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Escape Route Improvement by Specialized Escape and Evacuation Simulation for Oil and Gas Facility

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Escape and evacuation of operators in oil and gas facility is one of the most important points in the design phase of facility, and also important in the operation and maintenance plan. Furthermore, in recent facilities such as offshore facility and onshore modularized facility, process areas become more complicated and congested. In those facilities, adequate escape routes and means of escape (ladder, stairs, ramp, etc.) are provided for operator safe escape and evacuation in all situation, i.e., normal situation, accidental situation, and maintenance situation. In some cases, Escape, Evacuation and Rescue Analysis (EERA) are conducted in design phase in order to confirm that the designed escape and evacuation facilities are enough safe for operator escape and evacuation. However, there is no simulation program which can simulate realistic operator escape and evacuation behaviour in the oil and gas facilities. The characteristics of operators escape and evacuation in the oil and gas facilities are usage of ladder, congested areas, situation change in accident scenario, barricade in maintenance period, etc.
In this research, first, the specialized escape simulation program is developed based on the existing escape simulation for public area escape by the University of Tokyo. To develop the specialized escape simulation for oil ang gas facility, experimental test to obtain specific parameters of oil and gas facilities escape is conducted. Second, using the developed escape simulation program, case studies are conducted for several maintenance plans and propose the evaluation method of the maintenance planning from escape route aspect.

1. Introduction

Safe operators escape and evacuation is one of the most important points for oil and gas facilities, where large amount of flammable and/or toxic material are handled, and the area is very congested by piping, equipment, instrument and electrical appliances, etc. The characteristics of escape in oil and gas facilities are summarized as below.

- Ladder might be used in escape. In normal public escape situation, ladder is not considered as a mean of escape.
- Operators know what they shall do in emergency situation since they must have safety induction before entering the facility.
- Operators form a group. The group members will evacuate together by leader's instruction.
- Conditions of escape route may change due to the escalation of accident. Operators need to change direction of evacuation depending on the escalating situation.

1.1 Current situation of escape simulation for oil and gas facility

There are several escape simulation technologies in the market. However, those are focusing on the escape from industrial building or wide area evacuation from a city in natural hazard situation. The specialized escape simulation which reflects the characteristics summarized in the above section does not exist. An assessment method called "Emergency, Evacuation and Rescue Analysis (EERA)" is available to assess the facility design in terms of operator safe escape and evacuation. However, this assessment is limited to calculates escape

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time based on the designed walking distance from a specific point to the muster area and does not simulate operators escape behaviour.

1.2 Purpose

The purpose of the research is to establish the specialized escape simulation program for oil and gas process facilities and provide the following supports

- Support the escape route design in the facility
- Support the escape route planning in maintenance period
- Support the investigation of the accident

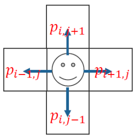
1.3 Development step

First, the base escape model for the simulation development was researched and concluded that the extended floor field model developed by the University of Tokyo was applied (Nishinari et al., 2003). To obtain the key unique parameters of escape simulation in oil and gas facility, an experimental test was conducted at the training facility of Mitsui Chemicals in Chiba, Japan. The original escape simulation program of the University of Tokyo was modified and developed to the specialized escape simulation program for the oil and gas facility based on the result of experimental test.

2. Extended floor field model

The floor field model, which is a cellular automata for studying evacuation dynamics, was investigated and extended by the University of Tokyo (figure 1, Nishinari et al., 2003). In the model, an operator's position at the next time step is decided by the following parameter:

- Static floor field: distance to the goal
- Dynamic floor field: tendency to follow other persons
- Effect of direction: tendency to move straight
- Effect of walls: tendency to keep away from the walls
- Effect of friction: resolution of conflicts in clogging situation



$$p_{ij} = N \exp(k_D D_{ij}) \exp(k_S S_{ij})\, p_i(i,j) pw$$

S_{ij} : Static floor field $\quad k_S$: Effect of Static floor field
D_{ij} : Dynamic floor field $\quad k_D$: Effect of Dynamic floor field
$p_i\ (i,j)$: Effect of direction $\quad p_w$: Effect of walls

Figure 1: Extended floor field model

The open-source software, NetLogo is used as programming platform. NetLogo is a multi-programmable modelling environment, which is used by hundreds of thousands of students, teachers, and researchers worldwide.

