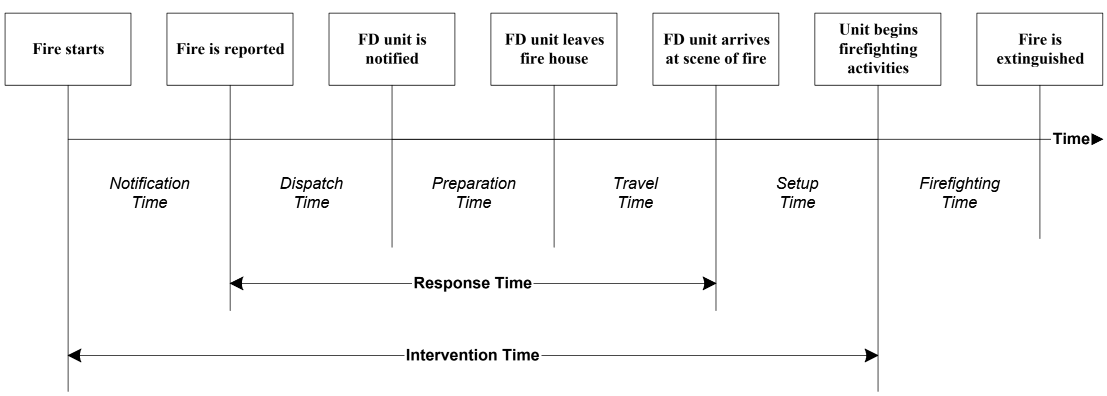

Figure 2.1. Typical sequence of events in a fire from ignition to extinguishment

In this model, the response of the fire department to a fire incident is analyzed in detail. All the steps taken are being evaluated in order to determine the time needed to carry out a number of activities that add to the response time. These events are the following:

- *Notification time:* Once a fire has started in a building it will eventually be detected either by automatic means or by the building occupants, and the fire department will be notified. The time elapsed from fire ignition to fire department notification is called the notification time and it is calculated by either the *Occupant Response Model* or the *Detection Model*, two FIERAsystem models.
- *Response time:* This is the elapsed time from the moment the fire department is notified until such time when the first fire unit arrives at the scene. As indicated in Figure 2.1response time includes:
    - *Dispatch time:* the time between the receipt of an alarm and the dispatch of a unit (notifying it to respond) by the dispatcher.
    - *Preparation time*: the time required for the dispatched unit to prepare and be ready to leave the fire department.
    - *Travel time:* the time required by the first unit to travel from the fire department to the scene of the fire.
- *Setup time:* the time required to setup and prepare equipment, vehicles and assemble firefighting teams just before any firefighting and rescue operations begin. The model does not compute this time, but it is given as input based on statistical values.
- *Fire-fighting time:* the time required by firefighters to extinguish the fire. It depends on the status of fire on arrival, the type of building and fuel loading, the resources, equipment and men on the site. The model does not compute this time.

The detail calculations of dispatch time, preparation time and travel time will be described in section 3. Figure 2.2 shows the flow chart of the fire department response model.

