Department of Fire Protection Engineering in WPI

Fire Performance Monitoring: FirePM

User's Guide

(FirePM 1.0, FDS 6.7.1, DRAFT)

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Preface

This document describes how to use the Fire Performance Monitoring tool, FirePM, developed at the department of Fire Protection Engineering in WPI, to monitor the evolvement of the building fire performance which is defined by the users in the input configuration file. Although this first version of FirePM is tested with FDS version 6.7.1, it is also applicable for other FDS versions since literately it is version-independent.

Based on the input configuration files, FirePM derives FDS files from a baseline FDs file, analyzes the simulation results of these FDs files to calculate the sensitivity matrix and power curve fitting parameters, and monitors the changes of building fire performance caused by the change of dynamic input data. Therefore, this Guide doesn’t not contain information on how to operate FDS nor Smokeview, the companion visualization program for FDS.

Disclaimer

The department of FPE, WPI, makes no warranty, expressed or implied, to users of FirePM 1.0, and accepts no responsibility for its use. Users of FirePM 1.0 assume sole responsibility for determining the appropriateness of its use in any particular application; for any conclusions drawn from the results of its use; and for any actions taken or not taken as a result of analyses performed using this tool. Users are warned that FirePM is intended for use only by those competent in the fields of fire and evacuation simulation, and is intended only to supplement the informed judgement of the qualified user. The software package is a computer model that may or may not have predictive capability when applied to a specific set of factual circumstances. Lack of accurate predictions by the model could lead to erroneous conclusions with regard to life safety. All results should be evaluated by an informed user.

Contents

1. Introduction

This document describes how to monitor the change of fire performance of a building in-use based on a sensitivity matrix method (SMM) and a power-function-based Response Surface Method (RSM). This software includes three major tools (GenFiles, DoA, and FirePM) and one data-fabricating test tool (GSD). GenFiles is responsible for deriving many FDS files from a baseline FDS file based on the users' input configuration file (SM_Info.txt). DoA is responsible for analyzing the simulation results of these derived FDS files and working out the sensitivity matrix and power curve fitting parameters. FirePM calculates the predicted change of building fire performance as soon as the input data file (Dyn.txt) changes with the help of the sensitivity matrix and power curve fitting parameters. GSD is a tool to randomly update the input data file (Dyn.txt) which in real cases should be updated either manually by the user or automatically by the data acquiring system equipped in the target building. The protocol of updating the input data file (Dyn.txt) in real applications is still under our research and is therefore absent in this version of manual.

The core idea of this tool is that although a fire accident is an acute phenomenon that is rare and unpredictable and cannot be relied on by us to monitor a building's fire performance, the evolution of factors that could someday in the future cause a fire accident is in fact a chronic phenomenon that is frequent, predictable, and observable. In other word, with the assumption that the evaluation of fire effects is a deterministic problem, it is possible to predict (monitor) the changing of the building fire performance by predicting (monitoring) the changing of the underling influencing factors.

1.1. Getting Started

The FirePM software is a natural derivation of the author's PhD research topic "Closing the Building Fire Performance Gap" which focuses on the importance and significances of clearly defining, recognizing and closing the building fire performance gap which indicates the fire performance gap of a building during its design stage and its operational stage. Three articles detailing the topic are expected to be published soon. The following figure shows the diagram of this software:

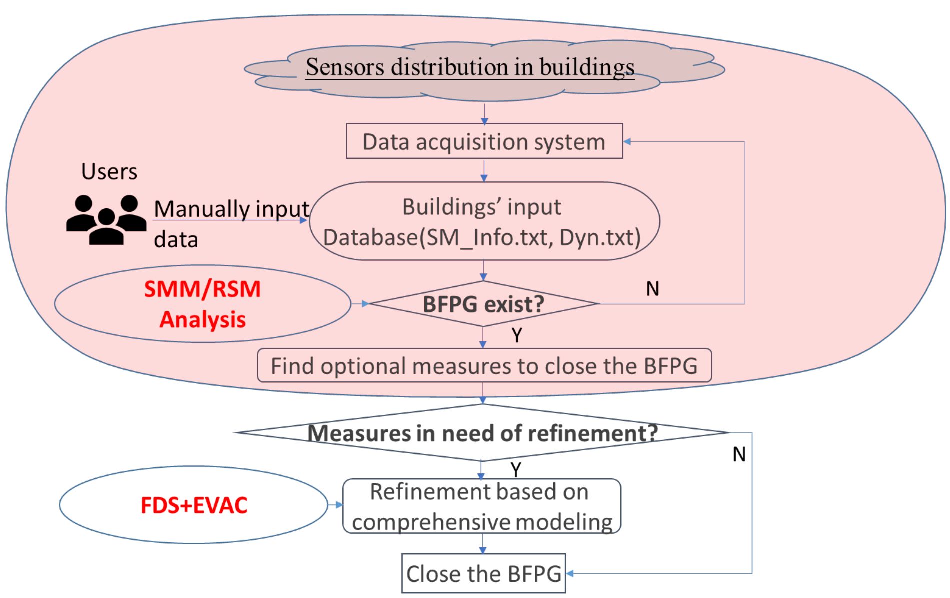


Figure 1 Flow chat of closing the building fire performance gap (BFPG)

(SMM: sensitivity matrix method; RSM: response surface method)

As shown in Figure 1, this current version of FirePM barely covers the area enclosed by the red oval, which includes four tools: GenFiles (means generate (more FDS) files), DoA (means do analysis), FirePM (means fire performance monitoring), and GSD (means generate simulation/synthetic data). as the building's input "database", SM_Info.txt is the configuration file input by the users, Dyn.txt is the dynamically changed input data (Manually or automatically by the Data Acquisition system, if equipped). In this software the Dyn.txt is updated by the tool of GSD which should be replaced in real applications by the actual data input methods. The tool of Genfiles derives many FDS files based on the configuration file SM_Info.txt which will be detailed later on in this manual. The tool of DoA computes the sensitivity matrix of SMM and power function regression parameters of RSM by analyzing the simulation results of the FDS files delivered by the tool of Genfiles. The tool of FirePM repeatedly check if the Dyn.txt input data file has been newly updated. Once Dyn.txt is updated, FirePM starts a new round of calculation to check if the BFPG exists. If it exists, FirePM provides some optional measures that are theoretically acceptable to close the BFPG. It is the job of the users to judge if these measures are in fact feasible. The users are also responsible for making a decision about whether some chosen measures need further refinement by FDS simulation.

The FirePM is developed under the following version of LINUX OS, for other OS, small modification of the source code may be needed:

NAME="Red Hat Enterprise Linux Server"

VERSION="7.3 (Maipo)"

ID="rhel"

ID_LIKE="fedora"

VERSION_ID="7.3"

PRETTY_NAME="Red Hat Enterprise Linux"

ANSI_COLOR="0;31"

CPE_NAME="cpe:/o:redhat:enterprise_linux:7.3:GA:server"

HOME_URL="https://www.redhat.com/"

BUG_REPORT_URL="https://bugzilla.redhat.com/"

REDHAT_BUGZILLA_PRODUCT="Red Hat Enterprise Linux 7"

REDHAT_BUGZILLA_PRODUCT_VERSION=7.3

REDHAT_SUPPORT_PRODUCT="Red Hat Enterprise Linux"

REDHAT_SUPPORT_PRODUCT_VERSION="7.3"

1.2. Intended Use of FirePM

Currently, FirePM is a research tool for sensitivity analysis as well as searching the possibility of finding a series of substitute algebra equations which can be used to provide fire protection engineers with science-based prescriptive codes. While it looks like a quantitative tool to produce predictions of the change of building fire performance when the input variables vary, it is not yet fully validated due to the limitations of the underlying mathematical facts as well as the complication of a large range of real applications. However, it can be used as a semi-quantitative or at least a qualitative tool to tell people the varying direction of the building fire performance when the input data change with some extent of confidences. For example, it can be used to quickly evaluate the risk of some temporal activities in a building: 1) if the sprinkler system has to be closed for a while for retrofitting, will the building be exposed to high risk of fire? What measures should be done to keep the building safe during the retrofitting period? 2) If the building plans to host an extremely high number of visitors for couple of days, will the fire risk/building fire performance be acceptable during these days? If the answer is yes, what are the possible measures to keep the building fire performance? 3) if the building has to store temporally much more combustibles than designed, what is the risk during this time? What should we do to keep the building safe? Such kind of problems reflect the uncertainties of building's usage in reality. However, it is expensive or unrealistic for the building managers to do sophistic performance simulations every time when these temporal activities/events occur. Here comes the FirePM. Although not very accurate, the results of applying FirePM, which is very quick, can deliver useful conceptual information about the change of the building fire performance or fire risk when these activities/events happen. The sophistic building fire performance simulations are only necessary when the FirePM shows clearly that quite abnormal unacceptable conditions will happen.

1.3. Limitations

As the first version of the building fire performance monitoring tool, the following limitations needs to be beard in mind:

(1) The application range of the SMM is case-sensitive.

Since the SMM is based on the locally linearization (Taylor's expansion) of a non-linear problem which is usually described by a group of Partial Differential Equations (PDEs), the application range of the SMM depends on the linear degrees of the problem itself as well as the locations where a sensitivity matrix is derived. It is very common that different linear degrees exist in different definition domains of the input variables for a specific problem. Sometimes it is possible that a sensitivity matrix applies when all the input variables change in a quite wide intervals without generating predictions of obviously abnormal results compared to the FDS simulations. That's why a sensitivity matrix derived from some specific locations within the definition domains of input variables needs to be verified by the FDS simulations, which is shown in the file of CMB.csv discussed later in this manual.

(2) The derivation and application of the RSM is tentative

Since the RSM is based on the power function regression, which assumes that the relationship between one output variable and one input variable follows the power function/curve of the form of $y = ax^b$, the derivation of the RSM, or the calculated power curve fitting parameters (a and b), may not really fit the real problem well. The users are recommended to check the r-sqr(r squared) and s-sqr (s squared) in the file of RSMRlt.csv to have an idea of how good the RSM is. Usually for a RSM to work reasonably, the r-sqr is expected to be greater than 0.9, but finally it's up to you to make a final decision. Also,

(3) The measures provided by the FirePM to close the building fire performance gap (BFPG) need further checks

Except for the predicted changes of building fire performance, the FirePM also delivers some measures to close the BFPG. The users need to bear in their minds that these measures are only mathematically reasonable since they are worked out based on the same sensitivity matrix which is used to predict the change of the BFPG. Final judgements are up to the users, based on either their experiences or knowledge or some other calculation methods. The FirePM here just gives some appropriate and directional advices about how to close the BFPG.

(4) Not applicable in lines of a FDS files where "ID" is absent

In the configuration file, SM_Info.txt, FDS_ID is needed to locate the variables in the FDS files. However, in some lines of the FDS files the "ID" for the object/obstruction is absent, as shown below:

```
&EXIT ID='GroundExit', IOR=-2,
    FYI= 'Comment line',MESH_ID='MESH-GFloor',
    COLOR='YELLOW',
    XYZ= -53.5, -43.8, 1.8,
    XB=  -54.5, -52.5, -44,-44, 0.4,2.0 /
&HOLE XB=  -54.55, -52.45, -44.1, -43.5, 0.3,2.2, EVACUATION=.TRUE./
```

These two records in a FDS+EVAC file indicate a definition of an exit and a HOLE which has the TRUE value for "EVACUATION", meaning that this HOLE is only used for evacuation calculation which is not needed in the fire calculation meshes. In this case the HOLE cannot be used as input variable in the FirePM since there is no "ID" entries in this record.

