Master of Science in Engineering

Time Estimating Simulation with Entering Procedure on Chemical, Biological, and Radiological Protective Facility

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Abstract

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As Chemical, Biological, and Radiological (CBR) attack increases, the importance of CBR protective facility is being emphasized. When CBR warfare emerges, a task force team, who exists outside of CBR protective facility, should enter the CBR protective facility through neutralizing process in Contamination Control Area (CCA) and Toxic Free Area (TFA). If a bottleneck occurs in the process or zones, the task force team cannot enter the CBR protective facility efficiently and may cause inefficiency in its operation performance or result in casualties. The current design criteria of the CBR protective facility is only limited to ventilation system and it does not consider how much time it takes to enter the facility.

Therefore, this research aims to propose the entering time estimation model with discrete event simulation. To make the simulation model, the procedures performed through CCA and TFA are defined and segmented. The actual time of the procedures are measured and adapted for the simulation model. After running the simulation model, variables effecting the entering time are selected for experiments with adjustments. This entering time estimation model for CBR protective facility is expected to help take time into consideration during the designing phase of CBR protective facility and help CBR protective facility managers to plan facility operation in a more realistic approach.

Keywords: Chemical, Biological, and Radiological Protective Facility, Entering Time, Simulation, Procedure Analysis

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Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

In this chapter, backgrounds of research and problems are presented. Also, research objective, scope and process are also described in the following chapters.

1.1 Research Background and Problem Statement

Considering Aum Shinrikyo terror (Japan, 1995) and Bacillus Anthracis (USA, 2001), Chemical, Biological, and Radiological (CBR) weapons can make a serious damage on people and society. CBR protective facility is a kind of shelter to stay without protective equipment. North Korea is now trying to overcome the gap of military power by developing CBR weapons. Because of these reasons, the importance of protection against CBR warfare is steadily increasing (Jeong 2010, Kim 2011).

When the CBR warfare emerges, a task force team, who exists outside of CBR protective facility should enter the CBR protective facility through neutralizing process in Contamination Control Area (CCA) and Toxic Free Area (TFA). If a bottleneck occurs in the process or zones through entering process, the task force team cannot enter the CBR protective facility efficiently and may cause inefficiency in its operation performance or result in causalities. The current design criteria of the CBR protective facility is only limited to ventilation system and it does not consider how much time it takes to enter the facility

(Ministry of National Defense 2012, U.S. Department of Defense 2008).

1.2 Research Objective

The objective of this study is to propose the entering time estimation model with discrete event simulation. Through the simulation, possible bottleneck can be predicted while a task force team enters CBR protective facility. Also, variables effecting the entering time are selected for experiments with adjustments. This entering time estimation model for CBR protective facility is expected to help take time into consideration during the design phase of CBR protective facility and help CBR protective facility managers to plan facility operation in a more realistic approach.

1.3 Research Scope and Process

This research is limited to standard military CBR protective facility. The actual time of the procedure performed through Contamination Control Area and Toxic Free Area are measured and adapted for the simulation model. AnyLogic (AnyLogic 7, The AnyLogic Company), one of discrete event simulation program, was selected as a research methodology.

The process of this study is the following:

1) Based on the literature review, understand the present condition and find problems related to CBR protective facility.
2) Have an interview with a military CBR protective facility expert and perceive a relationship between operation and entering time of CBR protective facility.
3) Define and classify procedures which are performed though CCA and TFA.
4) Develop a simulation model with CBR procedure analysis and time influence.
5) Verify the simulation model by comparing the actual time data and simulation result.
6) Find the reason of bottleneck and suggest improvements from analyzing experiment results.

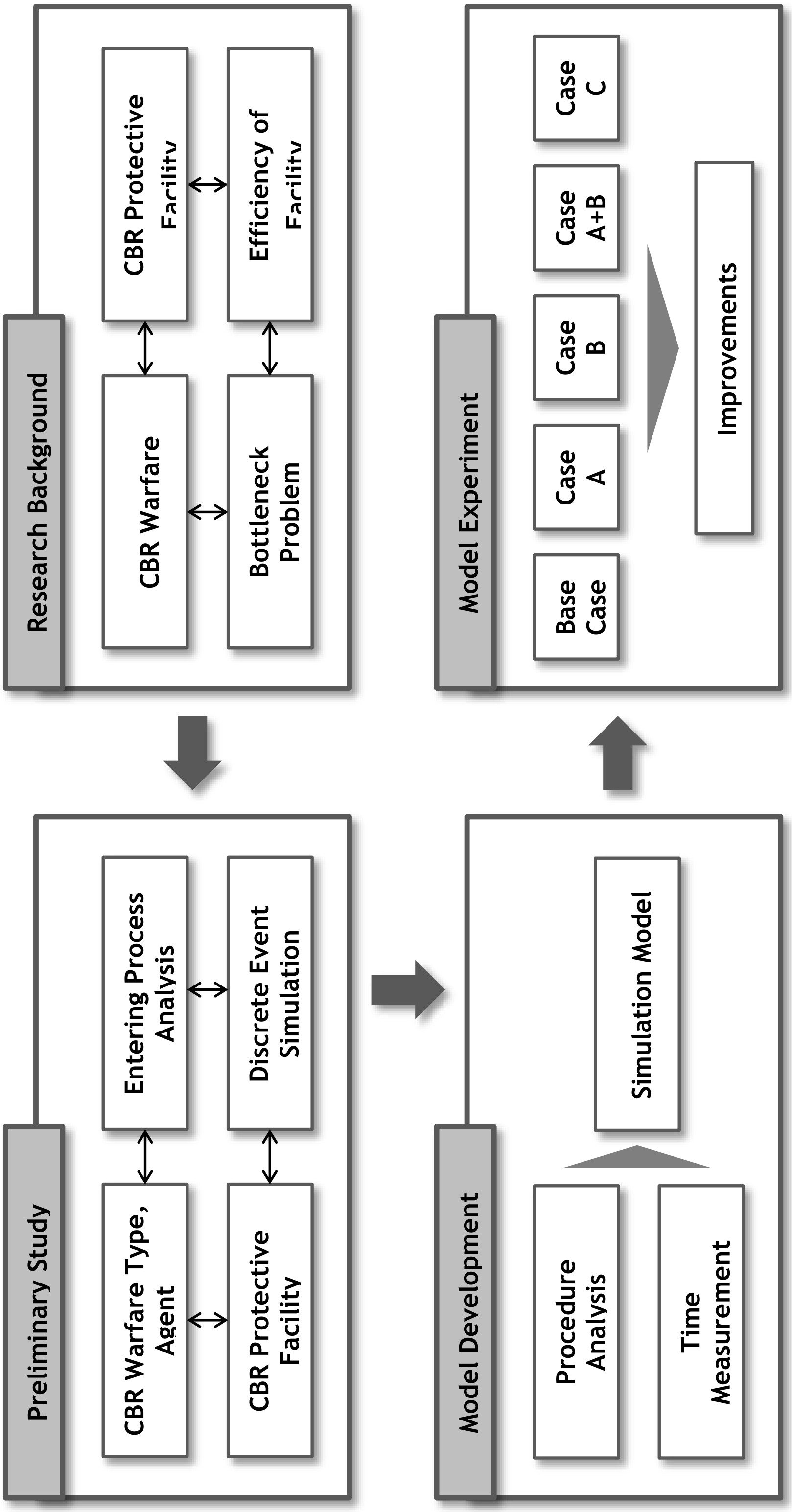


Figure 1-1 Research Process

Chapter 2. Preliminary Study

This chapter discusses the previous research of CBR protective facility and research methodology. First, it describes the concepts and principle of operating CBR protective facility. Secondly, it shows the previous study review which is related to CBR protective facility. Finally, discrete event simulation is introduced which is the main methodology of the study.