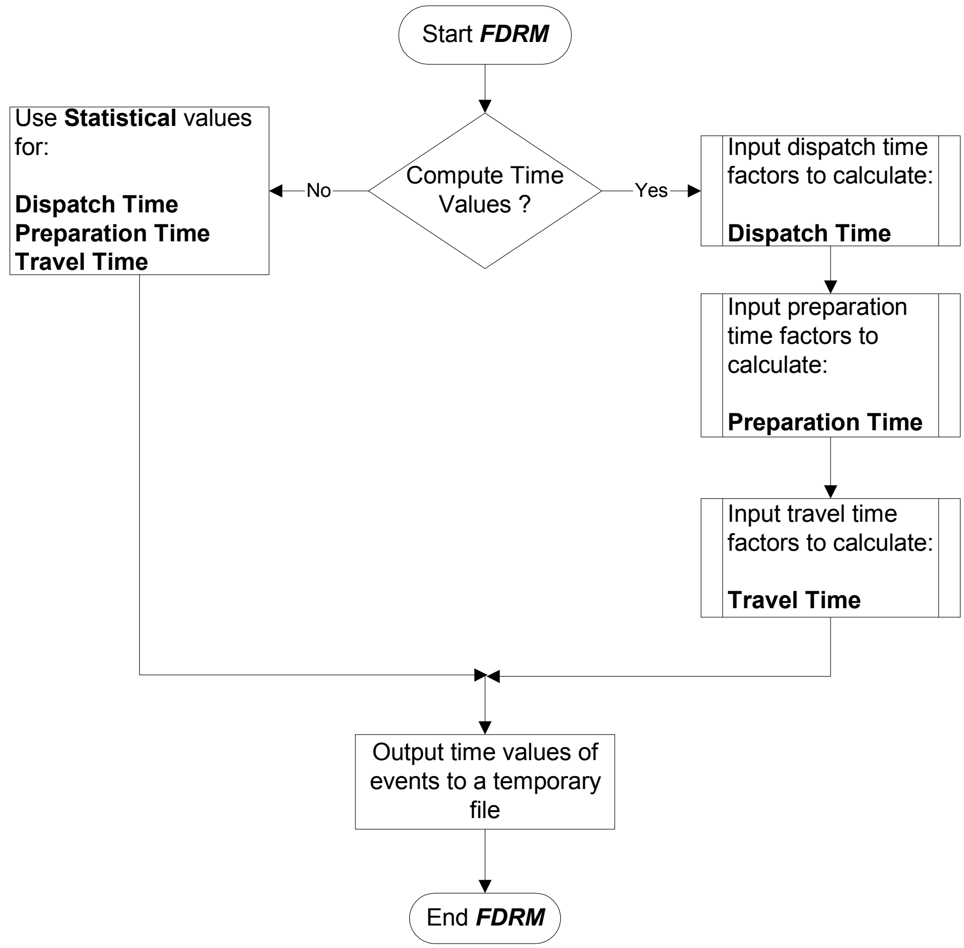

Figure 2.2. Fire Department Response Model flow chart

2.2 FDEM Model

The model calculations involve the determination of the total heat release rate, as a function of time, resulting from all fires as well as the total revised (after fire department intervention) heat release rate as a function of time for all fires. The sub model requires the following parameters to be input by the user:

- Fire department efficiency of application of water
- Available water supply as function of time
- Time of fire department intervention (for the stand-alone interface)
- Ambient temperature in compartments

- Fires characteristics, as function of time, such as: compartment of fire origin; time to critical heat flux; heat release rate; heat flux; source diameter; equivalent fire (centerline plume) temperature; and ceiling impingement temperature.

Based on the provided input, the model calculates, for each fire, the following parameters:

- Revised heat release rate as function of time
- Revised heat fluxes as function of time and distance
- Revised ceiling impingement temperature as function of time
- Revised equivalent fire temperature as function of time
- Revised source diameters as function of time
- Revised time to critical heat flux

3. CALCULATIONS

This section outlines the calculations performed by the FDRM and FDEM models.

3.1 FDRM Model Calculations

All fire ground operations are time critical. However, the ability of a fire department to respond to every incident prior to it becoming a major conflagration is virtually impossible due to factors beyond its control. There are too many variables to accurately predict the exact response time to every incident. However, it is possible to project, with reasonable accuracy, certain elements of the total response time equation. Proper management of the various time elements (dispatch time, preparation time and travel time) is important. It has been said that five minutes of well timed and well-planned activity at this stage can avoid five hours of catch-up later.

One of the main parameters that play an important role in the effectiveness of a fire department is the response time. This is defined as the time from the moment the fire department receives notification of a fire to the time when the first response crew arrives at the scene. As shown in Figure 2.1, the response time can be broken into a number of time periods: the dispatch time, the preparation time and the travel time which were described earlier.