(5) Not all the parameters needed for FirePM can be varied without recompilation

In the configuration file, SM_Info.txt, the users are able to change the name of the baseline FDS file. However, several other parameters are written in the head file, FirePM.h. if you want to change their values, you need to modify them in the head file and then recompile the tool (you can use this command : ./make all). These parameters are:

```
#define ZERO 0.000001 // it is used to compare if two double variables are same
#define MAXFILENUM 256  //it is used to limit the maximum file number to be generated by GenFiles
#define MAXLINENUM 2560 //it is used to limit the maximum file size of a FDS file
```

#define MAXSTRINGSIZE 4096 // it is used to limit the maximum string length

#define MAXNEWDIRNUM 50 //every different VarType registered in SM_Info.txt will have one dir

#define RPNUMCMB 1 // repeated times of combined FDS file, namely VarType = 'I*C'

#define RPNUMSNR 1 // repeated times of sensitivity analysis and response analysis FDS file, namely VarType = 'I*G' or 'I*P'

#define MAXINPUTSNUM 20 // defines the maximum number of input variables

#define MAXOUTPUTSNUM 20 // defines the maximum number of output variables

#define ALARMRATIO 0.1 // defines the ratio to alarm a changed building fire performance

1.4. Arrangement of this manual

Chapter 1 shows background and limitations about the tool of FirePM.

Chapter 2 focuses on the configuration file which is the most important file the users need to spend some time to deal with. A quick method is to copy the example file provided with this tool and modify it based on your specific FDS baseline file.

Chapter 3 details the fist tool of the software FirePM, which is GenFiles. It is designed to prepare many new FDS files based on the information in the configuration file (SM_Info.txt) for the users to run the FDS simulations. Note that it is the users' work to run these FDS simulaitons. FirePM only provide these FDS files and shell files for the users to run these files. Note that these shell files may need adjustments according to your own OS.

Chapter 4 explains how the DoA tool works. DoA is the core model of the FirePM software which extract useful information from the FDS simulation results (*devc.csv, *evac.csv), calculates the sensitivity matrix of the SMM and parameters of the RSM, and compare the predictions of SMM and RSM with the FDS simulation results.

Chapter 5 introduces the final tool: FirePM as will as an optional tool which can generate or simulate dynamically changing data to test the FirePM.

Chapter 6 illustrates a case study in a small R-2 compartment building which covers all the functions of the FirePM software.

2. Explanation of the configuration file: SM_Info.txt

2.1. Introduction

Before using the FirePM, the users should have a clear idea about their expectations. The most important thing is to define the building fire performance with specific output variables that can be delivered by the FDS simulation. Then the users need to designate some input variables in the FDS file which they think may change a lot or frequently in the operational period of the building. It is assumed that the building fire performance simulation work has been done since the delivery of the building and the FDS files for this building are available for the use of FirePM. Otherwise building fire performance simulation should be conducted before the use of FirePM because FirePM needs a baseline FDS file and the baseline simulation results including the baseline building fire performance which is acceptable to the stakeholders.

The configuration file, SM_Info.txt, includes three parts: base line file, input variables section, and output variables section. In SM_Info.txt, lines begin with “#” will be just for comment and won’t be processed. A case file of SM_Info.txt is attached in APPENDIX. Both the input variables and output variables sections use some fields of the structure SMInfo which is in the source code FirePM.h:

```
struct SMInfo // s structure holding the data input file (SM_Info.txt)
{
   char VarType[4];   // ISP, IRG, I*C , O_T
   char Alias[256];   // another nicky name of the input/output variabels, it should be provided by the user
   char TargetName[256];    //the main output variable (dy) we use to evaluate the building fire performance
   char FDS_ID[256];   // the ID in FDS files
   char FileVarName[256]; // the name of input/output variables appeared in the baseline FDS file
   char CriticalValue[256]; // used for output variables as a threshold of, for example, ASET
   char BaseValue[256];   // the value of input/output variables appeared in the baseline FDS file
   char LowerLimit[256];  // the lower boundary of input variabels
   char UpperLimit[256];  // the upper boundary of input variabels
   char Divisions[4];   //for vartype = ISP or IRG, it means how many files will be geneated between LowerLimit and UpperLimit for inout variables
};
```

2.2. Baseline file

The fist effective line (not comment lines) in the configuration file likes this:

BaseFile=./base/BASE_EVAC.fds

The users should put the baseline FDS file in ./base directory. All the other FDS files will be generated based on this baseline files with the information provided in the input variables section of the configuration file, which is addressed in next section.

2.3. Input variables section

(1) Introduction

Common records of the input variables like this:

No.1: VarType=IRG, Alias=CDW, FDS_ID=CorridorDoor, FDS_VarName=XB, BaseValue=-44.25|-43.5|-39.7|-39.475|-0.025|2.5, LowerLimit=-44.575|-43.5|-39.7|-39.475|-0.025|2.5, UpperLimit=-43.875|-43.5|-39.7|-39.475|-0.025|2.5,Divisions=5
No.2: VarType=ISP, Alias=HRR, FDS_ID=burner, FDS_VarName=HRRPUA, BaseValue=3000.0, LowerLimit=2700.0, UpperLimit=3300.0, Divisions=0

No.3: VarType=I_C, Alias=CDW, FDS_ID=CorridorDoor, FDS_VarName=CorridorDoor, BaseValue=-44.25|-43.5|-39.7|-39.475|-0.025|2.5, LowerLimit=-44.575|-43.5|-39.7|-39.475|-0.025|2.5,UpperLimit=-43.875|-43.5|-39.7|-39.475|-0.025|2.5,Divisions=1
No.4: VarType=I_C, Alias=SY, FDS_ID=POLYURETHANE+Wood(oak), FDS_VarName=SOOT_YIELD, BaseValue=0.052, LowerLimit=0.03, UpperLimit=0.07, Divisions=-1
No.5: VarType=I_C, Alias=EX, FDS_ID=exhaust, FDS_VarName=VOLUME_FLOW, BaseValue=0.25, LowerLimit=0.15, UpperLimit=0.35, Divisions=1
No.6: VarType=I_C, Alias=HRR, FDS_ID=burner, FDS_VarName=HRRPUA, BaseValue=3000.0, LowerLimit=2200,0, UpperLimit=4400.0, Divisions=-1

Where VarType indicates the variable types including IRG, IRP, ISP, ISG, and I*C where "*" can be any character allowable in a fire name. the first character, VarType[0], indicates whether a variable is an input one ('I') or output one ('O'). the second character, VarType[1], indicates the ways a record will be used in the FirePM if the third character, VarType[2], is not 'C'. VarType[1]='S' indicates the records are going to be used for the sensitivity matrix method (SMM), and 'R' indicates the records are going to be used for the response surface method (RSM) focusing on the power function regression analysis. If VarType[2]='C', the records with the same VarType of "I*C" work together to form a combined fire scenario different to the baseline fire scenario defined in the baseline FDS file, whereas in other two cases where VarType[2]='G' or 'P' indicates that only one variable is changed compared to the baseline FDS file, with 'G' meaning the variables are type of geometry and 'P' meaning the variables are type of physics. For example, in the first record shown above, VarType=IRG means this record includes a geometric variable, which is the corridor door width, and this record is used for RSM analysis. The second record, VarType=ISP, means this record includes a physical variable, which is the Heat Release Rate Per Unit Area (HRRPUA), and this record is used for SMM analysis. Record number 3 to number 6 form a combined fire scenario in which more than one input variables vary simultaneously (each record includes one change of one input variable)

(2) Explanation of fields

VarType:
The type of input variables

Alias:
The short term of input variables which will be used in the analysis of SMM and RSM due to its concise appearance.

FDS_ID:
The ID in the FDS record which includes the value designated by FDS_Varname

FDS_VarName:
The variable name in the FDS record which has the value designated by FDS_ID

BaseValue:

The baseline value of the same variable in the same FDS record

LowerLimit and *UpperLimit*:

a) if VarType[1]='S', the LowerLimit and UpperLimit indicate the left and right values of the sensitivity calculation formula, namely the x_1 and x_2 in

$$S = \frac{y_2 - y_1}{x_2 - x_1} \qquad E(1)$$

where S is a sensitivity;

b) if VarType[1]='R', the Lowerlimit and UpperLimit indicate the left and right boundary within which the variable can travel;

C) if VarType[2]='C', the LowerLimit and UpperLimit indicate one of them will be adopted in the combined fire scenario depending on the value of Divisions which will be discussed later on.

Divisions:

a) if VarType[1]='S', Divisions=0 which means it has no effect on this record;

b) if VarType[1]='R', Divisions is a non-negative integer meaning the number of cuts within the interval between the LowerLimit and the UpperLimit. For example, if Divisions=3, then the interval will be cut 3 times, which means there will be 3+2 points for this variable, then there will be 3+2=5 new files to be generated later on;

c) if VarType[2]='C', Divisions='-1' indicates that the LowerLimit will be used, otherwise if Divisions='1' the UpperLimit will be used.

(3) Notes for input variables

As shown in record No.1 and No.3 above, the variables are both CorridorDoor width, which is a geometric variable including 6 coordinates in the sequences of $x_1|x_2|y_1|y_2|z_1|z_2$. These 6 coordinates define exactly an obstruction/hole/vent in FDS files. Although there are 6 coordinates, to simplify the calculation process, only change of one coordinate in one record is supported. By comparing the basevalue and the LowerLimit value or UpperLimit value, the changing coordinate can be identified. It is the responsibility of the users to input changes of a meaningful coordinate. For example in the case of record No.1, the coordinates of x_1 and x_2 define the edge of the opened corridor door, and the width is x_2-x_1. Therefore changes of coordinates of y_1 and y_2 are meaningless because y_2-y_1 indicates the thickness of the corridor door. Similarly, meaningful inputs are also essential for other physical variables in order to obtain expected reasonable results. In this sense the user of FirePM should be quite familiar with the building fire performance design (but the understanding and application of the results of FirePM do not require so sophistic knowledge).

Although most of the input variables are straightforward, easy to understand and convenient to input in the FDS files, in reality the estimation of their changes may need considerable efforts. For example, it is easy to change the value of the HRRPUA in the FDS file, but in the real applications it is hard to estimate the actual HRRPUA in a building once a fire occurs since this kind of estimation needs many literature reviews to search relative fire experimental or simulating results. The same thing goes with the estimation of the soot yield which can also be simply input in the FDS files but hard to determine in the real fire conditions. Although experts' judgement can speed up the process of this kind of estimations and at the same time guarantee the quality of the estimations, more objective and automatic methods like machine learning/AI are more suitable in the view of software development. This will be the further research topic of researchers in FPE department of WPI and may also interests other researchers in the FPE community worldwide.

