

Operational Optimization at Screening Points During a Nuclear Disaster

Hengyang Li^(1*), Kyoko Oba⁽²⁾ and Muneyoshi Numada⁽³⁾

¹ Energy Engineering, Nagaoka University of Technology, Nagaoka, Japan,

² Nagaoka University of Technology, Japan,

³ Institute of Industrial Science (IIS), the University of Tokyo, Japan

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Abstract. In nuclear disaster scenarios, residents near affected areas may need to evacuate as the situation escalates. During the initial phase of evacuation in the Fukushima Daiichi Nuclear Power Plant accident following the Great East Japan Earthquake, approximately 20% of evacuees from restricted zones failed to undergo mandatory radiation screening. Niigata Prefecture, Japan, has established a manual for screening point management. However, the framework lacks a systematic examination of multifactorial variables affecting implementation under diverse nuclear disaster scenarios. To protect the public from exposure to radioactive substances released during a nuclear disaster, this study investigates the operational optimization of screening points through stay time modeling. For the considered evacuation scenario, simulations on the effects of the number of evacuees and the number of lanes installed (i.e., inspection capacity) are conducted. The results demonstrate a significant stay time reduction. The optimization criteria for the simulation are presented and the optimal number of lanes for mitigating radiation exposure risk is determined. This modeling approach provides quantitative evidence for optimizing screening point operations, which is particularly crucial during early-phase evacuations when radiation levels peak. The findings contribute to emergency response planning by establishing a framework for balancing evacuation efficiency with thorough radiation screening requirements.

Correspondent email :

lhy1584797@gmail.com

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1. Introduction

The impact of nuclear disasters, which occur due to an abnormal release of radioactive substances, extends beyond the facility premises. The largest nuclear disaster in Japan was the Fukushima Daiichi Nuclear Power Plant accident (hereafter referred to as the 1F accident) in 2011. Preparations for nuclear disasters have since been improved (Niigata Prefecture, 2022b, 2022c). The person responsible for implementing protective measures for evacuees is required to monitor the spatial dose near the nuclear power plant in an emergency and take any necessary measures.

Japan established its nuclear emergency framework through the 1999 Act on Special Measures Concerning Nuclear Emergency Preparedness (Japanese Government, 1999). This framework was subsequently enhanced by the Japan Nuclear Regulation Authority (NRA) and its NRA Guide for Emergency Preparedness and Response (Japan NRA, 2021). These directives have informed revised local disaster management plans and wide-area evacuation protocols nationwide.

Niigata Prefecture, which hosts the world's largest nuclear power plant, namely the Kashiwazaki-Kariwa Nuclear Power Plant (2023), developed its local disaster management plan (Niigata Prefecture, 2019a) in accordance with NRA guidelines. Post-1F accident evaluations led to the 2014 Niigata Prefecture Wide-Area Evacuation Action Guidelines for Nuclear Disasters (Niigata Prefecture, 2018), further refined into the Niigata Prefecture Nuclear Disaster Wide-Area Evacuation Plan (Niigata Prefecture, 2019b) with specific implementation manuals. The 2022 Niigata

Prefecture Screening and Simple Decontamination Manual (Niigata Prefecture, 2022a) (hereafter referred to as the Niigata Prefecture Manual) standardized procedures for Evacuation Inspections and Decontamination Sites (i.e., screening points). However, operational challenges persist in adapting these protocols to diverse emergency scenarios. As noted by Malešić et al. (2015), effective evacuation requires testing and modeling that considers various factors, such as the number of evacuees, available transportation, transport infrastructure capacity, and citizen behavior. Otun (2021) emphasized the application of appropriate tools for assessing and identifying locations where the use of public facilities can be improved.

The present study investigates the operation of screening points to protect residents from exposure to radioactive substances released during a nuclear disaster. We create a model for calculating the stay time of evacuees and examine stay time optimization.

2. Methods

Evacuation Scenario and Calculation Model

This section explains the development of a calculation model for examining the optimal conditions and feasibility of staffing and operational tasks at screening points. The following scenario is considered: an emergency event occurs at the Kashiwazaki-Kariwa Nuclear Power Plant and about 1,000 residents of a specific area in Nagaoka City evacuate to a shelter via Tsukioka Park (screening point) near Uonuma City in 390 private cars.

Target Area

The target area in this study is the Koshiji, Yamakoshi, Oguni, and Kawaguchi areas of Nagaoka City (Figure 1), which have a total population of about 22,600 (Nagaoka City, 2022).