3. Experimental test

In order to obtain the unique parameter of operator escape behaviour in oil and gas facility, experimental test was conducted in December-2019 by ten JGC employees who have work experiences in the oil and gas facility. The test was conducted at a training facility of Mitsui Chemicals in Chiba, Japan (figure 2), under the safety supervision of the Mitsui Chemicals experts. Ten subjects equipped with safety shoes, full-body harness, helmet, and safety glass, which represent the maintenance situation of the oil and gas facility. All experimental tests were conducted more than two times for all subjects, and obtained the following parameter:

- Walking speed on flat surface
- Walking speed on stair
- Descending speed on ladder, and entry time (side entry and front entry) to ladder
- Combination of above for demonstrating actual maintenance situation

Table 1 summarizes the obtained parameter from the experimental test. Those parameters are incorporated in the escape simulation program.

Figure 2: Training facility for experimental test

Table 1: Result of experimental test

Description	Result (average± σ)
Normal walking speed on flat surface	1.34±0.09 m/s
Emergency walking speed on flat surface	1.95±0.09 m/s
Walking speed on stair (slope conversion)	0.95±0.07 m/s
Speed on ladder	0.36±0.08 m/s
Entry time to front-entry ladder	3.75±0.55 s
Entry time to side-entry ladder	2.46±0.41 s

4. Accident scenarios insert function

As a specialized escape simulation program for oil and gas facility, the function of inserting accident scenarios is added in the simulation program to use in the accident investigation or to assess the escape route against the expected accident scenario. Based on the accident report or safety study result (such as fire risk assessment, QRA, etc.), the floor field of accident scenario is prepared. By changing the floor field within a single escape simulation, the available escape routes and means of escape are changed in accordance with the floor field in accident scenario. Once the floor field is replaced, operator shall move to other available escape routes and means of escape. For example, for the 3-floor process module in figure 3, 1) Operators start evacuation at time 0, 2) at time 15 (sec), flammable gas start accumulating at the south side of 1st floor and this area becomes unavailable. Operator who tries to use the south side of the 1st floor need to change the direction and move to north side escape route. 3) at time 30, explosion happens, and all floor of the south side cannot be used for escape. All operators need to change direction from south side to north side.

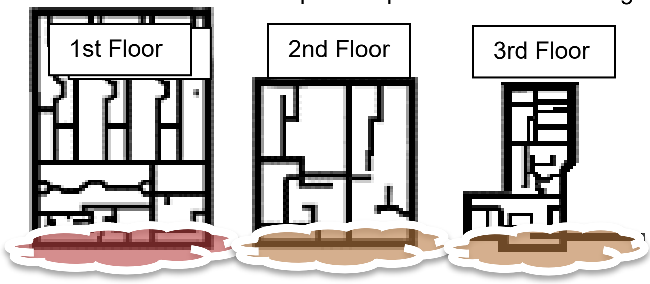


Figure 3: Image of accident scenario

5. Specialized escape simulation program

The specialized escape simulation program was established for oil and gas facility based on the original model by the university of Tokyo (section 2), experimental test (section 3), and additional function to add the accident scenario (section 4). Figure 4 is the overview of the specialized escape simulation.
The work steps of escape simulation are summarized as below.

- Input facility layout, escape route and maintenance plan (e.g., barricade during the maintenance). The base escape route layout (such as in AutoCAD drawing) should be converted to excel file. Once excel file is created, maintenance plan or accident scenario can be created in the excel file.

