UNCERTAINTY IN HYBRID SYSTEMS AND THE FIRE MANAGEMENT SYSTEM DESIGN

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Abstract: This paper approaches the problem of analysing control strategies in the case of fire in a building. The elements of this problem present behaviours of different nature and therefore the use of a hybrid modelling formalism is necessary. Petri nets are used to model the discrete aspects and differential equation systems are used for the continuous ones. In order to realistically evaluate the safeness provided by the fire management system, faults, failures and other uncertainties, such as people behaviour, should be included in the model. Due to the model complexity, results are obtained using Monte Carlo simulation. *Copyright © 2005 IFAC*

Keywords: fire management systems, hybrid systems, Petri nets, uncertainty, Monte Carlo simulation.

1. INTRODUCTION

This paper presents and discusses the use of hybrid system modelling and analysis techniques for the specification of control strategies for fire management systems. In a building, the fire management system provides means for preventing, detecting and treating fire occurrences, minimizing damages and assuring the safe evacuation of occupants. Fire systems include the necessary equipment for smoke and fire detection, sprinklers, emergency communication systems, etc.

Fire management systems are usually designed based on a set of rules and standards that specifies the basic components and characteristics of the system (NFPA, 2003). These rules and standards are based on traditional buildings, where the fire management system operates independently from other building systems. Recently, in the context of the so-called "intelligent building", intelligence and automation have been incorporated into the design of the building systems. These facilities open the possibility to specify a new range of control strategies that are based on the integration of the fire management system with other building systems. Because of their innovative aspects, these strategies are not considered or treated by the traditional standards and rules. The development of methods and tools for their evaluation is therefore of great importance.

Although many approaches and tools have already been proposed for studying and predicting what would happen in a building in the case of fire, they usually present one or more of the following disadvantages:

- The tool contains only the definition of equipments and control strategies used in traditional buildings. New technologies cannot be easily incorporated.
- The focus is on one aspect of the problem, such as fire modelling or people evacuation. In order to predict the combined effects of all the aspects, different tools must be integrated. This is possible only for non bi-directional dependence (such as if Tool_1 uses the results of Tool_2, Tool_2 cannot use the result of Tool_1).
- They simulate the behaviour of the system under nominal conditions. Errors, faults, failures and other uncertainties are usually not considered.

In this context the purpose of this work is to propose an alternative approach for the specification of control strategies for fire management systems. The full system, composed by the fire management system, the building equipment, people behaviour and fire, is considered as hybrid. It is modelled using Petri nets and differential algebraic equations. Particularly, this paper focus on how uncertain events can be taken into account by incorporating probabilistic elements into the model.

This paper is organized as follows. Section 2 introduces a general overview of the design process and of the modelling formalism. Section 3 presents a case study and discusses the results obtained by Monte Carlo simulation. Finally, Section 4 presents some conclusion and future works.

2. THE DESIGN PROCESS

2.1 General Overview

The design of the fire management system can be seen as a task involving techniques and methods of two areas: software and control engineering. The adopted design methodology has been presented in (Bastidas et al., 2003). It has been successfully applied to a number of problems, such as the design of the HVAC (Heating Ventilation and Air Conditioning) management system of a hospital and the design of the supervisory system of a cane sugar factory (Villani et al, 2004).

Briefly, this methodology is organized in a number of steps. Starting from the management system requirements and from the definition of the boundaries of the plant to be supervised, a set of UML diagrams (Unified Modelling Language (Booch, 1998)) is built, illustrating different aspects of the system dynamics and structure. Then, from the UML diagrams, a formal model of the system behaviour is obtained using Petri nets and differential equations. This model includes not only the behaviour of the management system but also that of the plant. It is then used to validate the management system, i.e., to guarantee that the plant will behaviour as expected under the variety of circumstances that it could be submitted. Finally, the part of the model corresponding to the management system is translated to a programming language, implemented and tested, interacting then with the real plant. Fig. 1 illustrates this approach.