2.1 CBR Warfare

Due to the technology growth, the ancient weapons, stones and woods, has been changed to guns and missiles, and the features of warfare was also changed. The advent of new CBR warfare threatens all creatures including human beings, and it is considered as a new kind of disaster. CBR warfare is defined as “A war that a chemical, biological, and radiological weapon kill and bring significant harm to a large number of humans or cause great damage to human made structures”. This CBR warfare can make a great disaster in our society, so it was restricted to product, keep and use CBR weapons. However, the threats of CBR warfare doesn’t disappear because it has military and political advantages against other countries. In recent years, CBR warfare is used by means of a economic and political chaos like Aum Shinrikyo terror (Japan, 1995) and Bacillus Anthracis (USA, 2001). The history of CBR warfare is shown in Table 2-1.

Table 2-1 The History of CBR Warfare

Period	Contents
1941	Japan used mustard gas to China
1962-1971	USA used a weed killer(Herbicide) to Vietnam
1981	The Soviet Union used yellow rain to Afghanistan
1981-	The Soviet Union used mold and toxin to Laos and Cambodia
1995	Aum Shinrikyo terror, Japan
2001	Al-Quaeda used the bacteria of anthrax to USA

2.2 CBR Agents

Like explosive threats, CBR threats may be delivered externally by missiles and other weapons. There may not be an official or obvious warning prior to a CBR attack. These CBR attacks are used to produce death, injury, temporary incapacitation, or irritating effects. CBR attacks are categorized by three agents.

(1) Chemical Agent

Chemical agents can be liquid, gas, or aerosol at standard conditions. Most of the toxic chemical agents are liquids, which evaporate at differing rates to produce vapor. Chemical agents produce immediate effects, unlike biological or radiological agents. Their effects occur mainly through inhalation, although they can also cause injury to the eyes and skin. Chemical agents are classified as Table 2-2.

Table 2-2 Type and Effects of Chemical Agents

Type	Effects	Contents
Nerve Agent	Difficulty in breathing, Muscle spasm	GA, GB, VX
Suffocative Agent	Making trouble at the cell of lung	CG, DP, PS
Blood Agent	Blocks the oxygen-carrying hemoglobin.	AC, CK, SA
Blister Agent	Making blister on skin	H, HD, HT

(2) Biological Agent

Biological agents are organisms or toxins that can kill or incapacitate people and livestock, and destroy crops. The three basic groups of biological agents are bacteria, viruses, and toxins. Some of them produce poisons in food or water, and the poison causes disease after the victim eats or drinks it. Biological agents are classified as Table 2-3.

Table 2-3 Type and Effects of Biological Agents

Type	Contagious	Infection Way	Incubation period	Lethality
Pest	Strong	Inhalation, Insect	2-3 days	90-100 %
Smallpox	Strong	Inhalation	7-17 days	1-30 %
Tularemia	None	Inhalation, Skin	1-21 days	5-10 %
Cholera	Weak	Inhalation, Oral	1-5 days	3-30 %

(3) Radiological Agent

Nuclear weapons produce explosions of great force and heat and release nuclear radiation. Their purpose is the mass destruction of property and people. Their effects are overpressure on human body, burn from heat, nausea and vomiting. The effect of radiological weapons is shown in

Table 2-4.

Table 2-4 Effects of Radiological Weapon

Type	Effects
Heat Radiation (35 %)	Blindness because of strong heat radiation Burn from heat radiation
Bomb blast (50 %)	Collapse from high pressure
Radioactive fallout (14 %)	Radiation wave is scattered
Electromagnetic Wave (1%)	Not operation of electronic product

2.3 CBR Protective Facility

CBR protective facility is a kind of shelter to stay without protective equipment. This facility is normally constructed under the ground because it should stand the attacks of missiles and other weapons. CBR protective facility is classified as 4 grades according to protection level, size and capacity. Table 2-5 indicates the classification of CBR protective facility. Normally, 2nd -4th grade of CBR protective facility is only used for civil defense, and 1st level of CBR protective facility is constructed for military purpose.

Table 2-5 Classification of CBR Protective Facility Grade

Grade	Protection Level	Evacuation Area	Facility Type
1st	Nuclear & CBR Missile	Over 660㎡	Military Purpose
2nd	Bomb	-	Tunnel, Subway
3rd	Bomb	-	Underground Shopping Center
4th	Bomb	Over 60㎡	Underground Floor of Building

For military purpose of CBR protective facility, it is necessary to maintain moderate concrete thickness, gas filter, ventilation system, electronic installation and so on. Especially, CBR protective facility has special structure and it is separated by Contamination Control Area, Toxic Free Area and Machine Room.

In ordinary times, CBR protective facility is used for normal military office, but when a CBR warfare emerges, all soldiers from military troop have to go inside this shelter and continue executing their duties.

2.4 Entering Procedures of CBR Protective Facility

When a CBR warfare emerges, a task force team, who exists outside of CBR protective facility, should enter the CBR protective facility quickly. But a task force team is already contaminated from CBR weapons, so it is necessary to get neutralization. Contamination Control Area (CCA) is a place for neutralizing soldiers. Figure 2-1 explains the floor plan of CBR protective Facility. The CCA consists of Equipment Store Area (ESA), Liquid Hazard Area (LHA), Vapor Hazard Area (VHA) and AirLock (AL). Every zone has neutralizing process and a task force team can enter Toxic Free Area (TFA) after them.