It is important to note that response times are random in nature; that is, they cannot be predicted exactly in advances. Even if a fire engine traveled from a particular fire-hall to the same street corner over and over again under similar conditions (same apparatus, driver, weather, time of day, etc.) there would still be variations in travel time from run to run. If the conditions changed between runs there would be even greater variations. If an alarm was received over and over again from a given location, the time elapsed until the units are notified to respond would also vary depending on the nature of the call and what else was happening in the communications office when it was received. Similarly, the preparation time would vary from run to run. The random nature of response time must be taken into account when doing an analysis using response times as a performance measure.

To get an idea of how large travel time is likely to be, compared to the other components of response time, let us make some rough estimates. Except under very high alarm rate conditions, even a manual dispatching system will be able to achieve rather short dispatching times. Thirty seconds to a minute are reasonable figures. Observations in the New York City and Denver fire departments showed that preparation times and setup times fall in the same range [2]. However, the time required for the closest unit to travel to the scene of an alarm is typically somewhere around three minutes. Thus, we have as a rough estimate for the first arriving company: average response time is five minutes; average setup time is one minute. Thus, of the total of six minutes, about half is travel time. For companies that arrive on the scene second or third, travel time is an even larger fraction of the total response time than it is for the first-arriving units.

3.1.1 Dispatch Time

The notification of a fire at a fire department is received by the dispatcher, a fire department employee stationed in the communications office whose responsibilities include receiving alarms, determining their type and location, dispatching fire-fighting units, maintaining information on unit availability, and keeping a record of activities. Dispatch time is defined as the time elapsed from the receipt of information about a fire to the setting of the fire-hall's alarm, which will initiate preparation of a unit to leave the fire department. Observations [2] have shown that the dispatch time is between 30 to 60 seconds.

The model accounts for the factors shown in Table 3.1 as being the most influential for the dispatch time. The dispatch time $t_{dispatch}$ is equal to the basic dispatch time t_{basic} supplied by the statistical database.

$$t_{dispatch} = t_{basic} \qquad \text{(Eq. 3.1)}$$

Table 3.1. Dispatch time factors

Factor	Description
[f_1]	Incident notification (auto alarm, 911 center, or public phone)
[f_2]	Experience of the fire-fighters
[f_3]	Training frequency of the fire-fighters
[f_4]	Local knowledge of the fire-fighters
[f_5]	Availability of the fire-fighters (probability of whole crew being in the station)
[f_6]	Notification of firefighters that are not in the station (public address system, page system, special phone)
[f_7]	Communication systems in the fire department (public address system, central alarm)

Then it is increased by the sum of all factors of influence, according to what the user selections were for those factors (for example, if the user chooses an auto alarm as a mean of incident notification, then f_1 will be considered as zero). Therefore, some selections may have a stronger impact on the increase of the dispatch time. Let

$$f_{sum} = f_1 + f_2 + f_3 + f_4 + f_5 + f_6 + f_7 \qquad \text{(Eq. 3.2)}$$

Then

$$t_{dispatch} = t_{basic} \bullet (1 + f_{sum}) \qquad \text{(Eq. 3.3)}$$

Then the dispatch time is further increased by the ratio of the number of concurrent calls over the total number of phone calls, both of which have been previously entered as user input.

If

$$r_{calls} = \frac{N_{concurrentCalls}}{N_{totalCalls}} \qquad \text{(Eq. 3.4)}$$

then

$$t_{dispatch} = t_{basic} \bullet (1 + f_{sum})(1 + r_{calls}) \qquad \text{(Eq. 3.5)}$$

The range of values that the model produces for the *dispatch time* without the influence of the r_{calls} ratio is from 10 seconds up to 44.5 seconds. In the absence of user's input, the default value for the dispatch time is set to 50 seconds.

3.1.2 Preparation Time

The time required for a company to assemble for an emergency response after receiving the dispatching alarm up to the time just before leaving the fire hall is defined as the *preparation time*. Observations [2] have shown that the preparation time falls within the range of 30 seconds up to 60 seconds.

The model accounts for the factors shown in Table 3.2 that influence preparation time.