Task List

The tasks to be performed for screening and simple decontamination in Niigata Prefecture are described in the Niigata Prefecture Manual. They are implemented separately for vehicles and residents. The inspection of residents is performed in accordance with the procedure outlined in Figure 2. Regarding the time required for each task (Table 1), estimated values based on the state of the Nuclear Energy Disaster Prevention Drill (Niigata Prefecture, 2021) were used as there are no historical data.

Setting of Passage Rate

The Nuclear Regulation Authority created the Comprehensive Judgment Criteria (GC) and Operational Intervention Levels (OIL) (Japan NRA, 2018) in April 2018. As supplementary material, the Concept of Setting Operational Intervention Levels (OIL: Operational Intervention Levels) in the Revision of the NRA Guide for Emergency Preparedness and Response was added in February 2013 (Japan NRA, 2013). The supplementary material contains the following description regarding the screening results of the 1F accident: “ There is extensive contamination screening data available from this accident. When examining the subset covering a relatively large population (192,933 individuals screened), 102 cases showed contamination levels exceeding 100,000 count per minute, while 894 cases fell within the 13,000-100,000 count per minute range. “ Considering the reliability of the

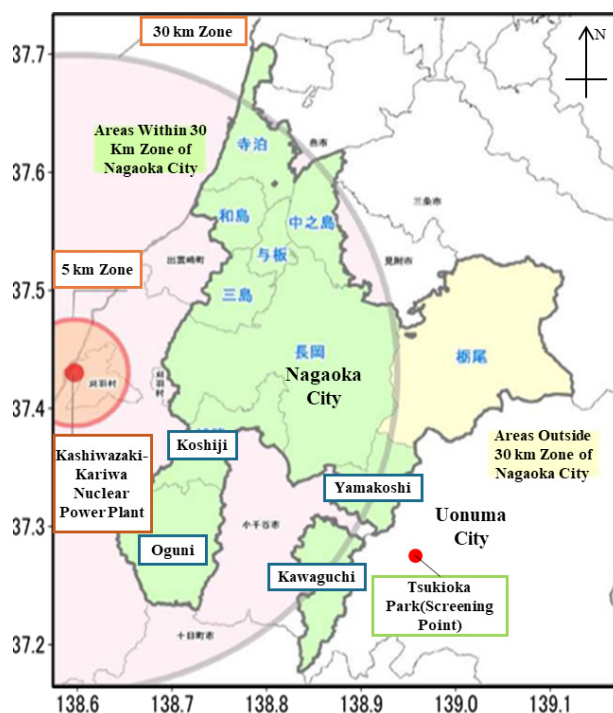


Figure 1. Target Area in Nagaoka City, Niigata Prefecture, Japan (Nagaoka City, 2015) (partially edited)

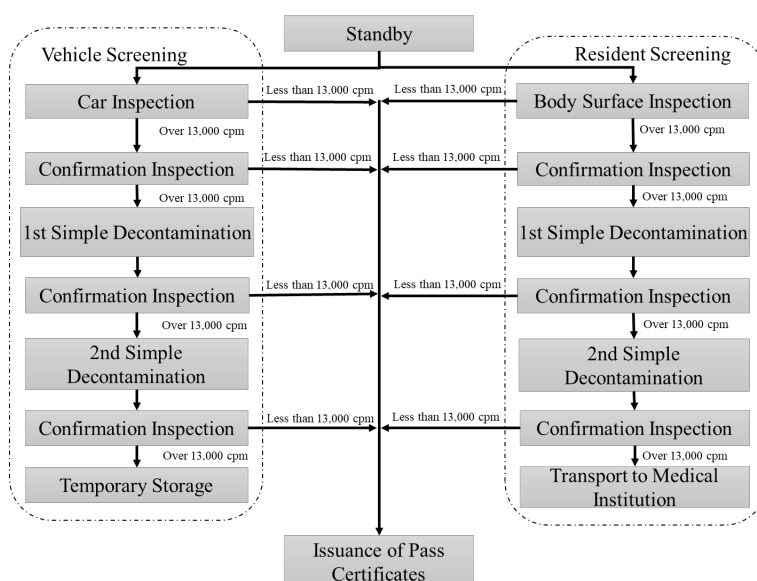


Figure 2. Task Flow for Screening Point (cpm: counts per minute)