- Decide accident scenario and prepare escape layout in accident scenario. The applicability of the accident scenario and insert timing of the accident scenario can be controlled on the left-bottom button of the escape simulation.
- Input operator for escape simulation. Operator can be placed in the excel file, or directly on the program by clicking the map.
- Conduct simulation. Individual operator movement can be observed on the simulator.
- Discussion and report

The main outputs from the simulation are summarized as below.

- Graphical movement of each person. Each person will move to the goal by the formula mentioned in section 2.
- Total time of escape. Total escape time of the furthest person from starting point to the goal.
- Average travel speed. This value depends on the number of corners, stair/ladder, and clouded point in the escape route.
- Average distance from starting point to the goal
- Heat map of the person passage. The location where many persons have passed during the escape is changed from white to black. Crowded point/bottle neck in the escape route can be identified.

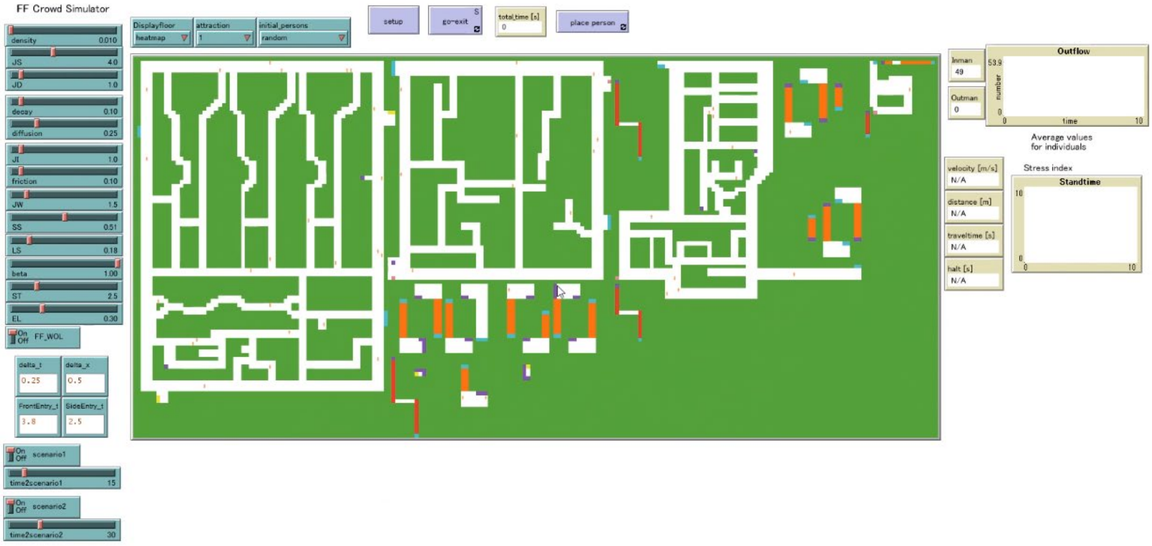


Figure 4: Overview of specialized escape simulation for oil and gas facility

6. Case study – assessment of escape route in maintenance period

In the long-time maintenance period, several maintenance activities will be conducted at the same time, and some of the escape route will be occupied by the maintenance tool, chemical drums, new valves for replacement, etc. As a principle, two means of escape are secured in normal situation, therefore, at least one escape route is available in an emergency so that operators can escape. In this case study, based on the same maintenance activity (=same number and position of operators), several barricade plans are assessed.

6.1 Case study scenario

4-floor process module is used as a basis of case study (approx. 30m * 40m in 1st floor). The maintenance activity and number of operators are summarized in table-2 and figure 5.