In the case of the fire management system, the modelling phase encompass the definition of a set of control strategies that activate the equipment related to fire control, such as sprinkler, emergency doors, etc. The control strategies comprise also the interface with other building systems such as HVAC system, access control system, elevator system, etc. The coordinate cooperation of all building systems aims to reduce the damages cause by a fire. In order to analyse the control strategies and define which one is the best for each situation, the plant model is composed not only by the fire control equipment, but it also includes the equipment from other building systems (ex: fans from the HVAC system), the fire behaviour, smoke diffusion and people behaviour.

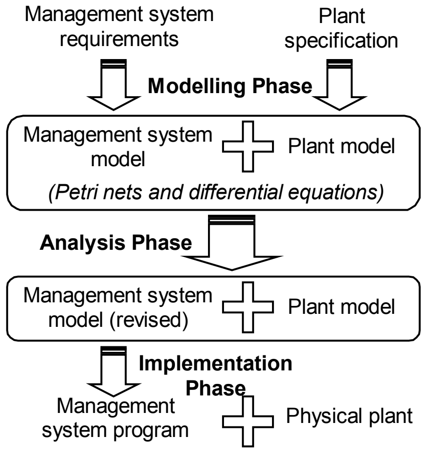


Fig. 1. Design approach.

The parameters used for evaluating the performance of a control strategy are building evacuation time, ability to control fire and smoke, number of people dead, number of people injured, among others.

Due to the limited space, not all the steps of the design methodology are detailed here. Priority is given to describing the modelling formalism.

2.2 Petri Nets, Differential Equation Systems and the Object Oriented Paradigm.

The modelling formalism has already been introduced in (Villani et al, 2004). It is based on the incorporation of object-oriented concepts to the Differential Predicate-Transition Petri nets (DPT net), proposed in (Champagnat et al, 1998).

Briefly, the model of a system is composed by the a set of 'n' classes (C_1, C_2, …, C_n). Each class C_i is modelled by a DPT net, which defines an interface between differential equation systems and Petri net elements. Its main features are:

- Each object of the class C_i is represented by a *token* in the DPT net of C_i.
- A set of variables (x_i) is associated with each *token* of the class C_i: they correspond to the attributes of the class.
- A differential equation system (F_{j_i}) is associated with each *place* (p_{j_i}): it defines the dynamic of the x_i associated with the *tokens* in p_{j_i}, according to the time (θ).
- An enabling function (e_{j_i}) is associated with each *transition* (t_{j_i}): it triggers the *firing* of the enabled *transitions* according to the value of the x_i associated with the *tokens* of the input *places* of t_{j_i}.
- A junction function (j_{j_i}) is associated with each *transition* (t_{j_i}): it defines the value x_i associated with the *tokens* of the output *places* of t_{j_i} after the *transition firing*.

The communication among objects can be discrete or continuous. The continuous interactions are modelled by sharing continuous variables among objects. The value of the shared variables is determined by one object and can be used in the junction function, the equation systems or the enabling function of other objects.

The discrete interactions are method calls. Each class offers methods that are associated with its *transitions* and that can be requested by other classes. A method call is modelled as the fusion of two *transitions*: the *transition* t_{j_i} of the class C_i that offers the method and the *transition* t_{w_v} of the class C_v that calls the method. The method call happens when both *transitions* are enabled in their classes.

Particularly in the case of fire management system design, a number of uncertain behaviours can significantly affect the performance of the system. Therefore, the next section introduces the modelling of uncertainties in the design process.

2.3 Introduction of Uncertainty

Among the sources of uncertainty for fire management systems are:

- *People behaviour*. A number of reasons can make people behaviour in a way different than the one previously specified. One of the most important is fear. Different people react to panic in different ways. Some may face a dangerous path in a desperate attempt to leave the building. Others may simply run as far as possible of the fire, even if it means not trying to leave at all. There are also people that do not know the escape route and may take a wrong direction.
- *Fire behaviour*. The uncertainty in this case is related to the conditions under which the fire occurs. It comprises the kind of material that is burned, the humidity and other air-related variables, among many others.
- *Equipment failures*. Most of times failures are due to inadequate maintenance or inappropriate use. A common situation in fire management systems is when smoke sensors (and also sprinklers) are wrongly regulated and detect smoke when there is no fire. In such case, the occupants frequently disconnect the sensor instead of adjusting the sensor sensibility.