Table 1. List of Tasks and Corresponding Numbers of Lanes

Task Details	Task Number	Number of Vehicles(Residents) Lanes Processed Simultaneously
Standby	1	50
Car Inspection	2	2
Confirmation Inspection(Vehicles)	3	2
1st Simple Decontamination(Vehicles)	4	1
Confirmation Inspection(Vehicles)	5	1
2nd Simple Decontamination(Vehicles)	6	1
Confirmation Inspection(Vehicles)	7	1
Temporary Storage(Vehicles)	8	4
Body Surface Inspection	9	3
Confirmation Inspection(Residents)	10	2
1st Simple Decontamination(Residents)	11	2
Confirmation Inspection(Residents)	12	2
2nd Simple Decontamination(Residents)	13	2
Confirmation Inspection(Residents)	14	2
Transport to Medical Institution(Residents)	15	2
Take a Replacement Car	16	30
Issuance of Pass Certificates	17	2

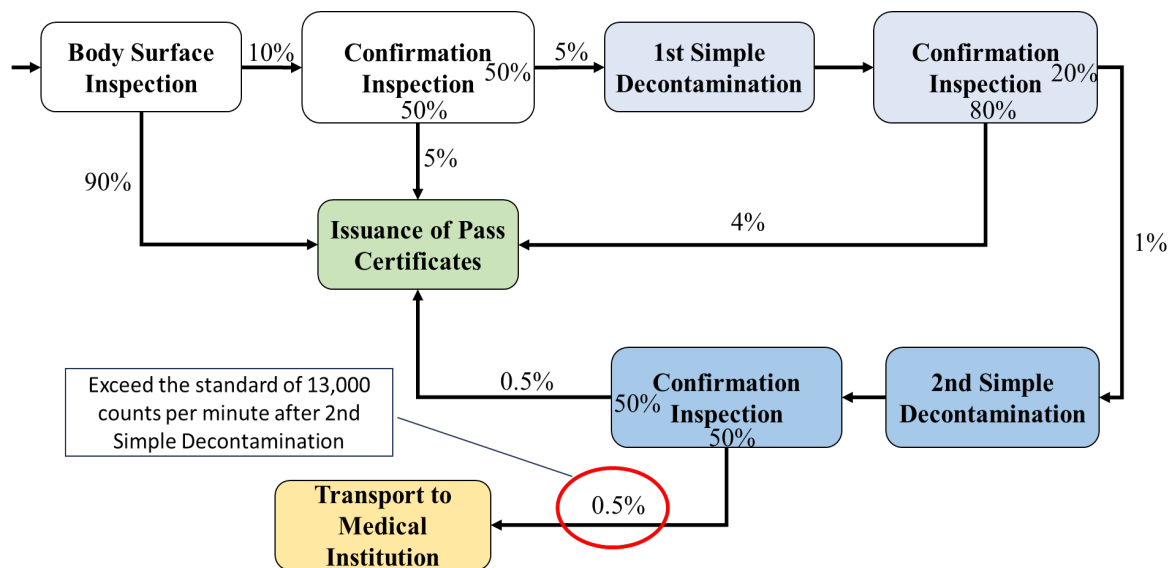


Figure 3. Passage Rate for Resident Screening

detection rate, based on these data, the probability of detection exceeding the standard of 13,000 counts per minute is about 0.5%. The passage rates shown in Figure 3 were determined based on the supplementary material.

Calculation Model

Based on studies on optimization models (Kobayashi & Moriguchi, 2018; OYAMA & NUMADA, 2018), a calculation model should be versatile, allow changes in variables due to resource changes, be able to include a large number of people, and facilitate the aggregation of results. In this study, these functions are realized by using Microsoft Excel to perform calculations and aggregations with macro functions and creating a Gantt chart by coloring cells.

The calculation is divided into the following three steps:

Step 1. Calculate and display tasks without previous tasks.

Step 2. Calculate and display tasks with previous tasks such that they start after the previous tasks have been completed.

Step 3. Filter the tasks without previous tasks and indicate the time it takes for these tasks on the Gantt chart. For each resident, count the number of identical tasks to be performed and compare the obtained value with the lane number limit (the number of tasks and people that can be processed in parallel) in Table 1 for each task. For tasks that exceed the lane number limit and all subsequent related tasks, shift the bar representing each task on the Gantt chart back by 1 minute. The calculation flow for this step is shown in Figure 4.

