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Feasibility Study on Estimating Operator Travel Times under Fire Events in Nuclear Power Plant using Agent-based Simulation

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1. Introduction

When assessing the fire-induced risks in a nuclear power plant (NPP), it is important to appropriately evaluate the time available or implementation time for various activities that the operator can take, such as fire suppression or operator manual actions (OMA). OMA is simply defined as the manual action taken outside the main control room (MCR) during a fire event to achieve and maintain safe shutdown. According to [1], a timeline to perform OMA consists of diagnosis, implementation time (e.g., travel time + action time), and time margin as shown in Fig. 1.

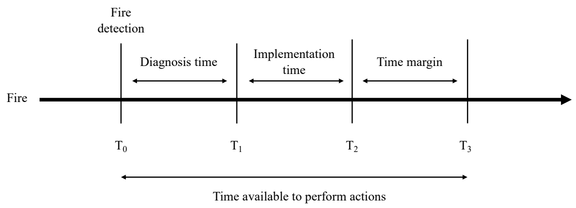


Fig. 1. A Timeline to perform an OMA [1]

In terms of a deterministic manner, which aims to demonstrate the feasibility of OMAs, the focus is on estimating whether there is sufficient time margin to perform an OMA. From a probabilistic perspective [2], the focus is on evaluating the failure probability of the manual action (i.e., human error probability, HEP) based on the total time required for the action. In sum, it becomes clear that the important factor from both a deterministic and probabilistic risk assessment perspective is the operator travel time, which is generally assessed based on the operator's experience or on-site walk-down.

However, the operator travel time can vary significantly depending on the fire scenario and on-site conditions. For example, if the shortest path to perform an OMA requires passing through the fire area in case of an actual fire event, the operator may need to take an alternative route instead of the shortest path. In other words, it is challenging to conduct evaluating the travel time while considering all various scenarios trough engineering judgment and on-site walk-down.

To address these challenges, this paper attempted to employ the agent-based simulations to model the movement path of operators based on 3D depictions of the reference NPP, including fire modelling to find out the factors affecting travel times. The goal of this paper is to show a simple example to demonstrate how agent-based simulation can support the determination of operator travel times.

2. Agent-based Simulation with Fire Modelling

2.1 Agent-based simulation with Fire Modelling

Agent-based model is a computational model that can describe interactions between agents (e.g., individuals and/or organizations). This simulation approach is widely used in the research field of fire evacuation [3, 4]. In terms of evacuation modelling, agent-based model is employed to estimate and compare with available safe egress time (ASET) and required safe egress time (REST). The advantage of such simulations is that they can be combined with fire modeling to simultaneously assess how evacuees are affected by the fire during evacuations as shown in Fig. 2.

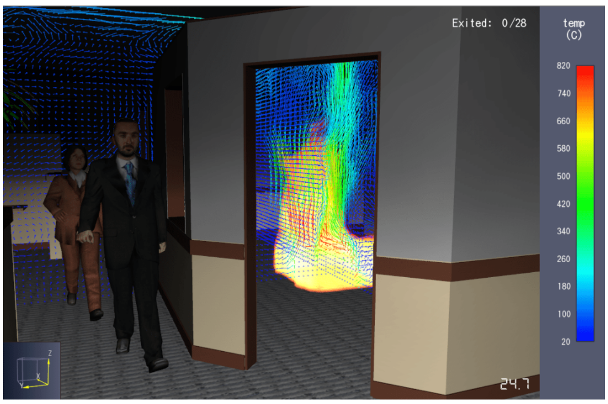


Figure 2. Example of the agent-based simulation with fire modelling using a specialized program [5]

It is important to note that most of these studies focus primarily on individual or crowd evacuation during fire events. On the other hand, the most important thing in case a fire in NPP is not evacuation but extinguishing the fire in a timely manner and maintaining the safety condition of an NPP.

Therefore, in this paper, we attempted to differentiate ourselves from existing agent-based evacuation models by inducing the operator to move to a specific point rather than the exit or encouraging the operator to find an alternative route instead of the shortest path. Table I shows the summary of the differences from the fire evacuation models.

Table I: Differences between evacuation model and operator travel time model

Purpose	Evacuation	OMA
Target agents	Evacuees	Operators
Destination	Exit	Specific area (where a fire occurs or where an OMA is required)
Path	Shortest route to exit	Depending on scenarios
Equipment	-	May be equipped with personnel protection gear
Training	Untrained	Well trained

2.2 Example of the agent-based model for the reference NPP

In this paper, specialized programs called Pyrosim [6] for the fire modelling and PathFinder [7] for the agent-based modelling were used to show the feasibility of this study. In addition, the target building of the reference NPP is the primary auxiliary building (PAB) and the simulation was conducted assuming a fire scenario as follow:

- A fire occurs at a switchgear (SWGR) room at 100ft in the PAB (See Fig. 3).
- The MCR operator needs to travel to the auxiliary feedwater pump (AWP) room located at 77 ft in the PAB to perform an OMA.
- At this time, the operator must descend 100 ft via Stair 1 from the 144 ft MCR and then move down 77 ft via Stair 2 (See Fig. 4).

It should be noted that the fire and OMA described above is just an assumed case therefore, it is not applicable to the reference NPP in practice. Hence, further research is required to refine the fire modeling and to find out an actual OMA list.