2.4. Output Variables section

(1) Introduction

Common output variables records like this:

No.1: VarType=O_t, Alias=ASET_5, TargetName=Time, FDS_ID= V1, FDS_VarName=V1, CriticalValue=5.00,Division=-1

No.2: VarType=O_t, Alias=ASET_10, TargetName=Time, FDS_ID=V1, FDS_VarName=V1, CriticalValue=10.00,Division=-1

No.3: VarType=O_R, Alias=RSET, TargetName=EVAC_Time,FDS_ID=AllAgents, FDS_VarName=AllAgents,CriticalValue=2,Division=-1

(2) Explanation of the fields

VarType:

The output variable type. VarType[0] is always 'O' meaning "output", VarType[1] is preserved for future use and currently is set to '_'. VarType[2] is up to the user to define. In the record No.1 shown above, VarType[2] = 't' indicates the target variable name is "Time". You can also name it with 'A' indicating "ASET". In the record No.3, the VarType[2]='R' indicates the target variable name is RSET.

Alias:

The short explanation about what the building fire performance means which will be used in the analysis of SMM and RSM. For example, in record No.1, Alias=ASET_5, which means the building fire performance is expressed by Available Safety Egress Time (ASET), and "5" means the criteria of untenable condition at the exits is the visibility (at 1.6m high) is lower than 5m. In record No.3, Alias=RSET, which means the building fire performance is expressed by Required Safety Egress Time(RSET).

TargetName:

The variable in the FDS output file ("*.csv") than can tell the exact value of the building fire performance expressed by the Alias. For example, in No.1, TargetName=Time, which means the Time is the unit of the building fire performance ("Time" is the first column in *devc.csv). In No.3, TargetName=EVAC_Time, which means the Evacuation Time is the unit of the building fire performance "EVAC_Time" is the first column in *evac.csv).

FDS_ID:

The ID in the FDS record which presents in the FDS output files.

FDS_VarName:

Different to the input variable section, here the FDS_VarName should be the same as FDS_ID because only the FDS_ID appears in the output files of FDS simulation. For example, look at the following FDS record:

&DEVC ID='V1', QUANTITY='VISIBILITY', XYZ=-52.231,-43.0,1.6/

The FDS_ID is ‘V1’, the FDS_VarName should have been ‘VISIBILITY’, but ‘VISIBILITY’ doesn’t appear in the FDS output files, only ‘V1’ appears. Therefore the FDS_VarName has to be ‘V1’ which is same to FDS_ID.

CriticalValue:

The threshold for the output variable designated by FDS_VarName to be met. For example, in record No.1, the CriticalValue=5, which means the threshold for ‘V1’ in the FDS output file, *devc.csv , to indicate the untenable condition is the visibility dropping down to 5 m.

Division:

It indicates how the CriticalValue is met. “-1” means the CriticalValue is met from top to bottom, “1” means the CriticalValue is met from bottom to top. For example, in record No.1, the Division = -1, which means the visibility decreases to the critical value of 5m, not increases to it.

(3) Notes for the calculation of the building fire performance

The building fire performance is expressed by the Alias which is related to the TargetName and FDS_VarName appearing in the FDS output files. In FDS, the number of record outputted by the FDS simulation is controlled by NFRAMES, and the total simulation time is controlled by T_END. Therefore, time step in the FDS output files can be calculated as T_END/NFRAMES. If this time step is big, some kind of interpolation between two records may be necessary for our analysis. For example, look at the following parts of records of FDS output file (*devc.csv):

Time	V1
….	….
100	7
104	3
……	….

At time=100s, the visibility is 7m, at time=104s, the visibility is 3m. since our critical value of visibility is 5m, we need calculate the ASET by some kind of interpolation. Linear interpolation is the most common one and is adopted in FirePM to calculate the building fire performance. That said, for this output shown above, it is easy to know that the linear interpolation of ASET is 102s

2.5. The importance of the configuration file (SM_Info.txt) in FirePM

The configuration file is very important to FirePM. As discussed below, the tools of GenFiles, DoA, and FirePM depends on the content of this file. The most important thing is that GenFiles uses the information in the input variable section of this file to derive many FDS simulation files from the baseline FDs file whose name is also registered in this configuration file. A linux shell (Mfds.sh), which the users can use to run the FDS simulations after refining it according to their own linux MPI settings and FDS version settings, is automatically generated under each directory holding the derived FDS files. After all the derived FDS files are simulated, the DoA use the information in the configuration file to analyze the FDS simulation results, so does the FirePM. More details will be addressed later on in this manual.

3. Explanation of the first tool: GenFiles

3.1. Introduction

Generally, FirePM can be deemed as a sensitivity and parameter analysis software which usually necessitates large number of simulations before its results can be used to simplify and speed up the real case applications. Therefore, the first step is to prepare these FDS simulation files. People can choose to do this manually when the number of files is low, but when the number is high it becomes cumbersome and prone to mistakes. The tool of GenFiles helps you to automatically generate the group of simulation files according to the information you provide in the configuration file (SM_Info.txt). Under the working directory, the following command can be used for GenFiles:

```
./GenFiles SM_Info.txt
```

3.2. How GenFiles works

Based on the information in the input variables section of the configuration file, GenFiles translates these records to another data structure as shown below (from FirePM.h):

```
struct GenInfo
{// a structure storing the records each of which will be derived from the baseline FDS file
    char VarType[4];   // ISP, IRG, I*C , O_T
    char Alias[256];   // another nicky name of the input/output variabels, optional
    char FDS_ID[256];   // the ID in FDS files
    char FileVarName[256]; // the name of input/output variables appeared in the baseline FDS file
    char BaseValue[256];   // the value of input/output variables appeared in the baseline FDS file
    char MoveTo[256];      // the value of inpot variables we want to jump to.
};
```

Where all the fields have the same definition as in the structure SMInfo except the new field “MoveTo”. This new field is translated from the fields of VarType, LowerLimit, UperLimit and Divisions in the SMInfo structure, indicating that in a new FDS file the BaseValue will be replaced by MoveTo. For each record of structure GenInfo, a new FDS file will be composed. Here are the translation rules:

(1) VarType[1] = ’S’ (equal to) and VarType[2] != ’C’ (not equal to)

There records are used in the SMM to generate the sensitivity matrix. Each record will be transformed into two records of struct GenInfo, one for the LowerLimit being assigned to MoveTo, the other for the UpperLimit being assigned to MoveTo. The sensitivity calculation is based on the $S = \frac{y_2 - y_1}{x_2 - x_1}$ *E (1)*. Where S is the sensitivity, x_1, x_2 are the value of LowerLimit and UpperLimit, respectively. And y_1 and y_2 are the simulated building fire performance values defined by Alias, respectively.

(2) VarType[1] = ’R’ and VarType[2] != ‘C’

These records are used in the RSM to calculate the parameters of power function regressions. The LowerLimit and the UpperLimit define the interval within which an input variable can vary. The Divisions defines the number of simulation files for each of this kind of record, which is Divisions+2. For example, if Divisions = 3, there will be 3+2=5 records registered in the structure of GenInfo, each of which will generate one FDS file derived from the FDS baseline file by feeding the MoveTo field with the following equation:

MoveTo = BaseValue + i x (UpperLimit – LowerLimit)/(Divisions+1) *E (2)*

Where i is the order of the new files increasing from 0 to Divisions+1 (the total number of new files is Divisions+2).

(3) VarType[2] = ‘C’

After the calculation of the sensitivity matrix (SMM) and the parameters of power function regression (RSM), it is necessary to evaluate how good the SMM and RSM are. This evaluation can be done by comparing the FDS simulation results and the values predicted by SMM and RSM for a combined fire scenario in which more than one (most of the time all the input variables listed in the input variable section of the configuration file, SM_Info.txt) variables vary simultaneously. The type of records in SM_Info.txt with VarType[2]='C' defines some different combined fire scenarios for the purpose of comparison. With each record having only one change of one variable, all the records with the same value of VarType form a combined fire scenario. Each record in SM_Info.txt will be transferred to the structure of GenInfo where MoveTo equals either the value of the LowerLimit (if Divisions = -1) or the value of the UpperLimit (if Divisions = 1). All the records in the structure of GenInfo having same VarType (and VarType[2]='C) will be fabricated to generate one new FDS file.

3.3. Note for GenFiles

(1) Run GenFiles

The use of GenFiles is simple, just input the following command under the directory where

GenFiles lives:

./GenFiles ./SM_Info.txt

Then all the needed new files will be generated and put into different directories with the name assigned with the VarType of the records in SM_Info.txt. That said, all the new files will be put under the following directories:

./ISP, ./ISG, ./IRG, ./IRP, ./I*C

And a shell, Mfds.sh will be generated and put under each of these directories.

(2) Dealing with the uncertainties of FDS simulations

FDS as a field model introduces and adopts some aspects that make its simulation results more consistent with the reality. This, however, also causes new issues about the repeatability, stability and convenience.

a) FDS initializes the flow field with a very small amount of "noise" to prevent the development of a perfectly symmetric flow when the boundary and initial conditions are perfectly symmetric, which partly contributes to the small discrepancy of some output variables between repeated simulations with identical FDS input files. This small amount of "noise" has only a very limited effect on some output variables of our interest like HRR, temperature, velocity, species concentration, and visibility. However, this very little effect may have considerable impacts on the sensitivity matrix generated from small change of input factors.
b) The resolution of FDS, which is controlled by the grid size, may have significant influence on the sensitivities of geometry-based input variables like width/height of a hole/vent/wall. To make a difference, the changing range of such kind of variables should cover at least one cell size, and the more cells are covered, the more accuracy the simulation results are. Or in other words, the curves of outputs with response to inputs are smoother and more monotonic with some promising and reasonable input intervals if the grid cell is smaller. However, this will increase exponentially the computational time. The following figure shows that in FDS different results may exist when one FDS file is run two times.