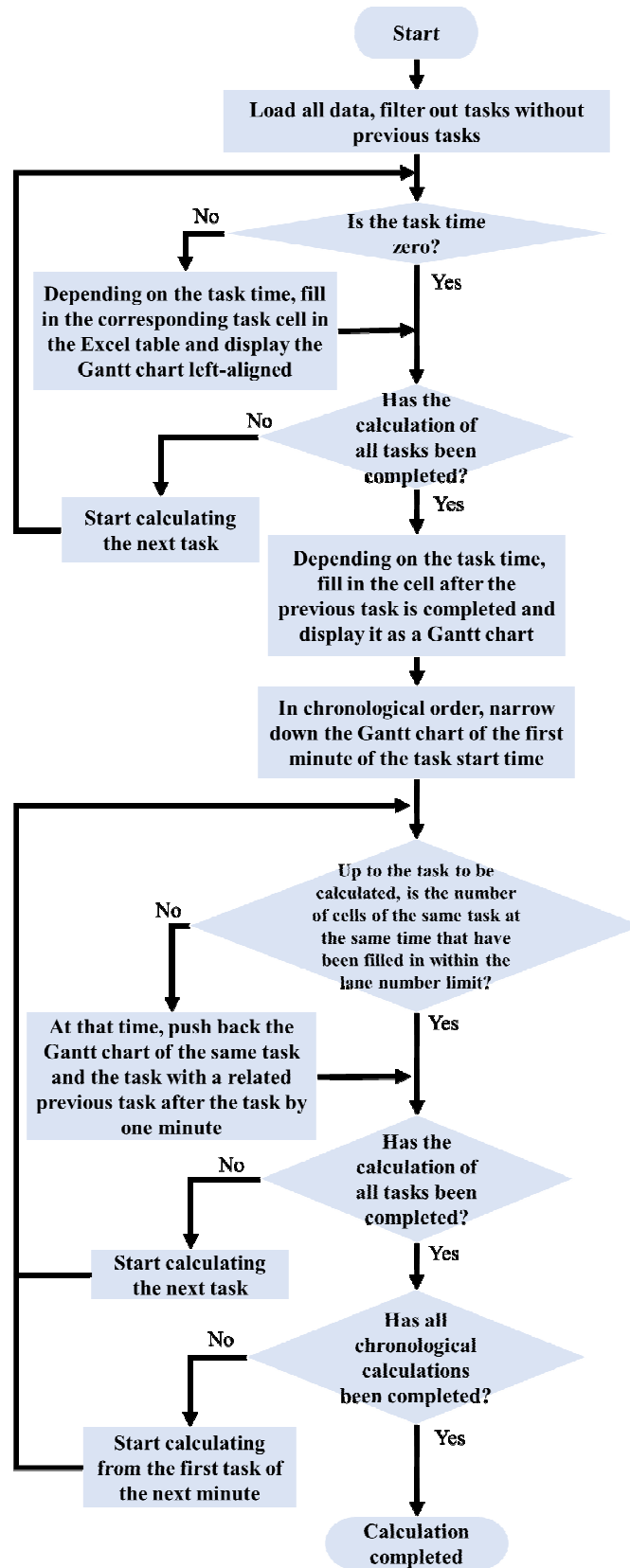


Figure 4. Flowchart for Step 3 of Calculation

3. Results and Discussion

Results

Simulation on Effect of Number of Evacuees

The first simulation was conducted to examine the effect of the number of evacuees. In this simulation, a scenario based on the current manual and predicted tasks at a screening point was considered. The maximum number of evacuees was set to 1,000, the number of lanes for designated location car

inspection was set to 2, and the number of lanes for designated location resident inspection was set to 3.

The number of evacuees was increased from 100 to 1,000 in increments of 100, for a total of 10 simulation runs. To control variables, each of the 390 vehicles was assigned to a fixed evacuee. The input and output of the calculation are shown in Figure 5.