Table 3.2. Preparation time factors.

Factor	Description
[f_1]	Years of experience of firefighters
[f_2]	Training frequency of firefighters
[f_3]	Local knowledge
[f_4]	Firefighters availability (probability of whole crew being in the station)
[f_5]	Potential for explosion
[f_6]	Potential for release of hazardous material
[f_7]	Potential for building collapse

The preparation time $t_{preparation}$ is equal to the basic preparation time t_{basic} supplied by the statistical database.

$$t_{preparation} = t_{basic} \qquad \text{(Eq. 3.6)}$$

Then it is increased by the sum of all influencing factors as listed in Table 3.2, according to what the user selections were for those factors. For example, if the user chooses the years of experience of the firefighters are greater than 2 years, then f_1 will be set to zero.

Let

$$f_{sum} = f_1 + f_2 + f_3 + f_4 + f_5 + f_6 + f_7 \qquad \text{(Eq. 3.7)}$$

Then

$$t_{preparation} = t_{basic} \bullet (1+ f_{sum}) \qquad \text{(Eq. 3.8)}$$

Then the preparation time is further increased by the ratio of the number of concurrent calls over the total number of phone calls, both of which have been previously entered as user input.

If

$$r_{calls} = \frac{N_{concurrentCalls}}{N_{totalCalls}} \qquad \text{(Eq. 3.9)}$$

then

$$t_{preparation} = t_{basic} \bullet (1+ f_{sum})\,(1 + r_{calls}) \qquad \text{(Eq. 3.10)}$$

The range of values that the model produces for the preparation time without the influence of the r_{calls} ratio is from 30 to 105 seconds.

3.1.3 Travel Time

Travel time is a major component of the *response time* of a fire department. It is defined as the time between the moment a unit leaves the fire station to the time when the first response team arrives at the fire scene and the platoon chief notifies the fire hall that they have arrived at the scene.

The travel time from a specific firehouse to the location of a specific incident depends primarily on the distance between the points, but it may also depend on the type of the vehicle, the driver, the traffic encountered, and the types of roads. Statistical data [2] have shown that the average time that is required for the closest unit to reach the scene of an alarm is around 180 seconds.

It has been found [2] that the travel time increases with the square root of the distance for short trips (on side streets and with a significant number of accelerations and decelerations) and increases linearly for longer trips [2]. Thus, the travel time can be expressed by the following mathematical model relating the travel distance, *D*, and the expected time to travel between the two points, *t (D)*:

$$t(D)=\begin{cases} 1.655\sqrt{D} & D \leq 0.61\ km \\ 0.65+1.0559\ D & D \geq 0.61\ km \end{cases} \qquad \text{(Eq. 3.11)}$$

Where t is the expected time to travel between two points in minutes and D is the distance between the two points in km. In many cities, the above formula has provided good estimates of the travel time. The time calculated from Eq. 3.11 is used as the basic travel time. The time is then modified to account for the impact of other parameters that affect travel time as listed in Table 3.3.

Table 3.3. Travel time factors.

Factor	Description
[f_{g1}]	Experience
[f_{g2}]	Local knowledge
[f_{p1}]	Street arrangement of primary road
[f_{p2}]	Frequency of curves and intersections of primary road
[f_{p3}]	Traffic volume of primary road
[f_{s1}]	Street arrangement of alternative road
[f_{s2}]	Frequency of curves and intersections of alternative road
[f_{s3}]	Traffic volume of alternative road

The time t_b spent on the distance from building to public road is calculated using the following equation:

$$t_b = \frac{d_b}{v_b} \qquad \text{(Eq. 3.12)}$$

Where d_b is the distance from building to public road and v_b is the average speed on the road from building to public road.