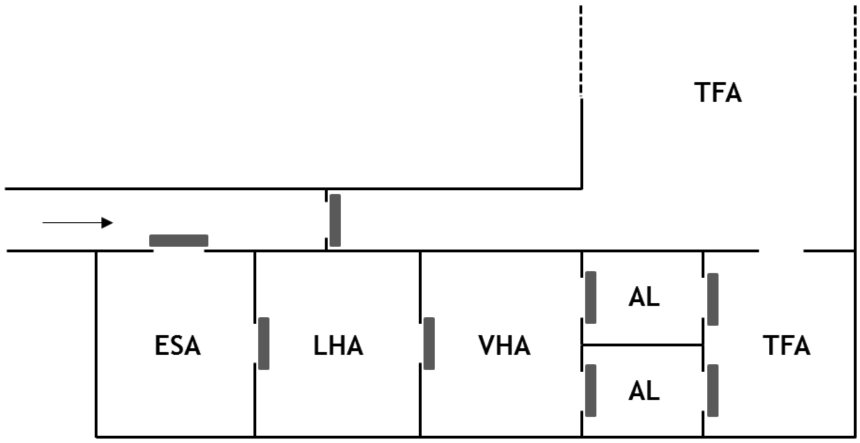


Figure 2-1 Floor Plan of CBR Protective Facility

To maintain its own class of overpressure by each zone, the entrance door should be closed except when soldiers move to another zone. Soldiers who are contaminated by CBR weapons should enter ESA to check the contamination level by using chemical pollution detector. Soldiers can enter LHA when they finish neutralizing individual rifle and combat shoes and discarding their contaminated equipment into trash box. In LHA, they have to discard military uniforms, take a water shower and enter VHA. In VHA, they have to discard their all equipment without gas masks and take a water shower again. Before entering AirLock, soldiers have to stop their breathing and take off gas masks. They have to take an air shower over 3minutes for neutralizing all contaminants on their bodies and move to TFA. Soldiers can receive new clothes after checking their contaminated level again (National Emergency Management Agency 2012).

2.5 Literature Reviews on CBR Protective Facility

As CBR attack occurs more and more over the world, the importance of CBR protective facility is being emphasized. Reviewing the former research, these studies analyzed the characteristic and hazard of CBR weapons and a civil CBR protective facility. But most of the studies are only limited to installation and ventilation system of CBR protective facility due to the specialty of subject. Former researches related to CBR protective facility are listed in Table 2-6.

Table 2-6 Previous Research with CBR Protective Facility

Researcher	Contents
Kowalski et al. (2003)	Presents the results of research on the performance of air-cleaning and air-disinfection systems used for protecting buildings against bioterrorism
Thompson et al. (2008)	Provides a literature survey of four subject areas dealing with the risk analysis of bioterrorism
Nakano et al. (2009)	Presents the methodology to assess building designs for protection against chemical and biological threats
Kim (2011)	Proposes some suggestions to improve efficiency through analyzing problems and surveying professionals
NEMA (2009)	Analyzes the necessity of CBR protective facility and provides reinforcement work for the existing facilities
NEMA (2011)	Make a standard model of emergency CBR protective facility for private citizen.
NEMA (2012)	Proposes the manual of civil defense equipment of CBR warfare
Sim & Hwang (2003)	Describes the air conditioning system of CBR protective facility

In the early stage, many researchers analyzed the hazard of CBR weapons and damage to buildings and suggested the necessity of CBR protective facility.

Kowalski (2003) used public-domain multizone-network airflow-modeling software to evaluate the performance of air cleaning components for protecting occupants against the release of biological weapons. This research indicated that high levels of protection are possible for building occupants with moderate levels of air cleaning when filtration is combined with ultraviolet irradiation.

Thompson (2008) provided a literature survey of four subject areas dealing with the risk analysis of bioterrorism applied to buildings: (1) perception of the risk of bioterrorism; (2) risk analysis of bioterrorism; (3) risk management of bioterrorism risks; and (4) risk communication of bioterrorism risks.

Nakano (2009) proposed a methodology to provide decision makers with the ability to assess multiple building designs for protection against an internal chemical and biological release. This methodology included modeling and simulation of chemical and biological contaminant dispersion, a quantitative means to calculate a building's protection level, and a weighted sum, multiple objective optimization for design selection.

N.E.M.A (National Emergency Management Agency 2009, 2011, 2012) analyzed the necessity of CBR protective facility and suggested improvements for design plan. It also provided a standard model of CBR protective facility for private citizen and the manual of civil defense equipment against CBR warfare.

Sim (2003) described the principle of air conditioning system and operation of CBR protective facility. It also indicated the required performance of other equipment and calculated the ventilation rate.

Kim (2011) proposed suggestions through analyzing problems and surveying field professionals and a general group. But, it only described operation skill and education of management, so it didn't include the real entering time which is the most important consideration of CBR protective facility.

To sum up, previous studies focused on hazard of CBR weapons and method to assess the functionality of anti-bio terrorism. Also, some of them conducted with civil CBR protective facility.

Unlike normal buildings, CBR protective facility has different consideration because of its own functionality of structure. Among the several factors, time is the most important influence to CBR protective facility. If it takes too much time to enter CBR protective facility, only few person can get neutralizing and save its lives. Thus, this research applied the time as an important variable which highly impacts the efficiency of CBR protective facility.

This study conducted comparison with real estimation data and simulation result. Through this study, construction manager and military expert can anticipate the influence of time to the CBR protective facility operation.

2.6 Discrete Event Simulation

Computer Simulation is a method to understand the characteristic actualities by making a similar model. It is divided into static system and dynamic system. Static system changes only at certain time but dynamic system changes with time simultaneously.

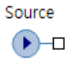
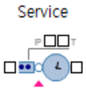
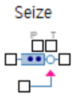
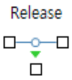
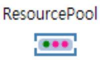
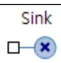
In the dynamic system, it is also classified continuous system and discrete time system. The continuous system changes simultaneously without any points and discrete time system is modified at a given point (Banks 2001). Among these systems, the discrete time system is used when the system model is clearly separated in state modification (Kim 1995)

This research only deals with military person who are fully aware of information and procedures to the exclusion of decision making, emotion and behavior. It assumes that they have to follow the preprogrammed procedures inside CBR protective facility. Therefore, this research is appropriate for discrete event simulation.

The AnyLogic7 program, which was developed by AnyLogic Company, makes it possible to deal with the principle of operating CBR protective facility. It can also control and check the simulation initial time, finish time, and total simulation time.

This study applied AnyLogic to estimate the entering time. According to this method, CBR protective facility entering time estimation model was developed to predict entering time and indicate the influence of variables in CBR protective facility.

Table 2-7 AnyLogic Modeling Element

Diagram	Title	Contents
	Source	It generates entities and it is usually a starting point of a process model
	Service	It seizes a given number of resource units, delays the entity, and releases the seized units
	Seize	It seizes a given number of resource units from a given resourcepool
	Release	It releases a given number of resource units previously seized from a given resourcepool by seize object
	Link	The stream of work process
	Resource Pool	It defines a set of resource units that can be seized and released by entities
	Sink	It disposes entities and it is usually an end point in a process model

2.7 Summary

This chapter referenced the preliminary study of CBR protective facility and research methodology. Even though many researches conducted for CBR protective facility, entering time which represents the efficiency of CBR protective facility is not properly adapted. If bottleneck is occurred through entering progress, the efficiency and functionality of CBR protective facility will decrease as well. Therefore, it needs to consider the time influence when operating and designing the CBR protective facility.

Discrete event simulation was already used in construction field and it is profitable to analyze the complicated problems. Furthermore, AnyLogic has some advantages on modeling CBR protective facility operation with discrete event simulation. With these reasons, this research selected discrete event simulation method to measure the entering time.

Chapter 3. Entering Time Estimating Simulation Model

This chapter discusses the CBR protective facility entering time simulation model. First, procedures performed through CCA and TFA are defined and classified. Secondly, simulation conditions and model developing process are demonstrated. Finally, the simulation model is verified with real data.