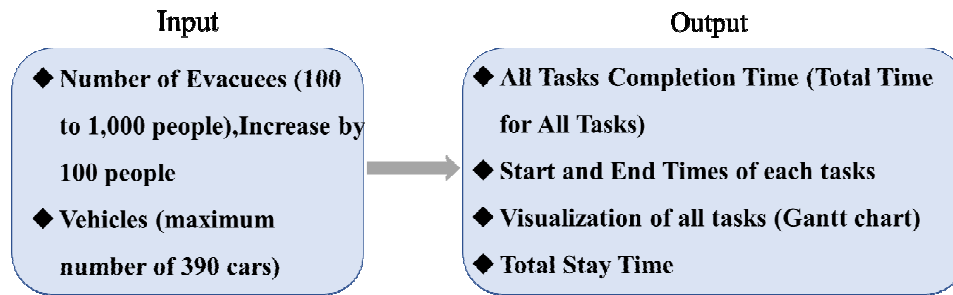


Figure 5. Input and Output of Simulation on Effect of Number of Evacuees

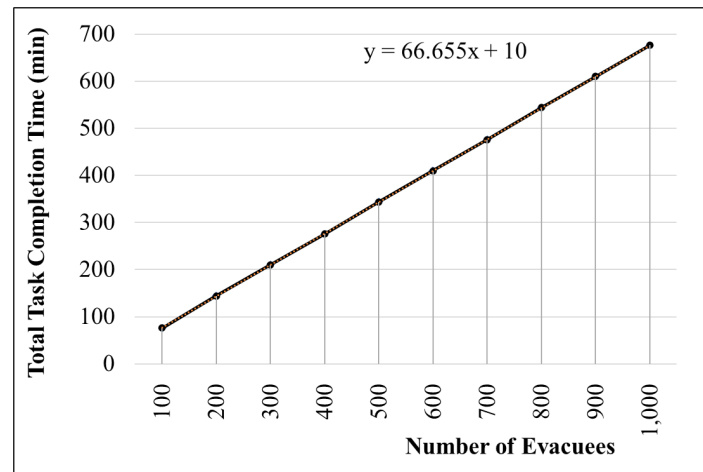


Figure 6. Total Task Completion Time Versus Number of Evacuees

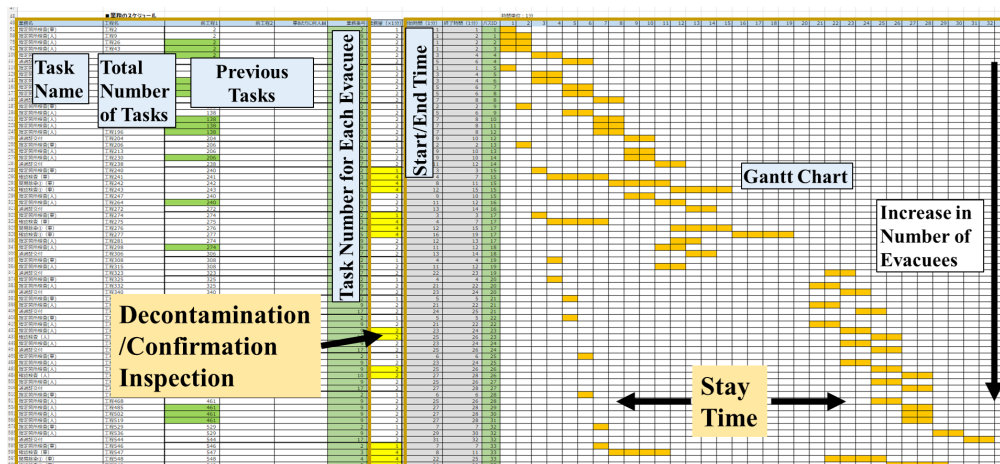


Figure 7. Visualization of All Tasks

The calculation results are divided into four parts.

- 1) **Total Task Completion Time:** It was found that the total task completion time increases almost linearly (Figure 6) with an increase in residents. For 1,000 residents, the total task completion time is 676 minutes (approximately 11.3 hours), which is considered a result far from the purpose of seeking effectiveness.
- 2) **Visualization of All Tasks:** A Gantt chart was created based on the start and end times of all tasks (Figure 7). The amount of work in the columns not enclosed in the center was determined based on Table 1. The marked part indicates a situation where there are tasks other than the designated location inspection (i.e., tasks performed on residents who have been detected as contaminated).
- 3) **Total Stay Time:** The total stay time for all residents was calculated. The relationship between the number of

evacuees in the simulation and the total stay time is shown in Figure 8. The total stay time nonlinearly increases with an increase in the number of evacuees.

- 4) **Total Stay Time Distribution for 1,000 Evacuees:** The total stay time for 1,000 evacuees was about 4,860 hours. Some residents passed after waiting for less than 10 minutes whereas other residents waited for more than 2 hours (Figure 9).

Simulation on Effect of Number of Lanes Installed

The number of lanes for designated location car inspection was varied in the range of 2 to 9 and the number of lanes for designated location resident inspection was varied in the range of 3 to 17. The progress of the screening point tasks was calculated.