The problem of modelling uncertainty in hybrid system has already been approached in many works of the literature (e.g. Pola et al. (2003)). These works can be classified according to how the uncertainty is introduced into the models. Most of them consider one or more of the following cases:

- The continuous dynamic is modelled by using stochastic differential equations.
- The occurrence of discrete events is set according to probabilistic laws.
- After the occurrence of an event, the new state of the system is set according to probabilistic laws.

Another important point is the formalism used as a background. Most of the works already published are based on hybrid automata. Examples are (Bujorianu, Lygeros, 2003) and (Hespanha, 2004). Among the formalisms that model the discrete dynamic using Petri nets are the Fluid Stochastic Petri nets. It starts from the definition of Generalized Stochastic Petri nets and incorporate elements for the modelling of continuous dynamics, such as continuous *places* (Horton et al, 1996) and (Wolter, 2000).

The introduction of uncertainty into the DPT nets is briefly approached in (Khalfaoui, 2003) and is also based on Generalized Stochastic Petri nets. It considers the following features:

- The dates of *transition firings* can be set according to stochastic distributions.
- When two or more *transition* are in conflict, the decision can be made by associating a fixed probability to each *transition*.

In this paper this definition is slightly modified. Instead of associating stochastic distributions to the dates of *transition firings*, we introduce probabilistic junction functions that set the value of the continuous variables after a *transition firing* according to stochastic distributions. No restriction is made on the kind of distribution that can be used. After the *firing*, these variables can then be used in enabling functions or equation systems, influencing both the discrete and continuous dynamics. In order to illustrate the incorporation of uncertainty into the fire management system models a case study is presented on the next section.

3. CASE STUDY: INTEGRATION OF THE FIRE MANAGEMENT SYSTEM WITH THE HVAC

The aim of this case study is to evaluate a set of control strategies for the integration between the HVAC system and the fire management system. The methodology presented in the previous section is applied to a commercial building. Due to the limited space, the example presented in this paper is limited to the evacuation through the main exit of the building.

The layout of the main exit is presented in Fig. 2. The main exit is located in one of the extremities of a hall. There are a restaurant and a kitchen in one of the sides of the hall. Due to the kitchen nature, this is an area particularly sensitive to fires. Supposing a fire happens in the kitchen, the fire reaches the hall by one of the three doors (Door 1, 2 and/or 3). The purpose of the example is to analyse how the HVAC can contribute to the safe evacuation of people throughout the main exit.

The HVAC equipment is composed by a set of air supply and returns points distributed along the hall and controlled by dampers. Return and supply fans impose the airflow (Fig. 3).

Three different strategies are considered for the HVAC in the case of fire:

- *Strategy 1:* Close all dampers and turn off the fans. By adopting this strategy the oxygen available for the fire is limited, reducing its spread. On the other hand, no oxygen is also available for eventual people trapped in the building and the smoke is not removed.
- *Strategy 2:* Open all dampers and turn on the fans. The purpose of this strategy is to remove the smoke and provide fresh air for people evacuation. On the other hand, the fresh air feeds also the fire.

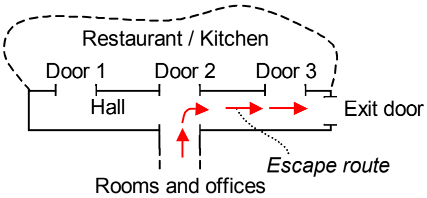


Fig. 2. Layout of the main exit.

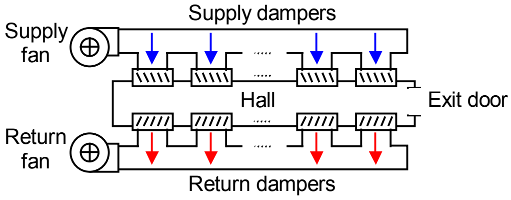


Fig. 3. HVAC equipment.