3.1 Analysis of Entering Process

Entering procedures performed at CCA and TFA are defined and classified by interview with a military expert and observation of soldiers' behavior. All procedures are classified as the characteristic of behavior; Movement, Control, Neutralization. Movement is the act of changing location from one place to another inside CCA and TFA (e.g. Enter into ESA, Move to equipment storage). Control is the classification of managing or exerting soldiers' activities by CBR protective facility operator (e.g. Measure contamination level by detector, Arrange the equipment). Neutralization is the act of making soldiers chemically neutral (e.g. Water shower, Air shower). The total procedure performed at CBR protective facility is defined and classified in Table 3-1.

Table 3-1 Procedures Performed through CCA and TFA

Zone	Activity	Procedure	Classification
ESA	1	Door opening (ESA)	Control
	2	Enter into ESA	Movement
	3	Measure contamination level	Control
	4	Move to combat shoe washer	Movement
	5	Neutralize the combat shoe cover	Neutralization
	6	Move to equipment storage	Movement
	7	Arrange the equipment	Control
	8	Move to trash box	Movement
	9	Discard contaminated equipment	Neutralization
	10	Move in front of the door to LHA	Movement
LHA	11	Door opening (LHA)	Control
	12	Enter into LHA	Movement
	13	Move to shower room	Movement
	14	Water shower	Neutralization
	15	Move to trash box	Movement
	16	Discard contaminated equipment	Neutralization
	17	Move in front of the door to VHA	Movement
VHA	18	Door opening (VHA)	Control
	19	Enter into VHA	Movement
	20	Move to trash box	Movement
	21	Discard contaminated equipment	Neutralization
	22	Move to shower room	Movement
	23	Water shower	Neutralization
	24	Dry wetness	Neutralization
	25	Move to gas mask storage	Movement
	26	Desorb gas mask & Stop breathing	Control
	27	Move in front of the door to AirLock	Movement

Zone	Activity	Procedure	Classification
AL	28	Door opening (AL)	Control
	29	Enter into AirLock	Movement
	30	Set the timer	Neutralization
	31	Air Shower	Neutralization
	32	Door opening (TFA)	Control
TFA	33	Enter into TFA	Movement
	34	Measure contamination	Control
	35	Move to clothes storage	Movement
	36	Wear clothes	Neutralization
	37	Come out from TFA	Movement

3.2 Simulation Model Development

(1) Simulation Condition

To estimate the entering time through simulation, this study configured simulation conditions as following;

1) Person who enters CBR protective facility is fully aware of total procedures and information through enough training.
2) There are no difference of physical and mental conditions on each person who enters CBR protective facility.
3) Person who finishes all procedures on each zone can move to next zone if there is an empty space (M.N.D 2012)

(2) Simulation Model Development

A Marine CBR protective facility, located in South Korea, was selected as the research CBR protective facility. Procedures performed at CCA and TFA were checked and monitored at this Marine CBR protective facility. The floor plan and structure of this Marine CBR protective facility was similar to the design standard described at 'National Defense Military Facility Design Criteria'. Table 3-2 shows the information of Marine CBR protective facility.

Table 3-2 CBR Protective Facility Outline

Index	Contents
Location	Hwaseong-si, Gyeonggi-do, South Korea
Military Type	Marine
Facility Area	XXX (㎡)
Facility Story	The second basement
Structure Type	Reinforced Concrete
Facility Capacity	YYY (persons)

Two military soldiers performed entering progress twice and time was also measured at the same time. The time was adapted to each event by calculating triangular distribution. The triangular distribution is typically used as a subjective description of a population for which there is only limited sample data.

Figure 3-1 explains the basic structure of simulation model. The modeling source, Source, generates entities and it is usually a starting point of a process model. In this model, Source can be represented by military soldiers and it controls the entry of soldiers. Modeling source, Sink, disposes entities and it is usually an end point in a process model.

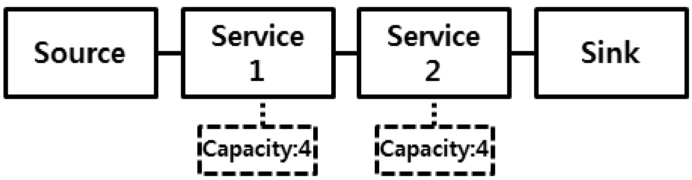


Figure 3-1 Basic Structure of Simulation Model

Figure 3-2 explains the principle of order and stream of procedures. Each procedure is represented by modeling source, Service, and each Service has its own ResourcePool which has the limitation of capacity and required time. For example, the maximum capacity of Procedure #13 (Move to shower room) is four because of the space limitation. The maximum capacity of Procedure #14 (Water shower) is two because of equipment limitation. In this case, two soldiers who already finished procedure #13 have to wait for a while because there is no space for executing procedure #14.

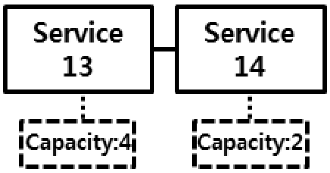


Figure 3-2 The Principle of Simulation Model

Figure 3-3 explains the principle of control between each zone in CCA and TFA. Every zone has its own capacity, in the same way that service. For example, the modeling source, Seize_ESA, controls the total number of soldiers who are executing procedure #1 and #2 cannot exceed the capacity of zone ESA. If a soldier finishes all procedures of ESA, the modeling source, Release_ESA, allows a soldier to move to LHA.

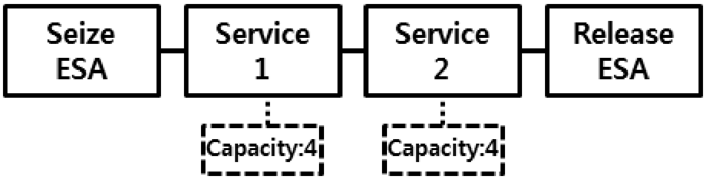


Figure 3-3 The Principle of Controlling Soldier's Entry

Following to these principles, all 37 procedures performed through CCA and TFA are represented as modeling sources, Service, and they have their own space and equipment limitations. Furthermore, movement between each zone is also controlled by modeling source, Seize and Release. According to these principles, CBR protective facility entering time estimation simulation model is made by AnyLogic, and it is shown in Figure 3-4.