Table 2: Maintenance Scenario in Case Study

Maintenance Activity	Location	Number of Operator
(1) Vessel internal inspection	1st floor south side	3
(2) Chemical replacement: column 1	2nd floor north-west side	10
(3) Chemical replacement: column 2	2nd floor north-east side	10
(4) Heat exchanger bundle installation	2nd floor west side	12
(5) Emergency shut-down valve installation	3rd floor south-east side	5
(6) Instrument inspection	3rd floor south-west side	3
(7) Blow down valve installation	4th floor	5

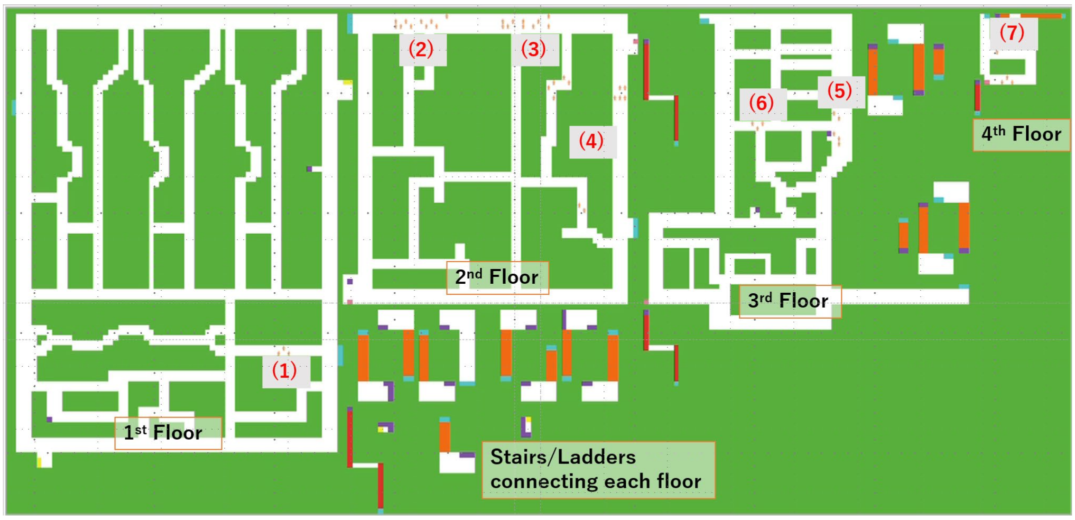


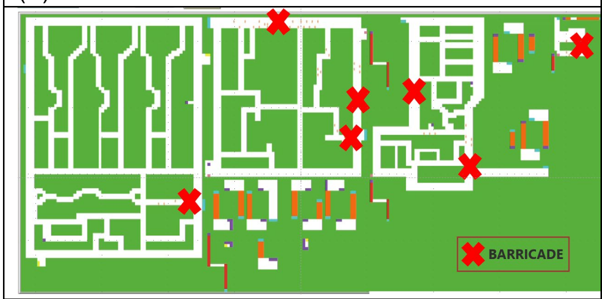
Figure 5: Escape layout and maintenance map in case study

6.2 Case study result

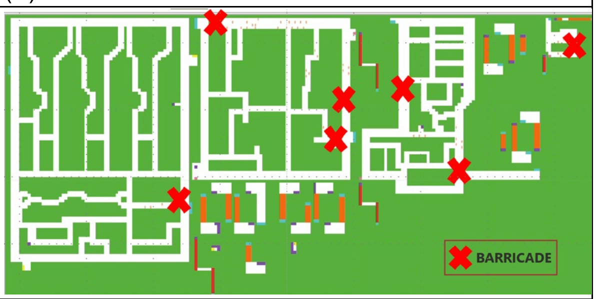
In the case study, operator number and location are kept same as per table 2 and figure 5. Based on this maintenance plan, four barricade plans are simulated (in figure 6). Total time, average velocity, average distance, and average travel time from the simulation are summarized in table 3. Barricade plan (B) is the base barricade plan for the case study. One barricade is added on 3rd floor in plan (C), which will be an additional obstruction for operators on 3rd floor. From plan (C), one barricade on north side of the 2nd floor is moved to neat the stair in plan (D).