Fig. 3 shows the results of the fire modelling in the SWGR room using Pyrosim program. Note that all inputs for fire modelling are based on example case within Pyrosim tutorials. As a result of the fire modelling, the following outputs can be identified.

- Distributions of temperature, heat release rate distribution, visibility, etc

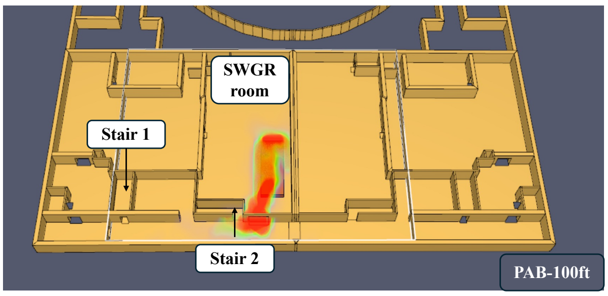
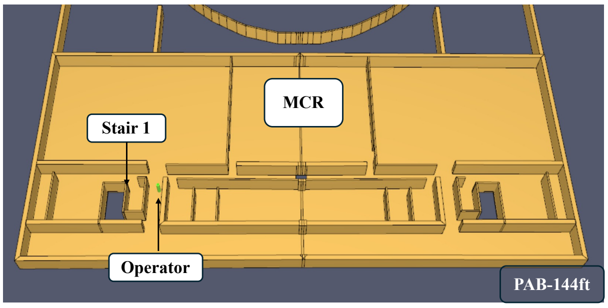
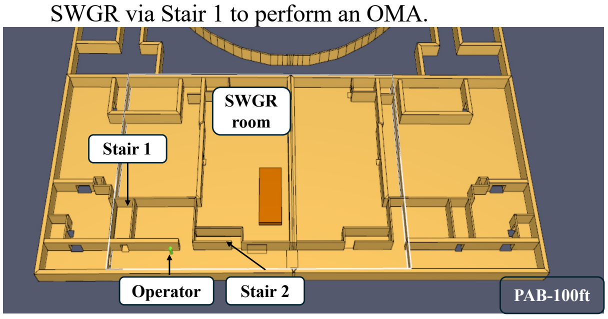


Fig. 3. Example illustrating a fire ignition scenario in the SWGR room located at 100ft in the PAB

The next step is to describe operator movements using an agent-based model. Fig. 4 depicts a scenario in which the operator starts at the 144 ft MCR in the PAB, moves to the 100 ft level via Stair 1, and then proceeds to the 77 ft level through Stair 2, which is located right next to the SWGR room where the fire has occurred. Note that the depiction of the 125ft and 77ft-level floor in the PAB were omitted in this paper to facilitate the illustration of the example case.



(a) The operator located at 144ft MCR moves down to 100ft SWGR via Stair 1 to perform an OMA.



(b) The MCR operator needs to move down to 77ft AWP room via Stair 2 at 100ft in the PAB.

Fig. 4. Agent-based simulation of the example scenario (Travel path: 144ft MCR-100ft Stair 2- 77ft AWP room)

To simulate the operator movements presented in Fig. 4, the following parameters should be determined:

- Movement path
- Waypoint
- Movement speed (m/s)
- Speed fraction at stairs or ramps (up/down)

Given the specific characteristics of the operators in a NPP, variables related to crowd movement can be excluded. As a result of the agent-based simulation, the following outputs can be identified

- Operator travel time
  - Total travel time to perform an OMA
  - Travel time to a specific point (not the destination)

As a final step, the results of the fire modelling (Fig.3 with temperature distribution) can be combined with the agent-based simulation results (Fig. 4), as shown in Fig. 5.

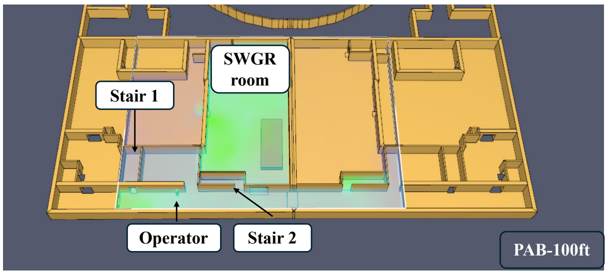


Fig. 5. The results of the agent-based simulation combined with the fire modelling results

As shown in Fig. 3, 4 and 5, this approach is expected to be useful in determining operator travel time while simultaneously identifying factors that may impede movement due to fire. For example, if the temperature is too high or visibility is insufficient due to the fire at the time the agent passes through Stair 2, the operator would need to take an alternative route to reach the 77 ft AWP room. In this case, alternative routes can be easily described using the agent-based model, allowing operator travel times to be estimated without having to visit the site in person.

3. Conclusions

In this paper, we attempted to model PAB of the reference NPP using the specialized programs to show that the agent-based simulation with fire modelling can help the determination of operator travel times. Consequently, it is expected that various scenario affecting operator travel time during fire events can be analyzed through the proposed approach in this paper.

Although this paper assumes a simple fire scenario and an OMA, which are not applicable to the reference NPP in practice, future research should consider actual operator movement path for OMAs and analyze factors affecting operator travel time through more sophisticated fire modeling.

ACKNOWLEDGEMENTS

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