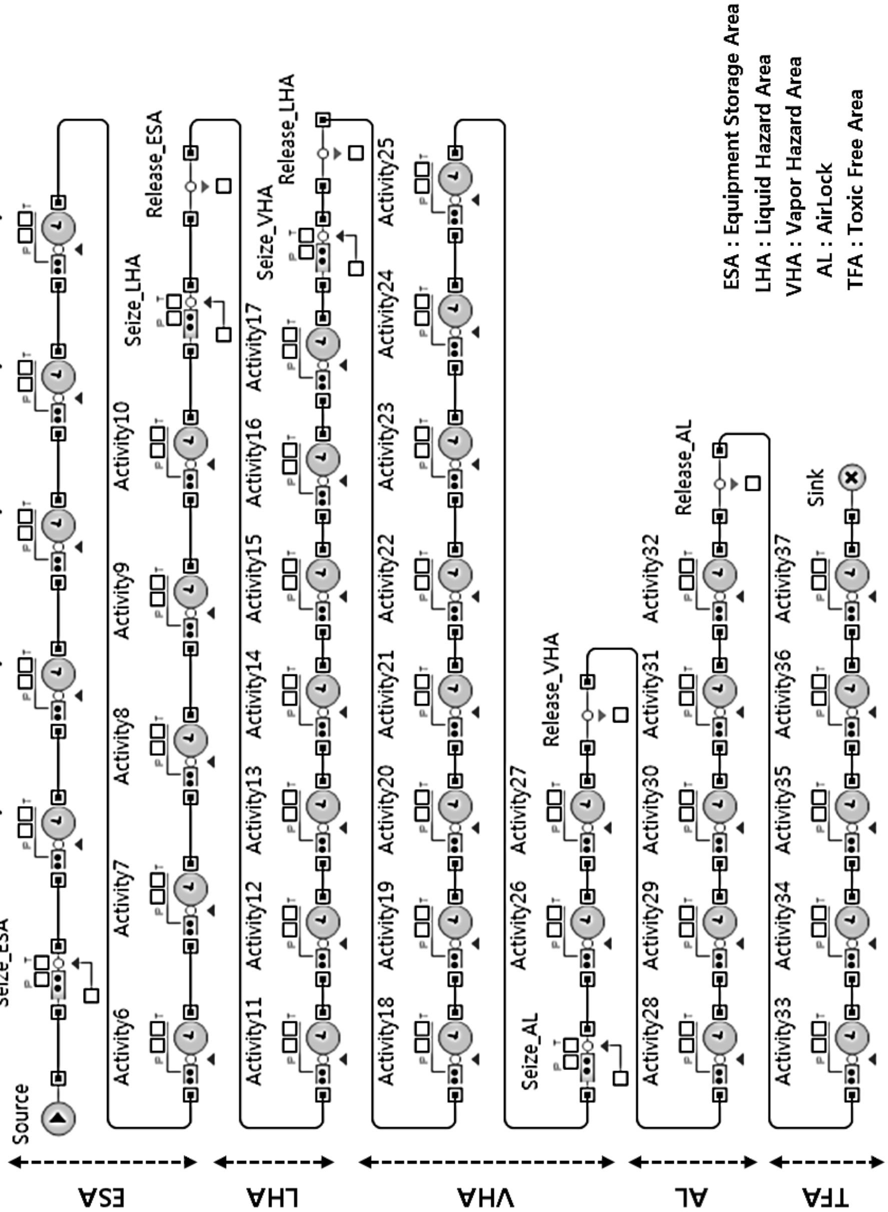


Figure 3-4 Entering Time Estimating Simulation Model

3.3 Simulation Result

The simulation was performed 100 times for each person. To absorb the fluctuation, the average values of simulation results were used to analyze. In this simulation result, the total entering time for two soldiers was 682.7 seconds and it had a similar result with real estimation data (680 seconds). According to military expert, when a CBR warfare emerges, the minimum number of task force team is 20. In this result, it took 2619.7 seconds for 20 soldiers to complete all procedures and enter to TFA. Figure 3-5 and Table 3-3 represented the simulation result of 20 soldiers.

Unit : sec

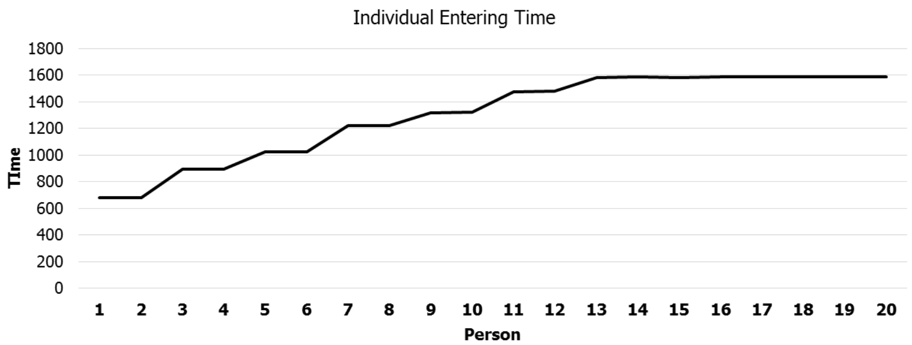


Figure 3-5 Entering Time Simulation Result

Table 3-3 Entering Time Simulation Result

Unit : sec

Person	Start Time	Finish Time	Duration
1	0.0	678.5	678.5
2	0.0	682.7	682.7
3	0.0	893.0	893.0
4	0.0	897.2	897.2
5	86.8	1108.8	1021.9
6	87.8	1114.0	1026.3
7	104.3	1323.5	1219.2
8	108.1	1328.9	1220.8
9	219.9	1537.9	1317.9
10	220.8	1544.1	1323.3
11	280.1	1753.7	1473.6
12	280.5	1759.5	1479.0
13	385.3	1968.3	1583.0
14	386.9	1974.9	1588.0
15	599.1	2183.7	1584.6
16	602.1	2189.9	1587.8
17	814.1	2399.6	1585.5
18	817.5	2404.6	1587.1
19	1029.5	2614.9	1585.5
20	1032.3	2619.7	1587.4

For initial entry, it took near 680seconds to finish their total progress, but more and more time was required near the end. Through this simulation, bottleneck was demonstrated during entering progress. Therefore, to find the place and reason of bottleneck, Time of delay between each procedure was analyzed. Time of delay means the period that a soldier should wait for the next procedure.

As the result of analysis, time of delay between each procedures is shown in Table 3-4.

Table 3-4 Delay Time between Procedures

Unit : sec

Procedure	Delay Time	Procedure	Delay Time
1	0	18	0
2	0	19	0
3	1.66	20	0
4	0	21	0
5	0	22	0
6	0	23	0.07
7	0	24	0
8	0	25	0
9	0.26	26	0
10	0	27	0
11	0	28-32 (AirLock)	226.40
12	0	33	0
13	0	34	0
14	4.17	35	0
15	0	36	0
16	0	37	0
17	0		

Analyzing the delay between procedures, most of all activities are progressed without delay, but procedure #28-#32 and #14 make a huge delay. This is because that the capacity of AirLock is only one, so that only one soldier can enter AirLock (#28-#32) and neutralize inside it. Furthermore, it takes over 180 seconds of purging time to neutralize by Air-shower but there is no consideration of design on AirLock system on the present condition. It is described that the requirement of AirLock is only two at the design book of CBR protective facility. Therefore, it is analyzed that the present design criteria causes the decrease of efficiency and functionality of CBR protective facility.

3.4 Summary

This chapter introduced the principle of entering CBR protective facility, developed a simulation model and analyzed the simulation result. Also, real estimation data is used to validate the simulation model. Through the simulation, it proved the bottleneck of CBR protective facility, and it means the decrease of efficiency of CBR protective facility.