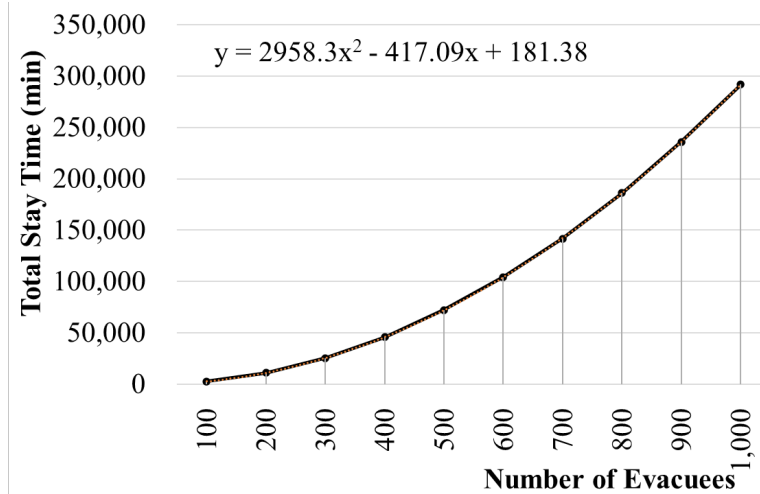


Figure 8. Total Stay Time Versus Number of Evacuees

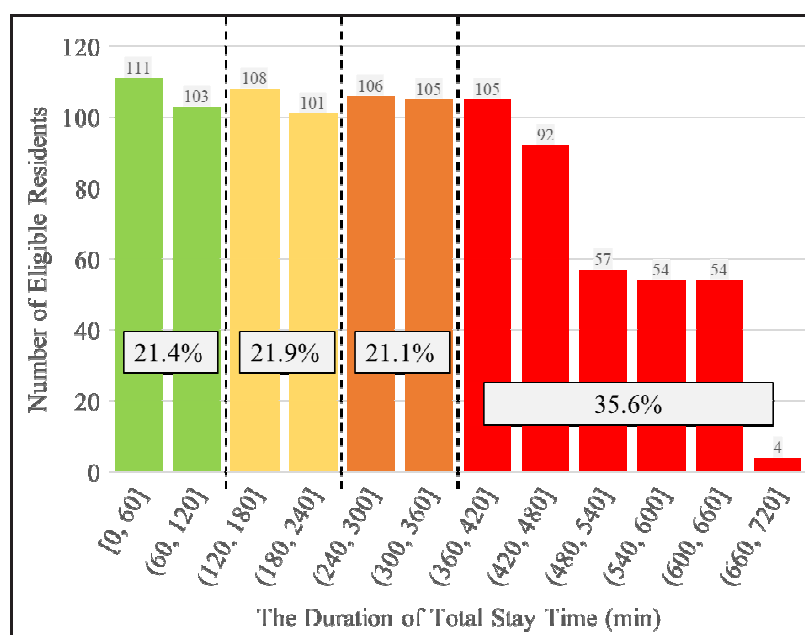


Figure 9. Distribution of Total Stay Time for 1,000 Evacuees

Table 2. Relationship between Number of Lanes and Total Task Completion Time (min)
(green cells show increase in total task completion time)

	Number of Lanes for Car Inspection							
	2	3	4	5	6	7	8	9
Number of Lanes for the Resident Inspection	3	676	670	670	670	670	670	670
	4	512	504	670	512	512	512	512
	5	414	406	406	414	414	414	414
	6	394	394	394	398	398	398	398
	7	394	394	394	394	394	394	394
	8	392	392	392	392	392	392	392
	9	695	392	392	392	392	392	392
	10	627	392	392	392	392	392	392
	11	573	572	392	399	393	393	393
	12	523	523	392	396	396	396	396
	13	485	492	392	412	396	396	396
	14	454	453	392	400	400	400	400
	15	423	419	429	428	430	430	430
	16	396	396	400	412	420	420	420
	17	393	397	397	399	392	392	392

- 1) **Total Task Completion Time:** It was found that the total task completion time tends to decrease with an increase in the number of lanes for designated location resident inspection; however, when a certain number of lanes is exceeded, the total task completion time increases (green cells in Table 2).
- 2) **Total Stay Time:** It was found that the total stay time initially sharply decreases with an increase in the number of lanes for designated location resident inspection. When the number of lanes for designated location resident inspection exceeds a certain value, the total stay time only slightly decreases (Table 3, Figure 10).
- 3) **Total Stay Time Distribution of Representative Examples:** The total stay time distribution was calculated with the number of lanes for designated location car inspection set to 2 and the number of lanes for designated location resident inspection set to 9. Unlike in Figure 9, the wait time for all residents was within 1.25 hours (75 minutes).