- *Strategy 3:* Impose the airflow in the opposite sense of people evacuation (from right to left). This strategy tries to find a compromise between strategy 1 and 2. It provides fresh air for people evacuation and, at the same time, directs the spread of fire.

The model of this case study is composed by 4 classes: C_1 - *Person*, C_2 - *Crowd*, C_3 – *Fire*, C_4 – *Smoke Detector* and C_5 - *Fire Management*.

Model of Class C_1 - *Person*

This class models the behaviour of an individual during the fire. Many previous works have already approached the problem of modelling people behaviour during an evacuation. Basically these works can be divided into two groups:

1) *Macroscopic approaches* – all the people in the building are considered as a single entity (a crowd) whose behaviour is approximated by fluid dynamics equations (Fahy, 1997).
2) *Microscopic approaches* – each person is considered as an autonomous entity (an agent) whose behaviour is mostly independent of the presence of other people in the building. The behaviour of a crowd 'emerges' from the combined behaviour of all agents. Examples are Lightfoot & Milne (2003) and Klüpfel et al (2001).

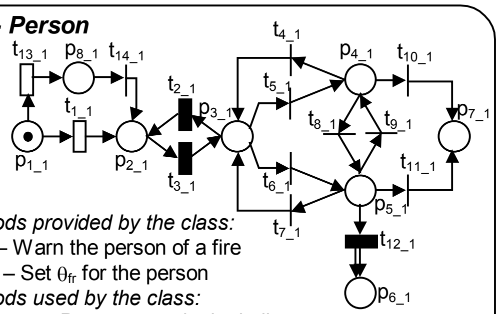
In this paper, an intermediated solution between the macroscopic and microscopic approaches is adopted. Each person is modelled as an object of the class C_1 - *Person*. The person takes decisions and behaviours as an independent entity. However, when the person is in the hall, his speed is set according to the total number of people in the hall. The model of this class is presented in Fig. 4. The meaning of each *place* is:

p_{1_1}: The person is working and has no knowledge of an eventual fire.

p_{2_1}: The person has been warned of a fire (*firing* of t_{1_1}) and is directed to the hall. The time for reaching the hall (*firing* of t_{2_1}) is θ_{evac} and is imposed by e_{2_1}.

p_{3_1}: The person is at the entrance of the hall and has to decide what to do. The options are going to the left (*firing* of t_{6_1}), to the right (*firing* of t_{5_1}) or returning to the rooms and offices (*firing* of t_{2_1}) and trying to find another exit (or waiting to be saved by the fire brigade).