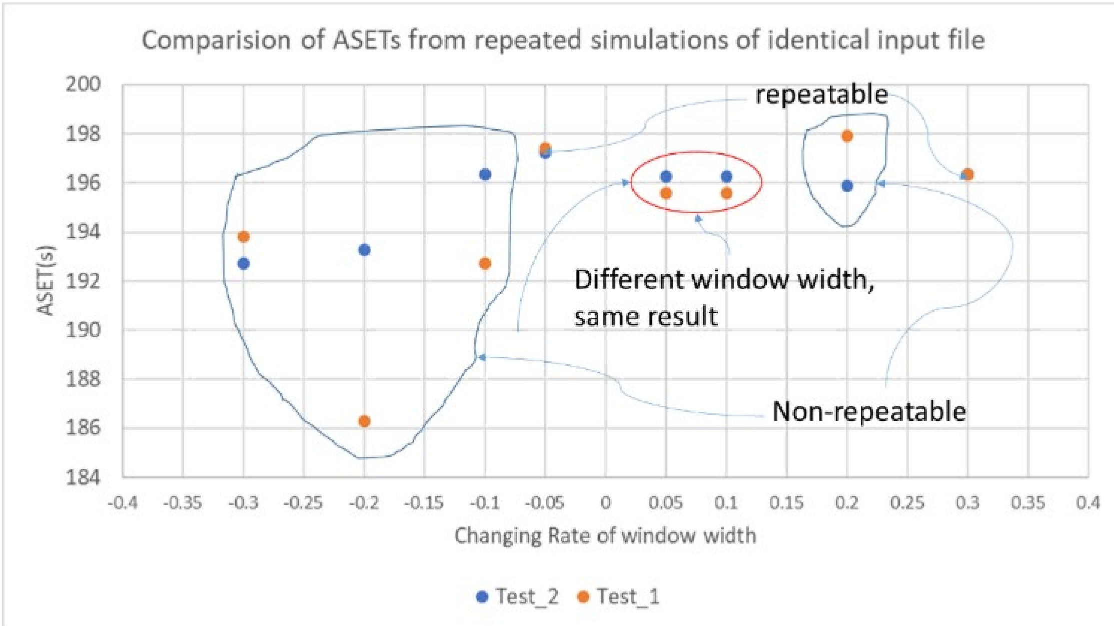


Figure 2 Uncertainty of FDS simulation

c) FDS allows different meshes run on different computer cores, which speeds the simulation process. However, this also partly causes the repeatability issue: different simulation results for an identical input file being run repeatedly. Deployment of all the jobs on one computer core may remove this part of the repeatability issue but on the other hand will inevitably result in much longer simulation time.

d) Due to the inherent turbulence of the smoke flow field driven by a fire, visibility change with time at some points (in our case at the exit 1 in the *Figure 4* shown in chapter 6) is not smooth and monotonic, causing that the time for the visibility to first pass through the preset threshold of 5m, or ASET, fails to change linearly with the input parameters, as shown in the figure below:

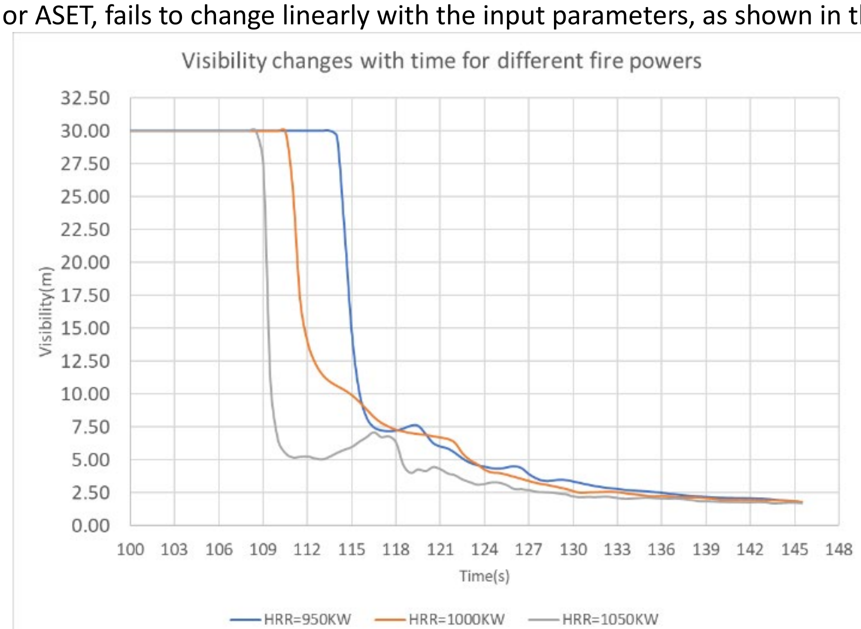


Figure 3 visibility changes with time for different fire powers

We can see from *Figure 3* that for the curve of HRR=1050KW, once the visibility is very close to 5m at 113s (5.03m), we cannot take 113s as the ASET because our criteria of deciding ASET is “visibility first penetrates 5m line”. Therefore, after some fluctuations it does penetrate the 5m line at about 118.4s. The ASET gap between the visibility being first very close to the 5m line and penetrating the 5m line is only 5.4s, which is insignificant comparing with the baseline ASET of 123s. However, when it comes to the sensitivity of HRR to ASET, it makes a lot of difference. The ASET for HRR=1000KW is about 123s, that for HRR=950KW is about 122.6s. It is clear that the change of ASET with HRR is not linear since 123s is not between 118.4s and 122.6s. One would have been wondering why we don’t replace the current criterion of deciding the ASET with other more flexible ones, like “close to 5m”. The issue with this flexible criterion is how to define “close”. Another seemingly promising method is the introduction of “moving average over a window”. The issue with this method is how to define the size of “window”. If the “window” is too narrow, the fluctuations still exist. If it is too wide, part of the import physical information will be removed and the sensitivity matrix becomes less meaningful. Since each alternative method of deciding the ASET has its own limitations especially in the context of this manual, the current criterion of first penetration seems reasonable. Nevertheless, in average it is pretty fair to each fire scenario once a fixed criterion is set.

Therefore, GenFiles will generate a copy of each new file for the users to run and the following tool of DoA will average the results from identical FDS files. The number of repeated files is actually adjustable by changing the RPNUMCMB and RPNUMSNR in the FirePM.h, as shown below:

```
#define RPNUMCMB 1        // repeated times of combined FDS file, namely VarType = 'I*C'
#define RPNUMSNR 1        // repeated times of sensitivity analysis and response analysis FDS file, namely VarType = 'I*G' or 'I*P'
```

This may be useful when the simulation results from identical FDS files are quite scattered, which is the case of running FDS+EVAC to obtain the RSET: the simulation results may change a lot when identical FDS files are run repeatedly, and the averaged results with more repeated runs seem to be more reliable. It is up to the users to decide the needed repeated times since different users have different constrains about the computer resource which is essential when many FDS simulations are being conducted.

4. Explanation of the second tool: DoA

4.1. Introduction

After the new FDS files are generated and run, the next step is to analyze the simulation results. DoA does three things in sequence: 1) calculating the sensitivity matrix for SMM, 2) calculating the power function regression parameters for RSM, and 3) comparing the simulated building fire performance with that predicted by SMM and RSM. Before the development of FirePM, the authors have done these three things in a residential building manually, which took days. With the FirePM, it only needs couple of minutes (excluding the time to simulate the FDS files).

Under the working directory, the following command can be used for DoA:

```
./DoA SM_Info.txt
```

4.2. Calculating the sensitivity matrix

First, the FDS simulation results (*devc.csv or *evac.csv) will be explored to extract useful information (the simulated building fire performance represented registered in SM_Info.txt) and save them to DoA.csv, which looks like this:

Table 1 Part of records in DoA.csv

InputVarType	OutputVarType	InputAlias	OutputAlias	TargetName	InputFileVarName	OutputFileVarName	InputBaseValue	OutputBaseValue	InputNewValue	OutputNewValue
IRG	O_t	CDW	ASET_5	Time	XB	V1	0.75	197.35	0.608	198.62
IRG	O_t	CDW	ASET_10	Time	XB	V1	0.75	183.5	0.608	185.67
IRG	O_t	CDW	ASET_5	Time	XB	V1	0.75	197.35	1.075	184.57
IRG	O_t	CDW	ASET_10	Time	XB	V1	0.75	183.5	1.075	176.87

Then a sensitivity matrix is calculated based on the information in DoA.csv, which looks like this (in the file of SMT.csv which is under the working directory):

Table 2 example of sensitivity matrix in SMT.csv

dy/dx	ASET_5	ASET_10
CDW	-27.0989	-16.985
EX	160.1806	121.1269
HRR	-0.01862	-0.01849
SY	-116.099	27.13867

Where the first row shows the target variables indicating various indices of the building fire performance, the first column shows the input variables which can affect the target variables, and the other cells show the sensitivity of target variables to the input variables.

The SMM is based on the expansion of a Taylor series around the design values $a^0 = \left(a_1^0, \ldots, a_n^0\right)^T$ and retaining only the terms up to the n^{th} order in the variations around a_i^0, which gives:

$$
\begin{aligned}
R_j &= R_j\left(a_1,...,a_k\right) = R_j\left(a_1^0+\Delta a_1,...,a_k^0+\Delta a_k\right) \\
&= R_j\left(a^0\right) + \sum_{i_1=1}^{k}\left(\frac{\partial R_j}{\partial a_{i_1}}\right)_{a^0}\Delta a_{i_1} \\
&+\frac{1}{2}\sum_{i_1,i_2=1}^{k}\left(\frac{\partial^2 R_j}{\partial a_{i_1}\partial a_{i_2}}\right)_{a^0}\Delta a_{i_1}\Delta a_{i_2} \\
&+\frac{1}{3!}\sum_{i_1,i_2,i_3=1}^{k}\left(\frac{\partial^3 R_j}{\partial a_{i_1}\partial a_{i_2}\partial a_{i_3}}\right)_{a^0}\Delta a_{i_1}\Delta a_{i_2}\Delta a_{i3}+... \\
&+\frac{1}{n!}\sum_{i_1,i_2,...i_n=1}^{k}\left(\frac{\partial^3 R_j}{\partial a_{i_1}\partial a_{i_2}...\partial a_{i_n}}\right)_{a^0}\Delta a_{i_1}...\Delta a_{i_n}
\end{aligned}
\qquad E(3)
$$

For large complex systems with many parameters like fire models, it is impractical to consider the nonlinear terms. As a first-order approximation neglecting the nonlinear terms, the response $R_j\left(a_1,...,a_k\right)$ becomes a linear function of the parameters $a=\left(a_1,...,a_n\right)^T$ of the form

$$
\begin{aligned}
R_j\left(a_1,...,a_k\right) &\approx R_j\left(a^0\right)+\sum_{i=1}^{k}\left(\frac{\partial R_j}{\partial a_i}\right)_{a^0}\Delta a_i \\
&= {R_j}^0+\sum_{i=1}^{k}S_{ji}\Delta a_i
\end{aligned}
\qquad E(4)
$$

Where $R_j\left(a^0\right)={R_j}^0$ and $S_{ji}=\dfrac{\partial R_j}{\partial a_i}$ is sensitivity of the response $R_j\left(a_1,...,a_k\right)$ to the input parameter a_i. All the S_{ji} form a rectangular sensitivity matrix S of order $n\times k$.

Equation (3) can be rewritten in fire performance gap version as:

$$
\begin{aligned}
G_j\left(\Delta a_1,...,\Delta a_k\right) &\approx R_j\left(a_1,...,a_k\right)-{R_j}^0 \\
&\approx \sum_{i=1}^{k}S_{ji}\Delta a_i
\end{aligned}
\qquad E(5)
$$

Which means that when input parameters have small changes around their baseline or reference values, the total fire performance gap due to simultaneous small changes of each input parameters equals the sum of each fire performance gap caused by the change of each single input parameter.

In FirePM, S_{ji} is calculated by Equation (1) which needs two values of each input variable and two values of each target variable. Traditionally the S_{ji} should be calculated by changing the input variables a little bit, and the equation (3) applies only when the input variables have limited changing ranges. In real applications, however, the definitions of “limited” vary a lot depending on the linear degrees of different problems. If the problems are quite quasi linear within some definition domains of the input variables, the equation (3) may still be applicable when the input parameters changes considerably. In other highly non-linear problems, however, its applicable range maybe quite small. It is the users' responsibility to decide the distance between x2 and x1 when generating the sensitivity matrix. Also the judgement of the applicable range of the SMM may need more tries or deep understandings of the nature of the problems

The details about how the sensitivity matrix is worked out is listed in the file of "SMT_detail.csv" which is under the same directory as "SMT.csv".