Since the unit wouldn't cover the sum of the distance of both the primary and secondary routes, the probability of the primary route not being available is introduced as P. If the primary route is not available then the alternative route is used. P multiplies the time spent on the alternative route (t_s) to give the probable time spent on the alternative route. At the same time (1- P), which represents the availability of the primary route, is used to multiply the time spent on the primary route (t_p). Thus, an estimate of the expected travel time would be:

$$t_{travel} = t_p (1 - P) + t_s P + t_b \quad \text{(Eq. 3.13)}$$

However, the time spent on the primary route and the alternative route is influenced by three dominant factors: street arrangement, frequency of curves and intersections, and traffic volume. For each route the corresponding factors are summed up and eventually modify the travel time.

Thus

$$f_p = f_{p1} + f_{p2} + f_{p3} \quad \text{(Eq. 3.14)}$$

and

$$f_s = f_{s1} + f_{s2} + f_{s3} \quad \text{(Eq. 3.15)}$$

Considering the above two factors, namely, f_p and f_s, Eq. 3.13 becomes:

$$t_{travel} = t_p (1 + f_p)(1 - P) + t_s (1 + f_s) P + t_b \quad \text{(Eq. 3.16)}$$

There are two additional general factors, namely, the experience and the local knowledge of the firefighters. Those two factors modify the final value of t_{travel} by the multiplier $(1 + f_g)$, where:

$$f_g = f_{g1} + f_{g2} \quad \text{(Eq. 3.17)}$$

Then Eq. 3.16 becomes:

$$t_{travel} = [\, t_p (1 + f_p)(1 - P) + t_s (1 + f_s) P + t_b \,]\,(1 + f_g) \quad \text{(Eq. 3.18)}$$

3.2 FDEM Model Calculations

The total heat release rate, $Q_f(t)$, is calculated by summing the heat release rate from all fires within the building:

$$Q_f(t) = \sum_{i=1}^{n_{fire}} Q_{f,i}(t) \quad \text{(Eq. 3.19)}$$

Where:

$Q_{f,i}(t)$ Heat release rate of each fire, i;

n_{fire} Number of fires

The time of fire department intervention, $t_{intervention}$, is the time at which the fire department can first begin to use the water supply to attack the fires. This time should take into account notification of the fire department, travel to the scene, and setup of the fire department apparatus. Assuming that the reported fires are controlled by the fire department at the time of intervention, the available water supply in L/s, W(t), is used to calculate the revised total heat release rate within the building, $Q_{ff}(t)$, in kW:

$$Q_{ff}(t) = Q_f(t_{intervention}) - W(t) \cdot \eta \cdot 2600 \qquad \text{for } t >= t_{intervention} \qquad \text{(Eq. 3.20)}$$

Where η is the efficiency of application of water.

Each fire is modified as a result of the fire department intervention. A suppression ratio, $\theta(t)$, is defined as the modified heat release rate at time, t, divided by the heat release rate at the time of fire department involvement. This ratio represents the proportion of the heat release rate remaining after the fire department has suppressed the fire. The model uses the assumption that this suppression ratio will be equal for all fires in the building. Therefore,

$$\theta(t) = 1.0 \qquad \text{for } t < t_{intervention}$$

$$\theta(t) = \frac{Q_{ff}(t)}{Q_f(t_{\text{intervention}})} \qquad \text{for } t >= t_{intervention} \qquad \text{(Eq. 3.21)}$$

and the heat release rate for each fire is calculated as follows:

$$Q_{ff,i}(t) = Q_{f,i}(t) \qquad \text{for } t < t_{intervention}$$

$$Q_{ff,i}(t) = \theta(t) \cdot Q_{f,i}(t_{\text{intervention}}) \qquad \text{for } t >= t_{intervention} \qquad \text{(Eq. 3.22)}$$

The characteristics and parameters of each fire are modified in a manner similar to that of the *FIERA Suppression Effectiveness Model*. A description of the theory for these can be found in [10,11]. These parameters include: the heat flux at various distances, the plume temperature at the ceiling of the compartment, the time to critical heat flux, the equivalent fire temperature, and the equivalent diameter of the source. The following equations calculate the revised parameters of each fire due to the intervention of fire department:

3.2.1 Modified Heat Flux

$$\frac{q''_m(t,r)}{q''_o(t,r)} = \frac{Q_{ff,i}(t)}{Q_{f,i}(t)} \qquad \text{(Eq. 3.23)}$$

Where: $q''_o(t,r)$ Heat flux at radius, r, and time, t, for each fire

$q''_m(t,r)$ Modified heat flux at radius, r, and time, t, for each fire

3.2.2 Modified ceiling impingement temperature

$$\frac{T_{p-m}(t) - T_{amb}}{T_{p-o}(t) - T_{amb}} = \left(\frac{Q_{ff,i}(t)}{Q_{f,i}(t)} \right)^{2/3} \qquad \text{(Eq. 3.24)}$$

Where: $T_{p-o}(t)$ Ceiling impingement temperature at time, t, for each fire

$T_{p-m}(t)$ Modified ceiling impingement temperature at time, t, for each fire

T_{amb} Compartment ambient temperature

3.2.3 Modified equivalent fire temperature

$$T_{eq,m} = \left(\frac{Q_{ff,i}(t)}{Q_{f,i}(t)} \right)^{0.4} \left(\frac{T_f^4 - T_{p-m}^4}{T_f^4 - T_{p-o}^4} \right) \left(T_{eq-o}^4 - T_{p-o}^4 \right) + T_{p-m}^4 \qquad \text{(Eq. 3.25)}$$

Where: T_f Flame temperature, is assumed to be 1000°C

$T_{eq-o}(t)$ Equivalent fire temperature at time, t, for each fire

$T_{eq-m}(t)$ Modified equivalent fire temperature at time, t, for each fire

3.2.4 Modified source diameter

The diameter of the fire, entered by the user or from one of the FIERAsystem Fire Development models is assumed to remain unchanged due to suppression. Suppression is assumed to only affect the height of the flames. Therefore, the diameter is not modified by the Fire Department Effectiveness model (i.e., $D_m = D_o$).

4. SUMMARY

4.1 FDRM Model

This model calculates the time required for the fire department to arrive at the fire scene after receiving notification of a fire. This time is known as the fire department response time. For this calculation, the model considers the most important factors that influence the response time.

Research has indicated that the typical fire department response time is about 5 to 6 minutes. This time can be broken down to a typical dispatch time, which is around one minute, a typical preparation time, which is around one minute and the travel time, which varies significantly but it is usually about 3 to 4 minutes. The setup time for small buildings without any special hazards is about a minute. Typically, the time from the moment the dispatch center receives a call to the moment when firefighters are ready to begin operations is around 6 minutes.

The model is designed and developed so it can be easily modified to accommodate future research results in this area. Further research is needed to better estimate the influence of the various factors used in calculating the different times. This can be done through a systematic analysis of the statistical data from Canadian and other fire departments. With the combination of a weather database, it will be possible to study the impact of the time of the day and the weather conditions on the response time.

The increase use of digital city maps and geographic information systems will facilitate the collection of necessary data needed to improve the model. Such information will also assist to develop better fire department plans and optimize fire department locations.

4.2 FDEM Model

The fire department effectiveness model calculates the revised fire heat release rates, heat fluxes, ceiling impingement temperatures, equivalent fire temperatures, and source diameters due to the intervention of the fire department. This model is consistent with other FIERA models and it can be used as integral part of the FIERA system model or as a stand-alone user interface to enable the user to input new data, view the results of calculations, and open runs created at an earlier time.

The model consists of three modules: “Calculations module”, “Input Interface” and “Output Interface “. The calculation module, mainly, calculates the total heat release and the total revised heat release rates as functions of time (for all fires). In addition, the revised parameters for each fire as a result of fire department intervention are calculated.

The input interface allows input of the required parameters such as fire department efficiency of application of water, available water supply, fire department intervention time, ambient temperature in compartments, compartment of fire origin, etc.

The output interface displays the output of the model calculations such as the total heat release rate without fire department intervention, the total heat release rate after fire department intervention as well as the revised fires properties after fire department intervention.

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