C_1 - Person



Methods provided by the class:
t_{1_1} – Warn the person of a fire
t_{13_1} – Set θ_{fr} for the person
Methods used by the class:
$t_{3\_1}\rightarrow t_{1\_2}$ – Person enter in the hall
$t_{2\_1}\rightarrow t_{2\_2}$ – Person exit the hall
$t_{12\_1}\rightarrow t_{2\_2}$ – Person exit the hall
Class variables: $x_1 = \{x, \theta_{aux}, co_{aux}\}$
Equation systems:
F_{2_1}: $\dot{\theta}_{aux} = 1$;
F_{3_1}: $S_{right} = [(sm(x+\Delta x)>sm_{max})$ OR $(fr(x+\Delta x)>0)]$
$S_{left} = [(sm(x-\Delta x)<sm_{max})$ OR $(fr(x-\Delta x)=0)]$
F_{4_1}: $\dot{x} = -v_p$; $\dot{co}_{acc} = sm(x)$; $\dot{\theta}_{aux} = 1$;
F_{5_1}: $\dot{x} = +v_p$; $\dot{co}_{acc} = sm(x)$; $\dot{\theta}_{aux} = 1$;
F_{8_1}: $\dot{\theta}_{aux} = 1$;
Enabling functions: e_{3_1}: $\theta_{aux} \geq \theta_{evac}$; e_{12_1}: $x = x_L$;
e_{2_1}: $(sm(x+\Delta x)>sm_{max})$ OR $(fr(x+\Delta x)>0)$;
e_{4_1}, e_{7_1}: $(x=x_c)$ AND $(\theta \geq \theta_{min})$;
e_{6_1}: $(sm(x+\Delta x)<sm_{max})$ AND $(fr(x+\Delta x)=0)$;
e_{8_1}: $[(sm(x-\Delta x)>sm_{max})$ OR $(fr(x-\Delta x)>0)]$ AND $(\theta_{aux}>\theta_{min})$;
e_{9_1}: $[(sm(x+\Delta x)>sm_{max})$ OR $(fr(x+\Delta x)>0)]$ AND $(\theta_{aux}>\theta_{min})$;
e_{10_1}, e_{11_1}: $(co_{acc}>co_{acc\_max})$ OR $(fr(x)>0)$; e_{14_1}: $\theta_{aux} \geq \theta_{fr}$;
Junction functions: $j_{1\_1}, j_{2\_1}, j_{7\_1}, j_{8\_1}, j_{9\_1}$: $\theta = 0$; j_{13_1}: $\theta_{fr} = PD_{fr}$;
Fixed probabilities:
$(P_{2\_1}, P_{5\_1}, P_{6\_1})$ = ({(P_{00b} * (NOT S_{right} AND NOT S_{left}) + P_{01b} * (NOT S_{right} AND S_{left}) + P_{10b} * (S_{right} AND NOT S_{left}) + P_{11b} * (S_{right} AND S_{left})}, {(P_{00l} * (NOT S_{right} AND NOT S_{left}) + P_{01l} * (NOT S_{right} AND S_{left}) + P_{10l} * (S_{right} AND NOT S_{left}) + P_{11l} * (S_{right} AND S_{left})}, {(P_{00r} * (NOT S_{right} AND NOT S_{left}) + P_{01r} * (NOT S_{right} AND S_{left}) + P_{10r} * (S_{right} AND NOT S_{left}) + P_{11r} * (S_{right} AND S_{left})})

Fig. 4. Model of class C_1 - *People*.

The decision is taken according to the propabilities P_{right}, P_{left} and P_{back}, presented in Table 1. S_{left} and S_{right} indicate the presence of fire $(fr(x\pm\Delta x)>0)$ and/or high level of smoke $(sm(x\pm\Delta x)>sm_{max})$ to the left and to right respectively $(x\pm\Delta x)$. Both 'sm' and 'fr' are external variable from class C_3 - *Fire* and model the smoke and fire in the hall.

p_{4_1}: The person is going to the left. He can eventually change direction (*firing* of t_{8_1}) according to the level of smoke ahead in the hall $(sm(x+\Delta x)<sm_{max})$ and the presence of fire $(fr(x+\Delta x)<0)$. If he is at the entrance of the hall ($x=x_c$, *firing* of t_{4_1}) he can stop and reconsider what to do. While in the hall he dies (*firing* of t_{10_1}) if he is in contact with fire $(fr(x)>0)$ or because the smoke he inhaled surpasses a threshold $(co_{acc} > co_{acc\_max})$. This last kind of death is due to the effect of carbon monoxide, which is accumulative.

p_{5_1}: The person is going to the right. Similarly to p_{4_1}, he can change direction (*firing* of t_{9_1}), stop at the entrance of the hall (*firing* of t_{7_1}), or die (*firing* of t_{11_1}). When he reaches the end of the hall ($x=x_L$, *firing* of t_{12_1}) he is safe.

p_{6_1}: The person has reached the exit and is safe.

p_{7_1}: The person is dead.

p_{8_1}: Auxiliary place. When the smoke sensor fails, the time for each person to be aware of the fire (θ_{fr}) is set according to a probabilistic distribution (PD_{sm}), by the junction function of t_{13_1}.