This research analyzed the reason of bottleneck and the entering progress was delayed by insufficient AirLock installation to meet the required performance. As a result, it is necessary for establishing more AirLock inside CBR protective facility.

Chapter 4. Simulation Model Experiment

In this chapter, this research performed several experiments and suggested improvements to relieve bottleneck and to increase the efficiency of CBR protective facility. Also it demonstrated the significance of research and application.

4.1 Experiment Plans of Simulation Model

To find the specific variables which definitely affect the total simulation result, this study adjusts each variable while other conditions are fixed. As a result of base case, there was a big delay on procedure #28-32 and #14. Considering this result, AirLock and Shower room are chosen as main variables and experiment plans are listed with the change of these two variables.

Table 4-1 represented the experiment plans of simulation model.

Table 4-1 Experiment Plans of Simulation Model

Case	# of Shower Room	# of AirLock
Base	2	2
A	2	3
B	3	2
A+B	3	3
C	2	4

According to the design book of ‘National Defense Military Facility Design Criteria’, each number of AirLock and Shower room is two. For case A, increase the number of AirLock from 2 to 3. For case B, increase the number of Shower room from 2 to 3. For case A+B, to analyze the interaction of each variable, increase the number of Shower room and AirLock from 2 to 3 together. For case C, increase the number of AirLock from 2 to 4.

4.2 Simulation Results of Experiment

Figure 4-1 indicates the gap of base case and experiments for the result. Table 4-2 explains the delay time between procedures of experiments and Table 4-3 represents the simulation result of experiments.

Unit : sec

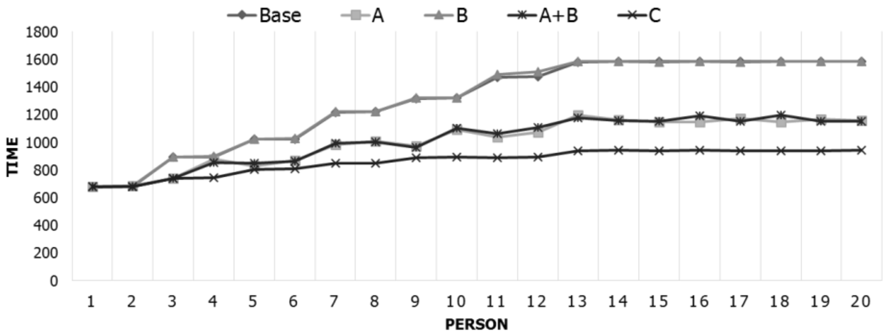


Figure 4-1 Entering Time Simulation Result by Experiments

Table 4-2 Delay Time Changes by Experiments

Unit : sec

Case	Water Shower(#14)	AirLock(#28-32)
Base	4.17	226.40
A	4.33	100.19
B	1.89	226.43
A+B	1.89	100.71
C	4.17	49.36

Table 4-3 Simulation Result by Experiments

Unit : sec, %

Person		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th	Total Time	Avg. Time
Base		678.5	682.7	893.0	897.2	1021.9	1026.3	1219.2	1220.8	1317.9	1323.3	1473.6	1479.0	1583.0	1588.0	1584.6	1587.8	1585.5	1587.1	1585.5	1587.4	2619.7	1296.1
A		680.4	683.9	742.8	878.2	828.7	869.5	982.1	1006.8	975.3	1092.5	1040.8	1075.8	1196.7	1162.6	1147.9	1148.7	1173.1	1147.9	1168.9	1157	1975.4	1007.9
		100.3	100.2	83.2	97.9	81.1	84.7	80.6	82.5	74.0	82.6	70.6	72.7	75.6	73.2	72.4	72.3	74.0	72.3	73.7	72.9	75.4	77.7
B		681.3	685.6	896.4	900.7	1023.0	1027.3	1222.4	1223.3	1320.2	1324.7	1491.3	1509.1	1584.5	1587.1	1583.4	1585.0	1582.9	1586.3	1583.6	1584.8	2620.2	1291.1
		100.4	100.4	100.4	100.4	100.1	100.1	100.3	100.2	100.2	100.1	101.2	102.0	100.1	99.9	99.9	99.8	99.8	99.9	99.9	99.8	100.0	100.2
A + B		679.6	682.7	739.9	855.2	849.6	866.2	992.8	1004.7	962.1	1104.6	1065.7	1107.7	1176.1	1156.9	1153.0	1194.9	1155.1	1194.9	1153.2	1155.9	1972.7	1012.7
		100.2	100.0	82.9	95.3	83.1	84.4	81.4	82.3	73.0	83.5	72.3	74.9	74.3	72.9	72.8	75.3	72.9	75.6	72.7	72.8	75.3	78.1
C		680.1	683.5	741.7	744.9	807.2	811.6	852.3	851.7	889.8	892.5	890.7	894.2	939.1	942.2	939.7	942.3	937.8	942.0	939.6	943.0	1606.5	863.2
		100.2	100.1	83.1	83.0	79.0	79.1	69.9	69.8	67.5	67.4	60.4	60.5	59.3	59.3	59.3	59.3	59.1	59.4	59.3	59.4	61.3	66.6

(1) Analysis of Experiment A

By comparing the simulation result of experiment A with base case, there were no changes in delay time on water shower (#14), but the delay time of AirLock (#28-32) remarkably decreased from 226.40 seconds to 100.19 seconds. As a result, it took a total of 1975.4 seconds for 20 soldiers (Task force team) to enter the CBR protective facility. The result was a decrease of 644.3 seconds (reducing effect of 24.6%) compared to the base case. Also, the average time for an individual to enter decreased from 1296.1 seconds to 1007.9 seconds, a 22.3% reducing effect. According to the analysis of the simulation result of experiment A, the delay time of AirLock (#28-32) was chosen as the variable which had the largest effect on the time to enter the CBR protective facility. Therefore, if more AirLock is established, the bottleneck can be relieved, increasing the efficiency of CBR protective facility because it can neutralize more soldiers within the same duration.

(2) Analysis of Experiment B

By comparing the simulation result of experiment B with base case, there were no changes in delay time on AirLock (#28-32), but the delay time of water shower (#14) decrease from 4.17 seconds to 1.89 seconds. As a result, it took a total of 2620.2 seconds for 20 soldiers to enter the CBR protective facility. It is shown that there was no difference between base case and experiment B. Also, the average time for an individual to enter was same result with base case. According to the analysis of the simulation result of experiment B, water shower (#14) was not a variable to affect the total entering time of CBR protective facility. Therefore, it can be inferred that procedure # 3, # 9, # 23 do not affect the total entering time because the delay time of procedure # 3, # 9, # 23 are smaller than procedure #14.

(3) Analysis of Experiment A+B

By comparing the simulation result of experiment A+B with base case, the delay time of AirLock (#28-32) eminently decreased from 226.40 seconds to 100.71 seconds. Also, the delay time of water shower (#14) decrease to 1.89 seconds. As a result, it took a total of 1972.7 seconds for 20 soldiers to enter the CBR protective facility. According to the analysis of the simulation result of experiment A+B, it had similar result with case A. Therefore, it can be inferred that the variable AirLock (#28-32) and water shower (#14) don't affect each other, and they are independent variables.