4.3. Calculating the power function regression parameters

In FirePM, Power function regression works as a kind of response surface methods (RSMs) To find the relationship between the outputs and the inputs, two rounds of power function regression ($y = Ax^B$) are adopted in FirePM. In the first round, the simulation data from the generated files under directories including "IR*" are used. Since these data are generated by changing a single input variable for several times, the first round of power function regression can deliver the relationship between one output and one single input (namely, tell us the parameters of A and B). In the second round of power function regression, our purpose is to find the relationship between one output variable and all the input variables. In this round, the simulation data from the generated files under directories including "I*C" are used. Since these data are generated by changing all the input variables simultaneously for several times, the second round of power function regression can deliver the relationship between one output and all the input variables. The key is to get the new input (x_{new}), which is calculated by:

$$x_{new} = \prod_{i=1}^{n} x_i^{b_i} \qquad E(6)$$

Where x_i is the i[th] input variable, and b_i is the power parameter in the first round simulation. The new output data are obtained from the simulation data files(*devc.csv,*evac.csv) which reflect the influences of changing all the input variables at the same time.

The power function regression is done by linearization of the power function:

$$y = ax^b \Rightarrow \ln(y) = \ln(a) + b\ln(x) \qquad E(7)$$

Which can be resolved by commonly used linear regression methods.

The calculated parameters are saved in the file of "RSMRlt.csv" which is also under the working directory.

A typical of it is like this:

Table 3 part records in RSMRlt.csv

OutputAlias	InputAlias	a	b	r_sqr	s_sqr	OutputBaseValue
ASET_5	CDW	186.84	-0.14	0.969177	0.000104	197.35
ASET_10	CDW	178.14	-0.09	0.982881	0.000022	183.5
ASET_5	HRR	1781.2	-0.28	0.984451	0.000138	197.35
ASET_10	HRR	1294.26	-0.24	0.979911	0.000139	183.5

ASET_5	SY	119.33	-0.17	0.868544	0.001496	197.35
ASET_10	SY	150.76	-0.07	0.91814	0.000137	183.5
ASET_5	EX	271.24	0.21	0.806874	0.004285	197.35
ASET_10	EX	257.2	0.2	0.84204	0.00306	183.5
ASET_5	CDW+SY+EX+HRR	1139.62	0.87	0.901035	0.005312	197.35
ASET_10	CDW+SY+EX+HRR	1872.58	1.13	0.984027	0.000803	183.5

In this table, there are two outputs(ASET_5 and ASET_10) and four input variables(CDW: corridor door width, HRR: heat release rate, SY: soot yield and EX: exhausting rate). The first 8 records show the power function parameters between a single output and a single input variable. The last 2 records show the power function parameters between a single output and all the input variables. r_sqr is the "correlation coefficient" which indicates the overall quality of the fit, and the s_sqr is an estimator for the variance in error e (e=y-y* where y is the experimental real output and y* is the data predicted by the power regression curve).

4.4. Comparison between simulating results and predicted results

Now that we have two prediction methods available: SMM and RSM, we can compare the predicted results with the FDS simulation results. This comparison is saved in "CMB.csv", which looks like:

Table 4 part of records in CMB.csv

InputVarType	OutputVarType	InputAlias	OutputAlias	InputNewValue	OutputNewValue	PreValueRSM	PreValueSMT
I_C	O_t	CDW+SY+EX+HRR	ASET_5	0.375000+0.03+0.35+2200	299.73	277.72	240.98
I_C	O_t	CDW+SY+EX+HRR	ASET_10	0.375000+0.03+0.35+2200	258.44	255.12	216.18
I1C	O_t	CDW+SY+EX+HRR	ASET_5	1.000000+0.08+0.10+3800.0	161.14	147.85	148.41
I1C	O_t	CDW+SY+EX+HRR	ASET_10	1.000000+0.08+0.10+3800.0	143.27	138.82	147.06
I2C	O_t	CDW+SY+EX+HRR	ASET_5	0.300000+0.08+0.4+3800.0	217.3	221.7	215.43
I2C	O_t	CDW+SY+EX+HRR	ASET_10	0.300000+0.08+0.4+3800.0	214.07	214.88	195.28
I3C	O_t	CDW+SY+EX+HRR	ASET_5	0.200000+0.07+0.3+3500.0	224.51	229.6	208.87
I3C	O_t	CDW+SY+EX+HRR	ASET_10	0.200000+0.07+0.3+3500.0	212.89	216.13	190.14
I4C	O_t	CDW+SY+EX+HRR	ASET_5	1.100000+0.04+0.2+2500	190.4	203.98	190.56
I4C	O_t	CDW+SY+EX+HRR	ASET_10	1.100000+0.04+0.2+2500	185.27	190.77	180.42
I5C	O_t	CDW+SY+EX+HRR	ASET_5	1.100000+0.028+0.2+3500.0	182.71	198.32	173.34
I5C	O_t	CDW+SY+EX+HRR	ASET_10	1.100000+0.028+0.2+3500.0	173.82	178.71	161.61
I6C	O_t	CDW+SY+EX+HRR	ASET_5	0.200000+0.07+0.3+2500	256.83	248.99	227.49
I6C	O_t	CDW+SY+EX+HRR	ASET_10	0.200000+0.07+0.3+2500	244.59	237.04	208.63

Where the first two columns indicate the input and output variable types, the second two columns indicate the aliases of the input variables and output variables, the fifth column indicate the values of the input variables corresponding to the sequence in the third column, and the last three columns indicate the FDS simulation results, the RSM predicted values, and the SMM predicted values, respectively. You may have noticed that the RSM predicted values are closer to the FDS simulation results than the SMM predicted values, which here doesn't necessarily mean the RSM is better than the SMT since the power function regression parameters of the RSM are derived from these FDS simulation results. To compare the performance of RSM and SMT, new data different from that being used for power function regression should be involved, which will be addressed later on in this manual.

5. Explanation of the third tool: FirePM

5.1. Introduction

With the help of the first two tools, GenFIles and DoA, FirePM can now conduct the task of building fire performance monitoring once the input data file(Dyn.txt) that includes the newest changes of the input variables listed in the input configuration file(SM_Info.txt) is updated. Under the working directory, the following command can be used for FirePM:

```
./FirePM SM_Info.txt
```

5.2. Input data file and output data file

Except the configuration file, which is SM_Info.txt, an independent input data file which stores the newly changed values of the input variables is in need for the tool of FirePM to work. A typical input data file(Dyn.txt) looks like this :

Table 5 part of records in Dyn.txt

Sequence	Var1	Var2	Var3	Var4
Time	CDW	SY	EX	HRR
1	-43.600|-43.5|-39.7|-39.475|-0.025|2.5	0.0363	0.45	1651.69
2	-43.600|-43.6|-39.7|-39.475|-0.025|2.5	0.0463	0.55	2651.69
3	-43.600|-43.7|-39.7|-39.475|-0.025|2.5	0.0563	0.65	3651.69

Where the first column shows the time stamp of sequence or the orders, and the other column shows the newly updated values of the input variables. Note that if a variable is a geometric one, you need to input all the six coordinates defining the object. However, only one coordinate is allowed to be different from its baseline value.

Then a typical output data file (FirePM.csv) looks like this:

Table 6 part of records in FirePM.csv

Time	ASET_5_BAS	ASET_5_SMT	ASET_5_SMT_MEA	ASET_5_RSM
41	197.35	275.08	CDW[2.8684]||EX[-0.4853]||HRR[4175.6648]||SY[0.6695]	367.28

Where the first column corresponds to the first column in the input data file(Dyn.txt), and the second column, ASET_5_BAS, indicates the base value of the building fire performance (represented here by ASET), the third column, ASET_5_SMT, indicates the value of the building fire performance predicted by the SMM, and the fourth column, ASET_S_SMT_MEA, indicates the mathematically feasible methods to close the building fire performance gap which is the different between ASET_5_SMT and ASET_5_BAS. Note that the gap can be positive or negative, and the meanings of being positive and negative depend on the physical property of the target variable representing the building fire performance. For example, In this case the gap (ASET_5_SMT – ASET_5_BAS) is positive, which means the current building fire performance is higher than the baseline value because the current ASET is longer. If the target variable is RSET, for example, the meanings will be opposite to the ASET because for RSET the shorter is better/safer. ASET_5_SMT_MEA gives measures to close the building fire performance gap, but in fact whether one measure is feasible needs to be further checked by the relative persons like the building managers. For example, in the record shown above, the current building fire performance is much better than the baseline performance, therefore some kinds of relaxations on the input variables may be allowable, which means the corridor door may be opened to a larger extent, the flow rate of the exhausting fans can be lowered to some extent to save the energy, more combustibles, which indicates a higher HRR, may be allowed, and sootier materials can also be put in the apartment (indicates increase of the soot yield of the material). All these four changes, however, are not realistic. For example, the increase of corridor door openness is 2.8684m, which is wider than the corridor width and therefore is not possible. But it does indicate that the corridor door can be fully open without incurring a shorter ASET than the baseline value which is supposed to be agreed by the stakeholders. The fifth column, ASET_5_RSM, indicates the building fire performance predicted by the RSM. On the other hand, if the ASET_5_SMT is less than the ASET_5_BAS(negative gap), the AST_5_MEA is supposed to give the mathematically feasible methods to close the building fire performance gap represented by ASET.

Note that the measures in ASET_5_MEA are “single-factor” measures, which means each measure corresponds to single input variable. For example, in the record shown above, the ASET_5_MEA includes 4 measures, each of which focuses on only one input variable, namely, either for the corridor door width to increase 2.8684m (which is larger than the width of the corridor itself) or for the HRR to increase 4175.6648kW, etc.. Theoretically there may be a large number of measures that combine the changes of various input variables, which is not addressed in this version of FirePM.

5.3. The test tool for FirePM: GSD

In real application, the tool of FirePM needs the input data file (Dyn.txt) being provided either automatically by some plugin modules in the building management system which will be developed in the future to translate the physical changes of the building’s inside finishes and/or outside façade into the changes of input variables listed in the configuration file (SM_Info.txt), or manually by the end users like the building managers. For the test of FirePM, a tool that can generate the synthetic input data, GSD, is provided along with the tool of FirePM. You just need to open two terminal windows, one for the GSD, and one for the FirePM. In the GSD window, input this command under the working directory of FirePM:

./GSD

Which will fabricate one input data every second and save the data to the input data file (Dyn.txt) at the same time print it out to the screen which, for example, is shown below:

```
[hwang8@turing-login-01 FirePM]$ ./GSD
                              477,-44.503|-43.5|-39.7|-39.475|-0.025|2.5,0.0535,0.11,1268.16
```

Then in the FirePM window, input

./FirePM SM_Info.txt

Which will read the input data file (Dyn.txt) continually with a break time of one second (sleep(1)), and output the calculated results to both the result file (FirePM.csv) and the screen which, for example, is shown below:

```
                 Time        ASET_5_BAS       ASET_5_SMT     ASET_5_SMT_MEA     ASET_5_RSM      ASET_10_BAS      ASET_10_SMT     ASET_10_SMT_MEA  ASET
_10_RSM

                  559            197.35*          234.84*   CDW[1.3834]||EX[-0.2340]||HRR[2013.9672]||SY[0.3229]          220.93*         183.50
    217.82*    CDW[2.0206]||EX[-0.2833]||HRR[1856.4397]||SY[-1.2646]         236.49*
```

The star after a value in the above clip indicates that the predicted building fire performance exceeds the preset changing ratio, ALARMRATIO defined in the head file FirePM.h, and therefore needs the users' attention. The default value of ALARMRATIO is 0.1, which means once the predicted building fire performance is either higher or lower 10% of that from the baseline FDS simulation, the users will be alarmed.