Table 1 – Fixed probabilities for t_{2_1}, t_{5_1} and t_{6_1}.

S_{left}	S_{right}	P_{right}	P_{left}	P_{back}
0	0	P_{00_r}	P_{00_l}	P_{00_b}
0	1	P_{01_r}	P_{01_l}	P_{01_b}
1	0	P_{10_r}	P_{10_l}	P_{10_b}
1	1	P_{11_r}	P_{11_l}	P_{11_b}

The method calls associated with *transitions* t_{2_1} and t_{3_1} informs the object of class C_2 - *Crowd* that a person entered or left the hall. This object can then estimate the speed of the person (v_p) according to the amount of people in the hall. For the objects of class C_1, v_p is therefore an external variable. The equation systems of p_{4_1} and p_{5_1} determine the current position of the person using v_p, and the accumulated volume of smoke inhaled by the person ('co_{acc}').

Model of Class C_2 - *Crowd (Fig. 5)*

This class sets the speed (v_p) of the people in the hall according to the number of people (N_p). The variable 'd_p' is the density of people in the hall.

Model of Class C_3 – *Fire (Fig. 6)*

From the discrete point of view, there are two possible situations for the fire: there is only smoke in the hall (the fire is in the kitchen/restaurant - p_{1_3}), or the fire has reached the hall (p_{2_3}). The variables '$sm(\theta,x)$' and '$fr(\theta,x)$' indicates the level of smoke and the presence of fire in the hall. It is important to observe that they are distributed parameters and change not only with the time 'θ' but also with the position 'x' in the hall. '$fr(\theta,x)$' is a discrete variable, it can be '0' (no fire) or '1' (fire). The smoke and fire enters in the hall through one of the doors (Fig. 2), which is located at 'x_f'. The fire reaches the hall (*firing* of t_{1_3}) when the level of smoke reaches a threshold ('$sm_{xf} \geq K_3$'). The variables v_{sm_R}, v_{sm_L}, v_{fr_L}, and v_{fr_R} are external variables from class C_5 – *Fire Management*. They model the growth rate of smoke and fire to the left and to the right, respectively. These rates are set according to the state of fans and dampers of the HVAC, i.e, according to the strategy implemented by the fire management system.

Model of Class C_4 – *Smoke Detector (Fig. 7)*

When the smoke reaches the threshold (K_{sd}) a fire is detected. An alarm is activated and it warns the people in the building (*firing* of t_{2_4}). Then, the smoke detector communicates the occurrence to the fire management system, which will execute the HVAC strategy. With probability of P_{sm_OK} a failure occurs in the smoke detector.

Model of Class C_5 – *HVAC (Fig. 8)*

In the case of fire, this class perform the HVAC strategy indicated by the variable 'S' and sets the variables 'v_{sm_R}', 'v_{sm_L}', 'v_{fr_R}' and 'v_{fr_R}' with the appropriate values.

For each strategy, the models have been simulated with occupancy varying from 1 to 200 people, and considering that the fire enters in the hall through each one of the doors. Simulation has been carried out using MatLab®. The model of each class is translated to MatLab programming language and implemented as a subroutine. Each object is associated with a set of variables.

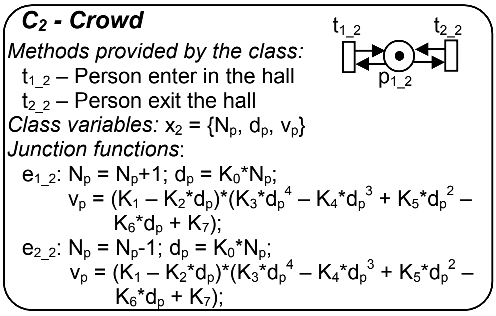


Fig. 5. Model of class C_2 - *Crowd*.