(A) No barricade

(B) Barricade Number-6



(C) Barricade Number-7 Pattern 1



(D) Barricade Number-7 Pattern 2 (only one barricade on 2nd floor change)

Figure 6: Barricade plan in case study

Table 3: Summary of Case Study – Barricade Plan (average in 1,000 times simulations)

Barricade Plan	Barricade Number	Total time	Average velocity	Average distance	Average travel time
(A)	0	78.27 s	1.28 m/s	58.72 m	47.31 s
(B)	6	78.79 s	1.28 m/s	60.22 m	47.99 s
(C)	7	84.83 s	1.33 m/s	73.23 m	56.49 s
(D)	7	93.08 s	1.32 m/s	81.85 m	64.43 s

6.3 Discussions

Based on the case study result, the following points are observed:

- In general, the result is varying due to the barricade number and location. Even for the same number of barricades, the result is different (in plan(C) and plan(D)).
- If the barricade is well planned, there is no big difference for operator escape. In plan(A) and plan(B), the barricade number is different from 0 to 6, however the difference of distance and travel time is limited between plan(A) and plan(B). Also, the average velocity is same in plan (A) and plan (B).
- Even if one barricade location is changed (2nd floor north side barricade location is changed from plan (C) to plan(D)), the difference of the result is significant. Even if the average velocity is same in plan(C) and plan(D), the distance and travel time is much larger in plan (D).

In this case study, it is concluded that if the maintenance plan is well studied, the impact of the barricade can be minimized for the operator escape action. On the other hand, if the maintenance plan is not well studied, the small difference of the maintenance plan may provide the significant impact for the operator escape action.

6.4 Case study - 2: operator number and location

As an additional case study, several cases of operator numbers and location in plan (B) are simulated. The scenarios and results are summarized in table 4.

Table 4: Summary of Case Study – Operator Number and Location Change (average in 1,000 times simulations)

Operator Plan	Operator Number	Total time	Average velocity	Average distance	Average travel time
(B-0)	1F:3 / 2F:31 / 3F:8 / 4F:5	78.79 s	1.28 m/s	60.22 m	47.99 s
(B-1)	1F:3 / 2F:31 **/ 3F:23** / 4F:5	79.72 s	1.23 m/s	63.42 m	52.95 s
(B-2)	1F:3 / 2F:31 / 3F:8 / **4F:15**	94.50 S	1.26 m/s	66.99 m	54.58 s
(B-3)	1F:3 / 2F:31 **/ 3F:0 / 4F:13**	92.04 S	1.27 m/s	64.21m	52.17 s

In operator plan (B-1), number of operators increased in 3rd floor. However, there is no difference in total time because total time depends on the operator at the furthest location (4th floor). Average velocity is decreased because the number of escape persons from 3rd floor is increased and the average number of using the stair/ladder is decreased in total. On the other hand, if number of operators is increased in 4th floor (plan (B-2)), the total time and distance/travel time are increased accordingly. In plan (B-3), 3rd floor operators are moved to 4th floor. Because the entrance of the stair on 4th floor become crowded by the increased number of operators on 4th floor, the total time is increased accordingly. From this further case study, it is concluded that operator number and location also impact on the operator escape. Especially, maintenance activity at the furthest location should be managed carefully. On the other hand, the maintenance activity can be increased without impact on the operator escape if the number and location of the operator and barricade is carefully decided.

7. Conclusions

The specialized escape simulation program for oil and gas facility is established, based on the simulation model by the University of Tokyo, and experimental test at the training facility. The several case studies are conducted and identified that the maintenance plan (maintenance activity, number and location of barricade and operator) affects the operator escape. This established escape simulation can be applied to support maintenance planning without affecting the operator safety from escape point of view. This simulation also can be applied for other purpose such as verification of escape plan, design of escape route, investigation of the accident.

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