6. Case study

6.1. Case introduction

As shown below, a propane gas-burner fire is put close to the lower-right corner of the lower-right apartment of a R-2 residential building. There are two corridor doors set close to each end of the main corridor. All the apartment doors are closed except the fire apartment, the entry doors of the building are kept open during the simulations.

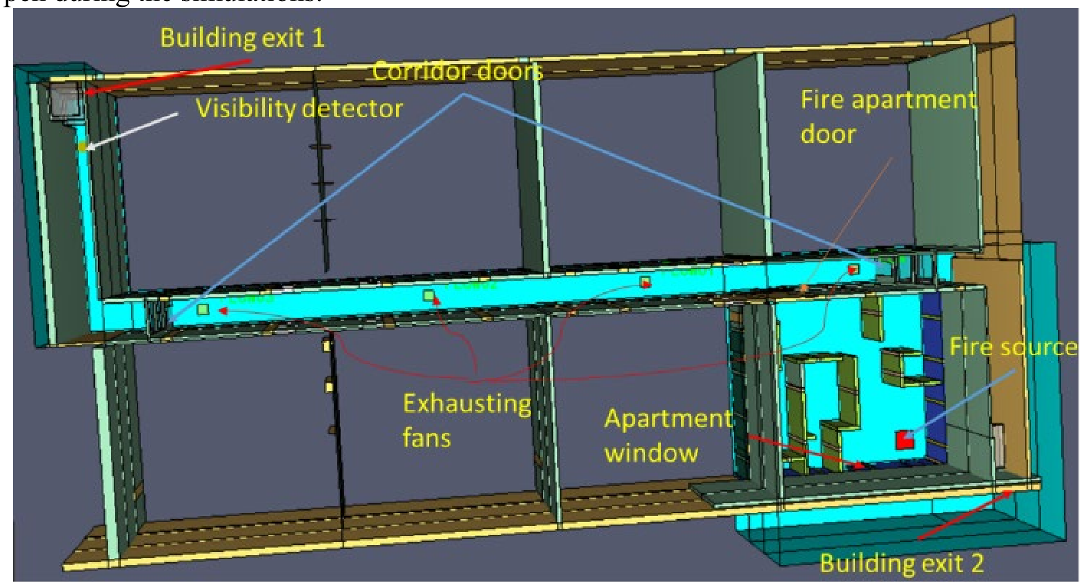


Figure 4 Room fire scenario in a 3-story R-2 building

Four input factors are considered:

(1) the width of the left corridor door, $W_c(m)$.

Corridor doors are key points which the smoke has to pass by before it arrives at the exits. Therefore, the opening widths of them directly regulate the smoke spread speed and thus the ASET of the apartment building. When a fire occurs, most of the time a corridor door is either open or closed. Sometimes it can also be partly opened purposely by someone. When this happens the open width can be random. To analyze the influence of the open width of a corridor door, in this case it is assumed that a corridor door can be opened to any width.

(2) the Heat Release Rate (HRR) of fire, $HRR(KW)$.

As the driving force of a fire, the HRR is the most important factor affecting the building fire performance. The changing patterns of HRR are very diverse, including changes of fire growth rate, peak HRR, lasting time, etc. For example, the replacement of the inner finishes and furniture may result in changes in each aspect. In this case study, we use the change of HRRPUA (HRR per unit area) to consider the changes of both the peak HRR and the fire growth rate, with the lasting time intact. For example, if we increase HRRPUA from 1MW/m^2 to 2/MW/m^2 and at the same time keep the ramp time (the time needed for the fire to reach the value of HRRPUA) stable, it equals doubling both the peak HRR and the fire growth rate. More detailed research is needed to investigate the relationship between the HRR and the combustibles, fire load, and the arrangement of items inside a compartment.

(3) the soot yield of fuel, Y_s

When other factors are kept constant, the increase of the soot yield can reduce the ASET by reducing the visibility. Both the ventilation condition and the material properties could affect the soot yield of fuel. Still, more research is needed to check the relationship between the soot yield and the influencing factors. In this case, to investigate the impact of soot yield on the ASET, it is assumed that the soot yield can be chronically changed without further illustration about the underlying reasons.

(4) and the flow rate of exhausting fans, $E_f(m^3/s)$

In an apartment fire, exhausting fans are expected to remove the hot smoke accumulated beneath the ceiling. In our case, four exhausting fans are set in the ceiling of the corridor. Exhausting fans usually have various working conditions providing a range of flow rates. Here it is assumed that the flow rate of exhausting fans can be chronically changed.

Only ASET, A_t ,which is measured by a visibility detector close to exit 1 with a threshold of 5m, is considered as the output variable. It is assumed in this case that all the four input factors change chronically, as what they could perform in real world. Therefore, the SMM is suitable to rapidly estimate the building fire performance, or the ASET in this case.

6.2. Input files

The baseline FDS file is “PF_base_wowb.fds”, which is in the ./base directory. The configuration file, SM_Info.txt, is also in the current working directory of the tool of FirePM. The input data file “Dyn.txt” needs to be provide either by the third party or by the tool of GSD. Note that GSD delivers an updated data record randomly from specific ranges of input variables, which may not be what you expected. It this is the case, you can modify the source code file, “GenSimData.c”, to meet your expectation.

6.3. output files

(1) After running the command of “./GenFIles SM_Info.txt”, a number of new FDS files will be generated and put in various directories (in this case, the directories are “./I_C, ./I1C, ./I2C, ./I3C,./I4C, ./I5C, ./I6C, ./ISP, ./ISG, ./IRP, ./IRG”

(2) Some shells with the name of “Mfds.sh” to run the FDS are generated in current directories as well as the generated directories where the new FDS files are living. An example shell in the directory of ./I1C likes this:

sfds -n 2 -T 2 -t 40:40 -p long -i /work/hwang8/FirePM/I1C/CDW_SY_EX_HRR.fds
sfds -n 2 -T 2 -t 40:40 -p long -i /work/hwang8/FirePM/I1C/CDW_SY_EX_HRR__0.fds

where sfds is the MPI version of FDS in the LINUX servers where the tool of FirePM is developed. The users may need to change this file to cope with their own operation system and resources.

(3) After running the command of “./Mfds.sh” under each directory hosting the new FDS files, the *.devc files will be generated which will be used by our tool. Note that this process may last quite a long time depending on your available computational resource.

(4) After running the command of “./DoA SM_Info.txt”, the following files will be generated:

./DoA.csv

Part of this file is:

Table 7 part of DoA.csv

InputVarType	OutputVarType	InputAlias	OutputAlias	TargetName	InputFileVarName	OutputFileVarName	InputBaseValue	OutputBaseValue	InputNewValue	OutputNewValue
IRG	O_t	CDW	ASET_5	Time	XB	V1	0.75	197.35	0.608	198.62
IRG	O_t	CDW	ASET_10	Time	XB	V1	0.75	183.5	0.608	185.67
IRG	O_t	CDW	ASET_5	Time	XB	V1	0.75	197.35	1.075	184.57
IRG	O_t	CDW	ASET_10	Time	XB	V1	0.75	183.5	1.075	176.87

The last two columns show the new input values and the corresponding output values obtained from the FDS simulation results files (*devc.csv or *evac.csv)

./CMB.csv

Part of this file is:

Table 8 Part of CMB.csv

InputVarType	OutputVarType	InputAlias	OutputAlias	TargetName	OutputFileVarName	OutputBaseValue	InputNewValue	OutputNewValue	PreValueRSM	PreValueSMT
I_C	O_t	CDW+SY+EX+HRR	ASET_5	Time	V1	197.35	0.375000+0.03+0.35+2200	299.73	277.72	240.98
I_C	O_t	CDW+SY+EX+HRR	ASET_10	Time	V1	183.5	0.375000+0.03+0.35+2200	258.44	255.12	216.18
I1C	O_t	CDW+SY+EX+HRR	ASET_5	Time	V1	197.35	1.000000+0.08+0.10+3800.0	161.14	147.85	148.41
I1C	O_t	CDW+SY+EX+HRR	ASET_10	Time	V1	183.5	1.000000+0.08+0.10+3800.0	143.27	138.82	147.06
I2C	O_t	CDW+SY+EX+HRR	ASET_5	Time	V1	197.35	0.300000+0.08+0.4+3800.0	217.3	221.7	215.43
I2C	O_t	CDW+SY+EX+HRR	ASET_10	Time	V1	183.5	0.300000+0.08+0.4+3800.0	214.07	214.88	195.28
I3C	O_t	CDW+SY+EX+HRR	ASET_5	Time	V1	197.35	0.200000+0.07+0.3+3500.0	224.51	229.6	208.87
I3C	O_t	CDW+SY+EX+HRR	ASET_10	Time	V1	183.5	0.200000+0.07+0.3+3500.0	212.89	216.13	190.14
I4C	O_t	CDW+SY+EX+HRR	ASET_5	Time	V1	197.35	1.100000+0.04+0.2+2500	190.4	203.98	190.56
I4C	O_t	CDW+SY+EX+HRR	ASET_10	Time	V1	183.5	1.100000+0.04+0.2+2500	185.27	190.77	180.42
I5C	O_t	CDW+SY+EX+HRR	ASET_5	Time	V1	197.35	1.100000+0.028+0.2+3500.0	182.71	198.32	173.34
I5C	O_t	CDW+SY+EX+HRR	ASET_10	Time	V1	183.5	1.100000+0.028+0.2+3500.0	173.82	178.71	161.61
I6C	O_t	CDW+SY+EX+HRR	ASET_5	Time	V1	197.35	0.200000+0.07+0.3+2500	256.83	248.99	227.49
I6C	O_t	CDW+SY+EX+HRR	ASET_10	Time	V1	183.5	0.200000+0.07+0.3+2500	244.59	237.04	208.63

The last four columns show the combined input new values, the FDS simulated values, the RSM predicted values and the SMM predicted values, respectively.