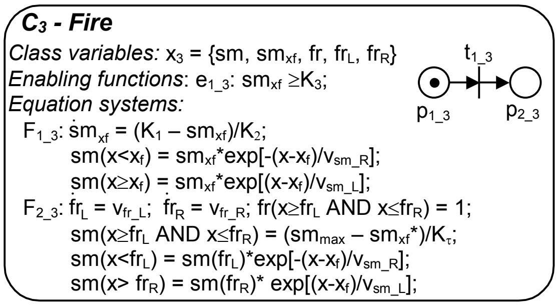


Fig. 6. Model of class C_3 – *Fire*.

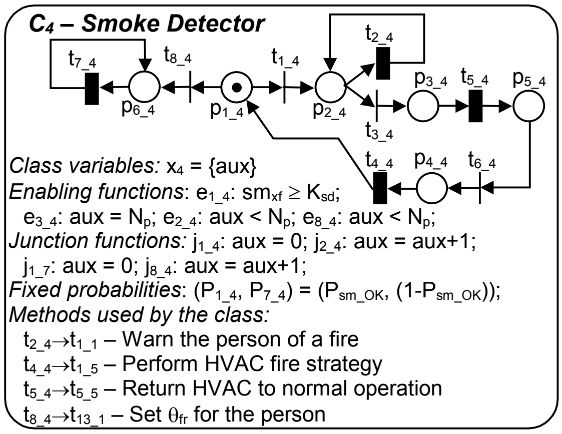


Fig. 7. Model of class C_4 – *Smoke Detector*.

Simulation is interrupted when the hall is completely taken by the fire ($fr(0 \leq x \leq x_L)=1$). An equivalent deterministic model has also being simulated in order to analyse the influence of uncertainty in the results. This deterministic model considers that people always know the escape route (t_{5_1} never *fires*), and always go to the right when $S_{right}=0$. Furthermore, the smoke sensor never fails.

The fire near Door 3 is the most critical situation. The results obtained in this case are presented in Fig. 9 and Fig. 10. They indicated that for both deterministic and probabilistic models, Strategy 3 is the best one, followed by Strategy 2 when the number of people to be evacuated is under 110, or by Strategy 1 when it is more than 110. However, the results are significantly worst when uncertainty is introduced, highlighting the importance of equipment maintenance and people training, which approximate the probabilistic model to the deterministic one.

It is interesting to observe that the introduction of uncertainty into the models attenuated the differences among the strategies. One of the reasons is that when the smoke detector fails, the HVAC configuration is not changed, which means that fans remain on and dampers open (equivalent to Strategy 2).

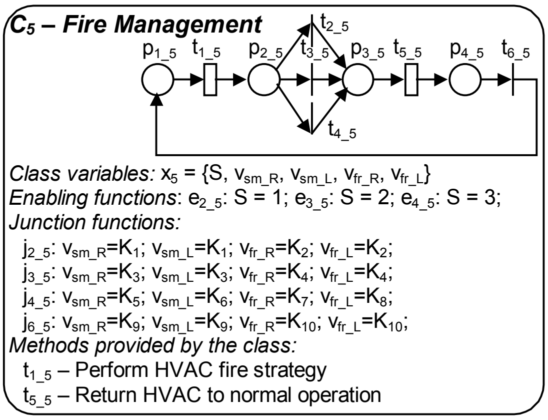


Fig. 8. Model of class *C5 – Fire Management*.

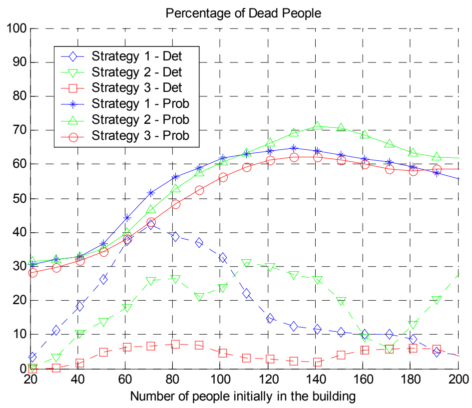


Fig. 9. Percentage of dead people.