In particular, 94.2% of the residents had a stay time of less than 1 hour. Most residents passed the screening point without waiting (Figure 11).

3. Result and Discussion

For a given screening point, the total task completion time increased linearly whereas the total stay time increased nonlinearly with an increase in the number of evacuees. The stay time distribution indicates that many residents waited for a long time. Furthermore, an analysis of the Gantt chart indicates that even a group of 100 people caused a delay and that the stay time of residents at the back of the group was longer than that of those at the front. If the tasks at the screening point are performed at the pace specified in the Nuclear Energy Disaster Prevention Drill, many residents will be forced to line up outdoors, greatly increasing their exposure risk. These results indicate that the current Niigata Prefecture Manual may increase the exposure risk of evacuees.

Table 3. Relationship between Number of Lanes and Total Stay Time (min)
(green cells show increase in total task completion time)

		Number of Lanes for Car Inspection							
		2	3	4	5	6	7	8	9
Number of Lanes for the Resident Inspection	3	291,859	306,154	312,491	316,291	318,826	320,636	321,994	323,050
	4	208,761	222,880	312,491	231,617	234,170	235,989	237,356	238,439
	5	159,416	173,287	179,624	182,264	184,817	186,636	188,003	189,086
	6	138,217	150,881	157,218	158,429	161,000	162,828	164,213	165,305
	7	123,723	136,373	142,708	146,507	149,039	150,849	152,207	153,263
	8	112,522	125,142	131,476	135,274	137,805	139,615	140,973	142,029
	9	20,658	113,122	123,035	126,828	125,918	127,791	129,203	130,313
	10	18,696	107,291	116,347	113,240	115,759	117,668	119,116	120,280
	11	17,146	17,833	111,257	109,300	113,620	115,439	116,824	117,898
	12	15,836	16,494	107,047	83,408	87,284	89,346	90,884	92,111
	13	14,781	14,701	103,478	55,138	62,067	64,615	66,540	68,082
	14	13,939	13,910	100,432	42,977	47,393	50,398	52,593	54,270
	15	13,567	13,393	12,942	32,752	37,865	41,291	43,879	45,824
	16	14,016	13,635	14,459	29,688	32,885	36,534	39,327	41,516
	17	17,470	18,241	17,512	17,051	32,695	36,258	39,008	41,125