./SMT.csv

Table 9 records of SMT.csv

dy/dx	ASET_5	ASET_10
CDW	-27.0989	-16.985
EX	160.1806	121.1269
HRR	-0.01862	-0.01849
SY	-116.099	27.13867

./SMT_detail.csv

Part of this file is:

Table 10 Part of records in SMT_detail.csv

InputVarType	OutputVarType	InputAlias	OutputAlias	InputBaseValue	OutputBaseValue	InputLeftValue	InputRightValue	OutputLeftValue	OutputRightValue	Sensitivity	ChangeRate
ISG	O_t	CDW	ASET_5	0.75	197.354579	0.675	0.825	199.154902	195.09006	-27.098946	0.2
ISG	O_t	CDW	ASET_10	0.75	183.501485	0.675	0.825	185.816868	183.269112	-16.985038	0.2
ISP	O_t	EX	ASET_5	0.25	197.354579	0.225	0.275	190.115988	198.125017	160.180582	0.2
ISP	O_t	EX	ASET_10	0.25	183.501485	0.225	0.275	179.742456	185.798803	121.126935	0.2
ISP	O_t	HRR	ASET_5	3000	197.354579	2700	3300	199.61784	188.448541	-0.018615	0.2
ISP	O_t	HRR	ASET_10	3000	183.501485	2700	3300	187.810228	176.717934	-0.018487	0.2
ISP	O_t	SY	ASET_5	0.052	197.354579	0.0468	0.0572	196.870957	195.66353	-116.098806	0.2
ISP	O_t	SY	ASET_10	0.052	183.501485	0.0468	0.0572	181.536302	181.818544	27.138668	0.2

This file shows how the sensitivities are calculated:

(OutputRightValue-OutputLeftValue)/(InputRightValue-InputLeftValue)

./RSM.csv

Part of this file is:

Table 11 Part of records in RSM.csv

InputVarType	OutputVarType	InputAlias	OutputAlias	TargetName	InputFileVarName	OutputFileVarName	InputNewValue	OutputNewValue
IRG	O_t	CDW	ASET_5	Time	XB	V1	0.608	198.62
IRG	O_t	CDW	ASET_10	Time	XB	V1	0.608	185.67
IRG	O_t	CDW	ASET_5	Time	XB	V1	1.075	184.57
IRG	O_t	CDW	ASET_10	Time	XB	V1	1.075	176.87
IRG	O_t	CDW	ASET_5	Time	XB	V1	0.725	197.35
IRG	O_t	CDW	ASET_10	Time	XB	V1	0.725	183.5
IRG	O_t	CDW	ASET_5	Time	XB	V1	0.842	191.82
IRG	O_t	CDW	ASET_10	Time	XB	V1	0.842	179.43
IRG	O_t	CDW	ASET_5	Time	XB	V1	0.492	203.13
IRG	O_t	CDW	ASET_10	Time	XB	V1	0.492	189.75
IRG	O_t	CDW	ASET_5	Time	XB	V1	0.958	188.26
IRG	O_t	CDW	ASET_10	Time	XB	V1	0.958	179.96
IRG	O_t	CDW	ASET_5	Time	XB	V1	0.375	216.46
IRG	O_t	CDW	ASET_10	Time	XB	V1	0.375	193.86
IRP	O_t	EX	ASET_5	Time	VOLUME_FLOW	V1	0.366667	207.89
IRP	O_t	EX	ASET_10	Time	VOLUME_FLOW	V1	0.366667	204.86
IRP	O_t	EX	ASET_5	Time	VOLUME_FLOW	V1	0.5	260.47
IRP	O_t	EX	ASET_10	Time	VOLUME_FLOW	V1	0.5	242.08

This file shows the data needed for RSM.

./RSMRlt.csv

Table 12 part of records in RSMRlt.csv

OutputAlias	InputAlias	a	b	r_sqr	s_sqr
ASET_5	CDW	186.84	-0.14	0.969177	0.000104
ASET_10	CDW	178.14	-0.09	0.982881	0.000022
ASET_5	HRR	1781.2	-0.28	0.984451	0.000138
ASET_10	HRR	1294.26	-0.24	0.979911	0.000139
ASET_5	SY	119.33	-0.17	0.868544	0.001496
ASET_10	SY	150.76	-0.07	0.91814	0.000137
ASET_5	EX	271.24	0.21	0.806874	0.004285
ASET_10	EX	257.2	0.2	0.84204	0.00306
ASET_5	CDW+SY+EX+HRR	1139.62	0.87	0.901035	0.005312
ASET_10	CDW+SY+EX+HRR	1872.58	1.13	0.984027	0.000803

This file includes the parameters of power function fitting curve which has the form of $y = ax^b$. the records with single input parameter in the InputAlias field show the power function fitting of one output and one input variables, and the records with multiple input parameters show the power function fitting of one output to the product of each input variable to its power presented in the b field. For example, the RSM regression equation between ASET_5 and the four input variables can be calculated as:

$$ASET\_5 = y = ax^b = 1139.62 \times (CDW^{-0.14} HRR^{-0.28} SY^{-0.17} EX^{0.21})^{0.87}$$

(5) After running the command of "./FirePM SM_Info.txt", the following files will be generated:
./FirePM.csv
Part of this file is:

Table 13 Part of records in FirePM.csv

Time	ASET_5_BAS	ASET_5_SMT	ASET_5_SMT_MEA	ASET_5_RSM
41	197.35	275.08	CDW[2.8684]||EX[-0.4853]||HRR[4175.6648]||SY[0.6695]	367.28
42	197.35	278.35	CDW[2.9890]||EX[-0.5057]||HRR[4351.3296]||SY[0.6977]	410.98
43	197.35	211.52		207.05
44	197.35	201.21		205.7

If the predicted building fire performance (ASET_5_SMT) is far enough away from the baseline building fire performance (ASET_5_BAS), namely it is alarmed, the field of ASET_5_SMT_MEA will give the corresponding measures to close the building fire performance gap. Otherwise it will be left blank.

If the tool of GSD is adopted to generated synthetic data, the following file will be generated:

./Dyn.txt

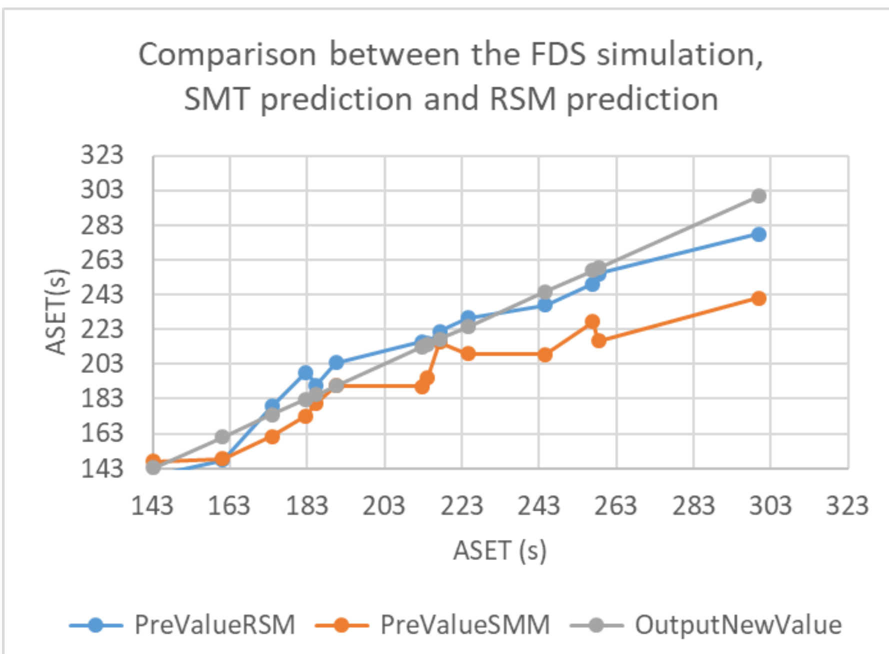
The content of this file is:

```
Sequence,Var1,Var2,Var3,Var4
Time,CDW,SY,EX,HRR
13245,-44.243|-43.5|-39.7|-39.475|-0.025|2.5,0.0745,0.24,3257.11
```

The first row indicates the structure of the file, the second row shows the head of the file (input variables), and the third row is the newly changed data about the input variables.

6.4. Conclusion

This case of a R-2 residential building shows the process of calculating the sensitivity matrix of the SMM and the power function regression parameters of the RSM as well as the application of the FirePM in monitoring the changes of building fire performance. The following chart is from the last three columns of the CMB.csv:



Where the grey straight line shows the value of FDS simulations, and the other two lines shows the values of predictions by RSM and SMM. The following conclusions can be made from this chart:

(1) Although the SMM curve is not so close to the FDS simulation line, the tendency is clear.
(2) Most of the time the predicted values of the SMM are lower than the FDS simulation results. As far as ASET is concerned, this is a good prediction because it is on the safe side. However, for other variables representing the building fire performance, thing may be different.
(3) It looks that the predicted values of the RSM is much closer to the FDS simulation line than the SMM. You may tend to conclude that the RSM is better than the RSM. But this may not be the reality. Here is the trick. In this case the power function fitting parameters are calculated based on the FDS simulation values listed in the column of OutputNewValue in the file of CMB.csv. when

the fitting power function is applied back in the same data, the higher consistence is not surprising. It is similar to the classic findings that “a fitting function tends to work better for interpolation than for extrapolation”. If the input variables travel out of the definition domains within which the fitting functions are regressed, more verification needs to be done to declare whether a RSM is better than a SMM. On the other hand, the values predicted by SMM, namely the column of PreValueSMM in the file of CMB.csv, is based on the sensitivity matrix derived from small changes of each single input variables (20% in this case), but the changing ranges of input variables are much larger than the small change of 20%. Therefore, the larger distance between the FDS simulation line and the SMM prediction curve is not surprising since by definition the SMM is supposed to apply to any problem only when the input variables move within a small range around their baseline values. However, the real size of “small” is problem and case sensitive: more work need to be done to understand this size of “small”. Without precise proofs, we can intuitively imagine that when the relationship or curve between an output variable and an input variable around the baseline point is monotonic and smooth, the more linear this section of the curve is, the more applicable the SMM is.

6.5. Discussion

The most important output files are SMT.csv which gives the sensitivity matrix, RSMRlt.csv which gives the RSM parameters, CMB.csv which shows how good the SMM and RSM are by using the known data, and FirePM.csv which shows the application results of the SMM and RSM by using newly changed input variables (the outputs are unknown and thus need to be predicted by SMM and RSM). Although various limitations exist for SMM and RSM, the consistence between the output values predicted by these two methods may provide us more confidence about the prediction of the real output values when the input variables change within some specific definition domains.

APPENDIX

An example of SM_Info.txt

#lines starting with '#" are not processed, only work as comments

#baseline fire name: all the other files are generated from this BaseFile with considerations of input variables' changes shown below

BaseFile=./base/PF_base_wowb.fds

#input variables: VarType,Alias, FDS_VarName,LowerLimit, UpperLimit,BaseValue,Divisions
VarType[0] = 'I' or 'O', 'I' means input variable, 'O' means output variables. in this file only 'I' is addressed
VarType[1] = 'S' or 'R' or '_', 'S' means the thereby generated files is going to be used in sensitivity Matrix Method (SMM);
'R' means the thereby generated files is going to be used in response surface model (RSM) or substitue model
'_' is reserved for future use or no special meanings
VarType[2] = 'G' or 'P' or 'C', 'G' means the variables to be changed are geograpic variables including 6 coordinates, every time only one
coordinate is allowed to change
'p' means the variables to be changed are physical variables, usually with the type of double
'C' means the variables to be changed are combined variables of type 'P' or/and type 'G', only one file will be
generated including all the changes indicated by each entries with the same VarType . the combined changes case is
used to check the accuracy of the SMM or RSM
Alias: another name of FDS_Varname which is more informative;
FDS_VarName: the variables name in FDS;
LowerLimit: the minimum value that a variable can be set;
UpperLimit: the maximum value that a variable can be set;
BaseValue: the value of a variable from baseline FDS file;
Divisions : for VarType[1] = 'R', namely the RSM model, the value of Divisions is used to decide how many files should be produced between
LowerLimit and UpperLimit; for VarType[1] = 'S', it doesn't matter since only 2 files will be produced which are LowerLimit and UpperLimit;
for VarTypep[2] = 'C', Division = 1 means UpperLimit will be adopted, Division = -1 means LowerLimit will be adopted to fabricate the combined
variation.