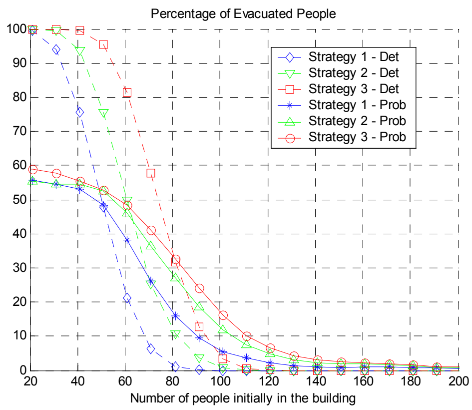


Fig. 10. Percentage of evacuated people.

4. CONCLUSION

This paper presents the application of hybrid concepts for design of fire management systems. For this purpose uncertainty is incorporated into the DPT nets. Its main advantage is the flexibility provided to the designer for testing and analysing innovative control strategies that may emerge as a result of the integration of building systems. Its main disadvantage, as already pointed by (Khalfaoui, 2003) is that it should be analysed by Monte Simulation - no analytical procedure is available at the present date. Furthermore, when the complexity of the models is increased, the computational effort required for obtaining reliable results by simulation may be prohibitive. Future works therefore may be on the direction of simplifying the simulation process and may include the development of specific simulation tools for DPT Petri nets.

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REFERENCES

Bastidas, G. et al. (2003) “Open Distributed Supervisory System Design using Petri nets”, *Prooc. of the IEEE International Symposium on Industrial Electronics (ISIE)*, Rio de Janeiro.

Booch, G., et al, (1998). *The Unified Modeling Language User Guide*, Addison-Wesley Longman, Inc. Harlow, England.

Bujoriani, M.L.; Lygeros, J. et al. (2003) “Stochastic hybrid models: an overview”. *12th Mediterranean Conference on Control and Automation (MED)*, Kusadasi.

Champagnat, R. et al. (1998) “Modelling and Simulation of a Hybrid System through Pr/Tr PN-DAE Model”, *3rd International Conference on Automation of Mixed Processes*, Reims.

Fahy, R.F. et al. (1997) “High Rise Evacuation Modeling – Data and Application”, *Proc. of 13th Meeting of UJNR Panel on Fire Research and Safety*, Gaithersburg.

Hespanha, J.P. (2004) “Stochastic Hybrid Systems: Application to Communication Networks”. *Hybrid Systems: Computational and Control (HSCC)*, Philadelphia.

Horton, G. et al. (1996) “Fluid Stochastic Petri Nets: Theory, Applications and Solution”, *NASA CR-198274 ICASE Report No. 96-5*, Inst. for Computer Applications in Science and Eng., NASA Langley Research Center, Hampton.

Khalfaoui, S. (2003) “Méthode de Recherche des Scénarios Redoutés pour l’Evaluation de la Sûreté de Fonctionnement des Systèmes Mechatroniques du Monde Automobile”, PhD Thesis, *Laboratoire d’Analyse et d’Architecture des Systèmes du CNRS*, Toulouse.

Klüpfel, H. et al. (2001) “Microscopic Modelling of Pedestrian Motion”, *Proc. of Int. Conf. on Pedestrian and Evacuation Dynamics*, Berlin.

Lightfoot, T.J.; Milne, G.J. (2003) “Modelling emergent crowd behaviour”. *Proc. of the 1st Australian Conf. on Artificial Life*, Canberra.

NFPA (2003) “NFPA 101 – Life Safety Code”. *National Fire Protection Association*, Quincy.

Pola, G. et al. (2003) “Stochastic hybrid models: an overview”. *IFAC Conference on Analysis and Design of Hybrid System (ADHS)*, St Malo.

Villani, E. et al. (2004) “Object Oriented Approach for Cane Sugar Production”, *Control Engineering Practice*, v.12, n.10, pp.1279-1289.

Wolter, K. (2000) “Modelling Hybrid System with Fluid Stochastic Petri Net”, *Proc. 4th Int. Conf. on Automation of Mixed Processes: Hybrid Dynamic Systems*, Dortmund.