(4) Analysis of Experiment C

By comparing the simulation result of experiment C with base case, there were no changes in delay time on water shower (#14), but the delay time of AirLock (#28-32) dramatically decreased from 226.40 seconds to 48.36 seconds. As a result, it took a total of 1606.5 seconds for 20 soldiers to enter the CBR protective facility. The result was a decrease of 1013.2 seconds (reducing effect of 38.7%) compared to the base case. Also, the average time for an individual to enter decreased from 1296.1 seconds to 863.2 seconds, a

33.4% reducing effect. According to the analysis of the simulation result of experiment C, if more than two AirLocks are established, the present problem can be relieved with increasing the efficiency of CBR protective facility.

4.3 Summary

In chapter 4, to solve the present problem of CBR protective facility and increase the efficiency of facility, experiments were performed and improvements were suggested. The result of experiment was approved that the number of AirLock (#28-32) is the most important variable to affect the entering time of CBR protective facility. According to the simulation result, if one more AirLock is established, 24.6% of time reducing effect is deduced. If two more AirLocks are established, it shows 38.7% of time reducing effect. Therefore, it is necessary to consider the number and floor space of AirLock on design phase of CBR protective facility, the efficiency of CBR protective facility can be increased by reducing the entering time.

Chapter 5. Conclusion

As CBR (Chemical, Biological, and Radiological) attack increases, the importance of CBR protective facility is being emphasized. When the CBR warfare emerges, a task force team, who exists outside of CBR protective facility should enter the CBR protective facility quickly. Therefore, it is necessary to forecast the entering time accurately and set up a design plan of CBR protective facility with considering it. But, the present design plan of CBR protective facility is only limited to installation and ventilation system such as ventilation and air conditioning system, so it doesn't consider how much time it takes to enter the CBR protective facility.

5.1 Research Result

(1) Analysis of Entering Process of CBR Protective Facility

To solve the bottleneck in the CBR protective facility, site inspection and expert interview were carried out and figured out the principle of operation of CBR protective facility. After understanding the principle of operation, procedures performed at CCA and TFA are defined and classified as the characteristic of behavior.

(2) Proposed Entering Time Estimating Simulation Model

This research presents the CBR protective facility entering time estimation model with AnyLogic which is the one of the discrete event simulation programs. Unlike other researches, this study considered time influence in the operation of CBR protective facility. Developed simulation model can find the cause of the bottleneck and derive variables which affect to entering time of total procedures.

(3) Improvements for the Efficiency of CBR Protective Facility

In order to relieve the bottleneck and improve the efficiency of CBR protective facility, this research deduced the variables of delay and conducted experiments by adjusting variables. According to analysis, the present condition of design plan is insufficient for its own performance. Therefore, it is necessary to establish more AirLock comparing to present condition. Also, CBR protective facility manager and designer can use this simulation model for the basic decision making tool related with CBR protective facility.

5.2 Contribution

The contribution of this research could be summarized as follows.

1) Using the suggested model in this research, the understanding of the functionality and efficiency in construction and operation of CBR protective facility and time factors could be validated.
2) The relation between entering time and improvement of efficiency of CBR protective facility is clearly defined in this research and it could suggest that the importance of considering time factor in CBR protective facility.
3) It is possible to estimate accurate entering time of CBR protective facility and it is helpful for engineers and managers to plan facility operation in a more realistic approach during the design phase.
4) With proposed CBR protective facility entering time estimation simulation model, this research can be applied to a CBR protective facility management tool in new and various types of facility. This model can be applied to civil CBR protective facility by changing the feature, floor plan, procedure and so on. Also, it can be developed to other research field like evacuation from disaster and fire.

5.3 Limitation and Future Study

This research has not fully validated with possible time gap from different installations, equipment and character. Therefore, this research required more verification with more usual adaptation. Also, this research is only limited to military CBR protective facility. However, civil CBR protective facility has different characteristics by different design plan and surroundings. Therefore, the effort of understanding civil CBR protective facility is essential to widen the scope of application.

In the further study, it is necessary to increase the accuracy and usability of CBR protective facility entering time estimation simulation model.

Appendices

Appendix A. Terms

Appendix B. Simulation Report

Appendix A. Terms

***Advance warning :**
an event, such as a credible warning or a warning under elevated threat conditions, that initiates operational actions to take to enhance protection

***Agent :**
a substance in the form of a toxic industrial chemical or material, biological or radiological agent, or military chemical, which together with the delivery tactic is a type of threat

***CBR event :**
an airborne release involving a CBR agent and caused by an industrial accident or an intentional release either external or internal to the facility

***Class of overpressure :**
an overpressure range or goal that is established based on the anticipated duration of a CBR event, the value of assets in a facility, and the facility's emergency operation procedures

***Collective protection :**
provision of a contaminant-free area where people can function without individual protective equipment such as a mask and protective garments

***Contamination control area :**
an area where people can safely remove contaminated individual protective equipment, and bring items into or out of a protective area in a proper airflow environment using the appropriate contamination control procedures

***Purge time :**
the period of time during which the unoccupied airlock is purged of toxic vapor after both airlock access doors have been closed

***Threat :**
aggressors, delivery tactics, and associated weapons, tools or explosives against which a facility is protected

***Toxins :**
metabolic by products of living organisms that are classified as biological agents even though they are nonliving substances

***AirLock :**

AirLocks are used in facilities with a high level of protection, where an overpressure must be maintained during operations（U.S. Department of Defense 2008). AirLocks serve the purpose of allowing entry and exit without a substantial exchange of air through open doorways. To allow entry or exit processing, an AirLock maintains a pressure differential continuously in the room or building that is protected, isolated, or controlled.

To prevent the direct transport of airborne contaminants through the AirLock, people must pause in the AirLock for a purging period during entry or exit. However, this purging alone does not prevent the transport of contamination through the AirLock. This is normally achieved by removing or neutralizing contaminants before entering the AirLock or while in the AirLock and by showering.

AirLock pressure is less positive than in the protective area and more positive than in the unprotected area. Airflow is from the protective area through the AirLock to the unprotected area. The AirLock is shown in Figure A-1.