VarType=IRG, Alias=CDW, FDS_ID=CorridorDoor,FDS_VarName=XB, BaseValue=-44.25|-43.5|-39.7|-39.475|-0.025|2.5, LowerLimit=-44.575|-43.5|-39.7|-39.475|-0.025|2.5, UpperLimit=-43.875|-43.5|-39.7|-39.475|-0.025|2.5,Divisions=5
VarType=IRP, Alias=HRR, FDS_ID=burner,FDS_VarName=HRRPUA, BaseValue=3000.0, LowerLimit=1500,0, UpperLimit=4500.0, Divisions=5

VarType=IRP, Alias=SY, FDS_ID=POLYURETHANE+Wood(oak),FDS_VarName=SOOT_YIELD, BaseValue=0.052, LowerLimit=0.02, UpperLimit=0.09, Divisions=5
VarType=IRP, Alias=EX, FDS_ID=exhaust, FDS_VarName=VOLUME_FLOW, BaseValue=0.25, LowerLimit=0.1, UpperLimit=0.5, Divisions=5

#For sensitivity analysis, no division, only the lower and upper limit are used

VarType=ISG, Alias=CDW, FDS_ID=CorridorDoor, FDS_VarName=XB, BaseValue=-44.25|-43.5|-39.7|-39.475|-0.025|2.5, LowerLimit=-44.325|-43.5|-39.7|-39.475|-0.025|2.5, UpperLimit=-44.175|-43.5|-39.7|-39.475|-0.025|2.5,Divisions=0
VarType=ISP, Alias=HRR, FDS_ID=burner, FDS_VarName=HRRPUA, BaseValue=3000.0, LowerLimit=2700.0, UpperLimit=3300.0, Divisions=0
VarType=ISP, Alias=SY, FDS_ID=POLYURETHANE+Wood(oak), FDS_VarName=SOOT_YIELD, BaseValue=0.052, LowerLimit=0.0468, UpperLimit=0.0572, Divisions=0
VarType=ISP, Alias=EX, FDS_ID=exhaust, FDS_VarName=VOLUME_FLOW, BaseValue=0.25, LowerLimit=0.225, UpperLimit=0.275, Divisions=0

VarType=I_C, Alias=CDW, FDS_ID=CorridorDoor, FDS_VarName=XB, BaseValue=-44.25|-43.5|-39.7|-39.475|-0.025|2.5, LowerLimit=-44.575|-43.5|-39.7|-39.475|-0.025|2.5, UpperLimit=-43.875|-43.5|-39.7|-39.475|-0.025|2.5,Divisions=1
VarType=I_C, Alias=SY,FDS_ID=POLYURETHANE+Wood(oak), FDS_VarName=SOOT_YIELD, BaseValue=0.052, LowerLimit=0.03, UpperLimit=0.07, Divisions=-1
VarType=I_C, Alias=EX, FDS_ID=exhaust, FDS_VarName=VOLUME_FLOW, BaseValue=0.25, LowerLimit=0.15, UpperLimit=0.35, Divisions=1
VarType=I_C, Alias=HRR, FDS_ID=burner, FDS_VarName=HRRPUA, BaseValue=3000.0, LowerLimit=2200,0, UpperLimit=4400.0, Divisions=-1

VarType=I1C, Alias=CDW, FDS_ID=CorridorDoor, FDS_VarName=XB, BaseValue=-44.25|-43.5|-39.7|-39.475|-0.025|2.5, LowerLimit=-44.5|-43.5|-39.7|-39.475|-0.025|2.5, UpperLimit=-43.8|-43.5|-39.7|-39.475|-0.025|2.5,Divisions=-1
VarType=I1C, Alias=SY,FDS_ID=POLYURETHANE+Wood(oak), FDS_VarName=SOOT_YIELD, BaseValue=0.052, LowerLimit=0.02, UpperLimit=0.08, Divisions=1
VarType=I1C, Alias=EX, FDS_ID=exhaust, FDS_VarName=VOLUME_FLOW, BaseValue=0.25, LowerLimit=0.10, UpperLimit=0.4, Divisions=-1
VarType=I1C, Alias=HRR, FDS_ID=burner, FDS_VarName=HRRPUA, BaseValue=3000.0, LowerLimit=1800,0, UpperLimit=3800.0, Divisions=1

VarType=I2C, Alias=CDW,FDS_ID=CorridorDoor, FDS_VarName=XB, BaseValue=-44.25|-43.5|-39.7|-39.475|-0.025|2.5, LowerLimit=-44.5|-43.5|-39.7|-39.475|-0.025|2.5, UpperLimit=-43.8|-43.5|-39.7|-39.475|-0.025|2.5,Divisions=1
VarType=I2C, Alias=SY, FDS_ID=POLYURETHANE+Wood(oak),FDS_VarName=SOOT_YIELD, BaseValue=0.052, LowerLimit=0.02, UpperLimit=0.08, Divisions=1
VarType=I2C, Alias=EX, FDS_ID=exhaust,FDS_VarName=VOLUME_FLOW, BaseValue=0.25, LowerLimit=0.10, UpperLimit=0.4, Divisions=1
VarType=I2C, Alias=HRR,FDS_ID=burner, FDS_VarName=HRRPUA, BaseValue=3000.0, LowerLimit=1800,0, UpperLimit=3800.0, Divisions=1

VarType=I3C, Alias=CDW,FDS_ID=CorridorDoor, FDS_VarName=XB, BaseValue=-44.25|-43.5|-39.7|-39.475|-0.025|2.5, LowerLimit=-44.6|-43.5|-39.7|-39.475|-0.025|2.5, UpperLimit=-43.7|-43.5|-39.7|-39.475|-0.025|2.5,Divisions=1
VarType=I3C, Alias=SY, FDS_ID=POLYURETHANE+Wood(oak), FDS_VarName=SOOT_YIELD, BaseValue=0.052, LowerLimit=0.04, UpperLimit=0.07, Divisions=1
VarType=I3C, Alias=EX, FDS_ID=exhaust, FDS_VarName=VOLUME_FLOW, BaseValue=0.25, LowerLimit=0.2, UpperLimit=0.3, Divisions=1
VarType=I3C, Alias=HRR,FDS_ID=burner, FDS_VarName=HRRPUA, BaseValue=3000.0, LowerLimit=2500,0, UpperLimit=3500.0, Divisions=1

VarType=I4C, Alias=CDW,FDS_ID=CorridorDoor, FDS_VarName=XB, BaseValue=-44.25|-43.5|-39.7|-39.475|-0.025|2.5, LowerLimit=-44.6|-43.5|-39.7|-39.475|-0.025|2.5, UpperLimit=-43.7|-43.5|-39.7|-39.475|-0.025|2.5,Divisions=-1
VarType=I4C, Alias=SY, FDS_ID=POLYURETHANE+Wood(oak), FDS_VarName=SOOT_YIELD, BaseValue=0.052, LowerLimit=0.04, UpperLimit=0.07, Divisions=-1
VarType=I4C, Alias=EX, FDS_ID=exhaust, FDS_VarName=VOLUME_FLOW, BaseValue=0.25, LowerLimit=0.2, UpperLimit=0.3, Divisions=-1
VarType=I4C, Alias=HRR,FDS_ID=burner, FDS_VarName=HRRPUA, BaseValue=3000.0, LowerLimit=2500,0, UpperLimit=3500.0, Divisions=-1

VarType=I5C, Alias=CDW,FDS_ID=CorridorDoor, FDS_VarName=XB, BaseValue=-44.25|-43.5|-39.7|-39.475|-0.025|2.5, LowerLimit=-44.6|-43.5|-39.7|-39.475|-0.025|2.5, UpperLimit=-43.7|-43.5|-39.7|-39.475|-0.025|2.5,Divisions=-1
VarType=I5C, Alias=SY, FDS_ID=POLYURETHANE+Wood(oak),FDS_VarName=SOOT_YIELD, BaseValue=0.052, LowerLimit=0.028, UpperLimit=0.07, Divisions=-1
VarType=I5C, Alias=EX, FDS_ID=exhaust, FDS_VarName=VOLUME_FLOW, BaseValue=0.25, LowerLimit=0.2, UpperLimit=0.3, Divisions=-1
VarType=I5C, Alias=HRR, FDS_ID=burner, FDS_VarName=HRRPUA, BaseValue=3000.0, LowerLimit=2500,0, UpperLimit=3500.0, Divisions=1

VarType=I6C, Alias=CDW,FDS_ID=CorridorDoor, FDS_VarName=XB, BaseValue=-44.25|-43.5|-39.7|-39.475|-0.025|2.5, LowerLimit=-44.6|-43.5|-39.7|-39.475|-0.025|2.5, UpperLimit=-43.7|-43.5|-39.7|-39.475|-0.025|2.5,Divisions=1
VarType=I6C, Alias=SY,FDS_ID=POLYURETHANE+Wood(oak), FDS_VarName=SOOT_YIELD, BaseValue=0.052, LowerLimit=0.028, UpperLimit=0.07, Divisions=1
VarType=I6C, Alias=EX,FDS_ID=exhaust, FDS_VarName=VOLUME_FLOW, BaseValue=0.25, LowerLimit=0.2, UpperLimit=0.3, Divisions=1
VarType=I6C, Alias=HRR, FDS_ID=burner, FDS_VarName=HRRPUA, BaseValue=3000.0, LowerLimit=2500,0, UpperLimit=3500.0, Divisions=-1

#output variables: VarType, Alias, FDS_VarName, CriticalValue, Division
the sensitivity matrix shows how the output changes with input variables
VarType[2]: 't' = time variables, 'R' = radiation variables
Alias is another name or explanation of TargetName which in turn is the target variables we want to monitor
CriticalValue is about FDS_VarName; the whole record can be explained as " (what is) the value of "TargetName" when the value of "FDS_VarName"
meets the "CriticalValue"

Division: -1 = CriticalValue is met from top to bottom; 1 = CriticalValue is met from bottom to top

VarType=O_t, Alias=ASET_5, TargetName=Time,FDS_ID=V1, FDS_VarName=V1,
CriticalValue=5.00,Division=-1
VarType=O_t, Alias=ASET_10, TargetName=Time,FDS_ID=V1,
FDS_VarName=V1,CriticalValue=10.00,Division=-1
#VarType=O_R, Alias=RAD_10, TargetName=Rad02,FDS_VarName=V1, CriticalValue=10.00,Division=-1
#VarType=O_t, Alias=RHF_5, TargetName=Time,FDS_VarName=Rad02, CriticalValue=5.00,Division=1