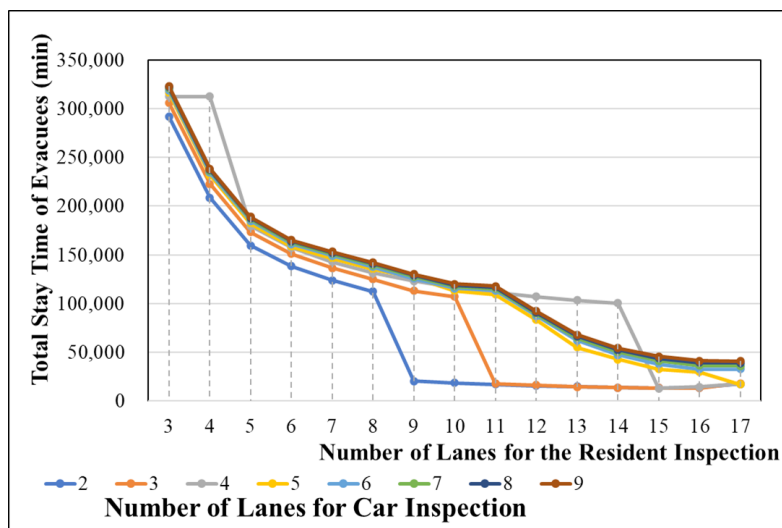


Figure 10. Number of Lanes Versus Total Stay Time

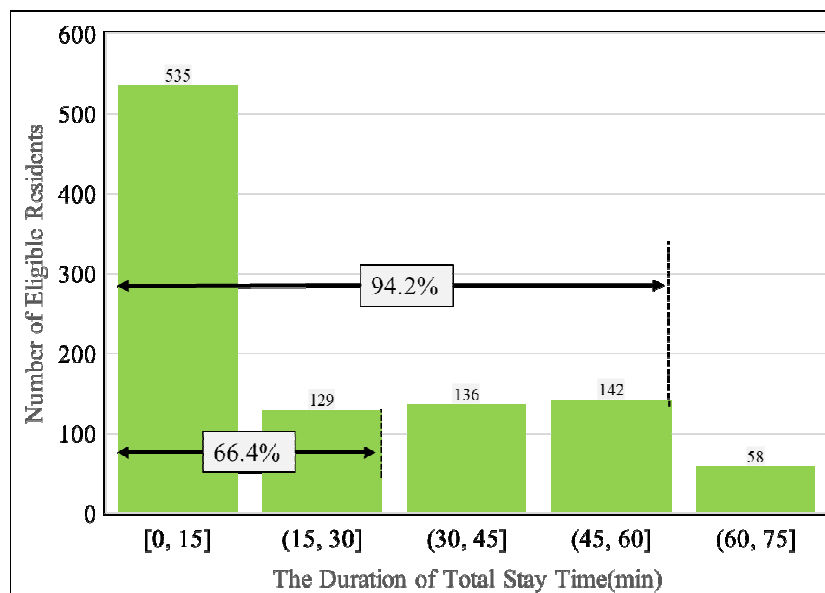


Figure 11. Distribution of Total Stay Time (number of lanes for resident inspection: 9, number of lanes for car inspection: 2)

Increasing the number of lanes installed significantly decreased the total stay time and decreased the proportion of residents with long stay times. However, beyond a certain number of lanes, the total task completion time increased. In addition, to prevent resource shortages (e.g., workers, inspection equipment), the number of lanes at a screening point should be determined with a certain margin. It is also possible to evacuate residents in stages (Shimada & Takahara, 2021).

The total stay time does not significantly change with a small change in the number of lanes. The simulation results of each task of designated location car inspection and designated location resident inspection indicate that increasing the number of lanes and decreasing the total stay time are not necessarily correlated (Figure 10). However, for a given number of lanes for designated location car inspection, the total stay time significantly decreased when the number of lanes for designated location resident inspection exceeded a certain value. Further increasing the number of lanes for designated location resident inspection only slightly decreased the total stay time.

The part where the total stay time significantly decreased (the part in Figure 10 where the value is 50,000 or less on the broken line) and the part where the total stay time does not significantly increase with a slight fluctuation in the number of lanes for designated location residents inspection (the part in Figure 10 excluding both ends of the step) overlap, and the number of lanes installed in the overlapping part has robustness against lane number fluctuations and can increase and decrease the stay time.

In this study, optimization is defined as shortening the stay time of residents and the total task completion time independent of slight changes in resources. In Figure 10, the number of lanes for designated location car inspection was set to 2 and the number of lanes for designated location resident inspection was set to 9. Compared to the case with 8 lanes for designated location resident inspection, the total stay time of residents was significantly reduced. If a resource shortage occurs and the number of lanes for designated location car inspection has to be 2 and the number of lanes for designated location resident inspection has to be 8, the total

stay time will suddenly increase (i.e., the margin is too small). Therefore, 2 lanes for designated location car inspection and 9 lanes for designated location resident inspection cannot be said to be optimal. The number of lanes to be installed should thus consider limited resources (e.g., workers, inspection equipment) and a certain margin. Furthermore, it was found that increasing the number of lanes at a screening point can shorten the total stay time but may increase the total task completion time (Tables 2 and 3).

Based on the results, the optimal number of lanes to be installed should be set to a value in the region where the total task completion time is relatively short (see Table 2), in the region where the total stay time is relatively short (see Table 3), and in the region where its change does not produce a large effect (see Figure 10). In addition, the number of lanes installed should be robust against resource fluctuations. Based on the above criteria, the optimal numbers of lanes for designated location car inspection and designated location resident inspection are 3 and 15, respectively.

4. Conclusion

This study modeled the tasks at screening and simple decontamination implementation sites during the evacuation of residents in the event of a nuclear disaster. Two simulations were conducted on the operation tasks at a screening point. The operational optimization at a screening point for a task was examined by varying the number of lanes for inspection. In the simulation on the effect of the number of evacuees, when the tasks at the screening point were performed with the number of lanes specified in the Nuclear Energy Disaster Prevention Drill, it was found that while the total task completion time increased linearly with an increase in the number of residents, the increase in the total stay time was nonlinear. In the simulation on the effect of the number of lanes installed, changes in the total task completion time and the total stay time were calculated in response to an increase in the number of task lanes at the screening point. Although the total stay time could be shortened by increasing the number of lanes, it was found that the total task completion time increased when the number of lanes exceeded a certain value. Furthermore, the optimization criteria for the simulation were summarized and

the optimal number of lanes was determined. The change in the number of lanes was examined. The possibility of reducing the radiation exposure risk was demonstrated.

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