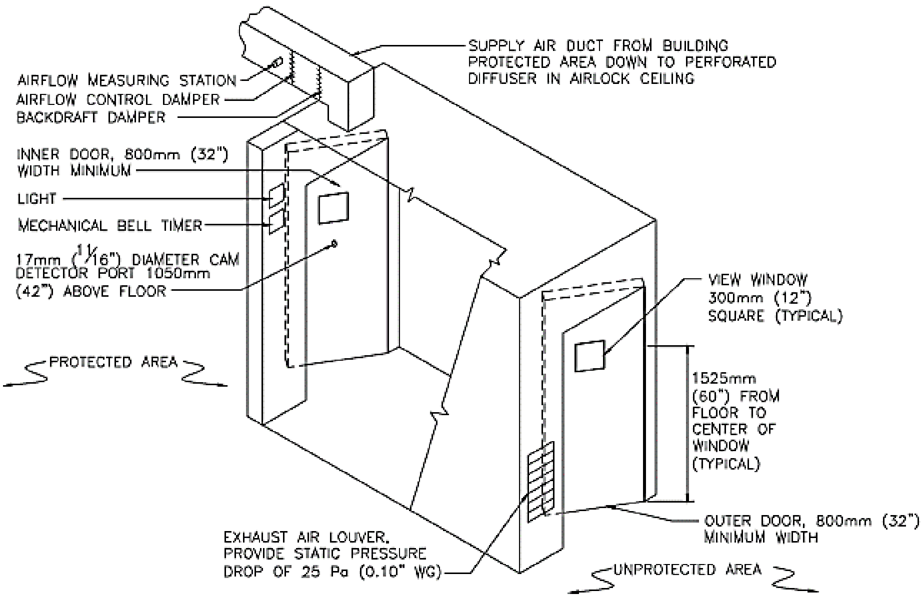


Figure A-1 Details of AirLock (U.S. Department of Defense 2008)

Processing procedures are the responsibility of the command authority. Table A-1 explains the procedures of AirLock ingress.

Table A-1 AirLock Ingress Processing Procedures

Order	Description
1	Before entering the AirLock, ensure that air is being discharged from the purge vents. Perform a thorough check with detector to ensure that there is no liquid contamination on body or equipment.
2	Look through the window to ensure that the AirLock is unoccupied. Enter the AirLock.
3	After entering the AirLock, remove all equipment left from the previous in-processing group. Set the timer for a 3-minute purge time.
4	When the purge time is complete, person in the Toxic Free Area should check the AirLock with a chemical agent monitor to ensure that contaminants have been sufficiently removed. Enter the Toxic Free Area.

Appendix B. Simulation Report

Entering Time Simulation Result
: **Base Case** (#of AirLock : 2, #of Shower Room : 2)

Person	Start Time	Finish Time	Duration
1	0.0	678.5	678.5
2	0.0	682.7	682.7
3	0.0	893.0	893.0
4	0.0	897.2	897.2
5	86.8	1108.8	1021.9
6	87.8	1114.0	1026.3
7	104.3	1323.5	1219.2
8	108.1	1328.9	1220.8
9	219.9	1537.9	1317.9
10	220.8	1544.1	1323.3
11	280.1	1753.7	1473.6
12	280.5	1759.5	1479.0
13	385.3	1968.3	1583.0
14	386.9	1974.9	1588.0
15	599.1	2183.7	1584.6
16	602.1	2189.9	1587.8
17	814.1	2399.6	1585.5
18	817.5	2404.6	1587.1
19	1029.5	2614.9	1585.5
20	1032.3	2619.7	1587.4

Entering Time Simulation Result
: **Experiment A** (#of AirLock : 3, #of Shower Room : 2)

Person	Start Time	Finish Time	Duration
1	0.0	680.4	680.4
2	0.0	683.9	683.9
3	0.0	742.8	742.8
4	17.5	895.7	878.2
5	69.8	898.5	828.7
6	88.2	957.7	869.5
7	128.3	1110.4	982.1
8	107.8	1114.6	1006.8
9	197.4	1172.7	975.3
10	233.3	1325.8	1092.5
11	289.4	1330.3	1040.8
12	313.5	1389.3	1075.8
13	343.6	1540.4	1196.7
14	383.4	1546.1	1162.6
15	455.7	1603.7	1147.9
16	606.8	1755.5	1148.7
17	587.7	1760.8	1173.1
18	671.3	1818.4	1147.0
19	800.7	1969.6	1168.9
20	818.4	1975.4	1157.0

Entering Time Simulation Result
: **Experiment B** (#of AirLock : 2, #of Shower Room : 3)

Person	Start Time	Finish Time	Duration
1	0.0	681.3	681.3
2	0.0	685.6	685.6
3	0.0	896.4	896.4
4	0.0	900.7	900.7
5	87.7	1110.7	1023.0
6	88.0	1115.3	1027.3
7	104.1	1326.5	1222.4
8	107.9	1331.2	1223.3
9	220.5	1540.7	1320.2
10	222.0	1546.6	1324.7
11	245.7	1754.8	1509.1
12	270.3	1761.6	1491.3
13	386.0	1970.5	1584.5
14	389.6	1976.7	1587.1
15	601.9	2185.3	1583.4
16	605.9	2190.9	1585.0
17	817.2	2400.1	1582.9
18	820.0	2406.4	1586.3
19	1031.7	2615.4	1583.6
20	1035.4	2620.2	1584.8

Entering Time Simulation Result
: **Experiment A+B** (#of AirLock : 3, #of Shower Room : 3)

Person	Start Time	Finish Time	Duration
1	0.0	679.6	679.6
2	0.0	682.7	682.7
3	0.0	739.9	739.9
4	0.0	895.5	895.5
5	87.6	896.9	809.3
6	87.8	954.0	866.2
7	105.4	1110.1	1004.7
8	120.6	1113.4	992.8
9	207.9	1170.0	962.1
10	220.3	1324.9	1104.6
11	262.8	1328.4	1065.7
12	277.4	1385.1	1107.7
13	363.4	1539.5	1176.1
14	386.8	1543.7	1156.9
15	446.3	1599.2	1153.0
16	558.4	1753.4	1194.9
17	603.5	1758.6	1155.1
18	614.1	1813.5	1199.4
19	815.6	1968.7	1153.2
20	816.9	1972.8	1155.9

Entering Time Simulation Result
: **Experiment C** (#of AirLock : 4, #of Shower Room : 2)

Person	Start Time	Finish Time	Duration
1	0.0	680.1	680.1
2	0.0	683.5	683.5
3	0.0	741.7	741.7
4	0.0	744.9	744.9
5	87.6	894.8	807.2
6	87.8	899.4	811.6
7	104.5	956.8	852.3
8	108.6	960.2	851.7
9	220.1	1110.0	889.8
10	221.3	1113.8	892.5
11	280.9	1171.6	890.7
12	281.3	1175.5	894.2
13	386.3	1325.4	939.1
14	387.0	1329.2	942.2
15	447.6	1387.3	939.7
16	448.5	1390.8	942.3
17	600.8	1538.7	937.8
18	602.4	1544.4	942.0
19	662.4	1602.0	939.6
20	663.5	1606.6	943.0

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국 문 초 록

최근 화생방 공격에 대한 위협이 증가함에 따라 화생방 방호시설의 중요성이 강조되고 있다. 화생방전 발생 시 화생방 방호시설 외부에 있는 작전인원은 화생방 방호시설 내 오염통제구역 및 무해구역에서 제독과정을 거쳐 방호시설 내부로 진입하게 된다. 이 과정에서 부족한 설비 등으로 인해 특정 절차 및 구역에서 병목현상이 발생할 경우 작전인원은 제시간에 방호시설 내로 진입 할 수 없게 되며, 이는 전시 작전 수행의 효율성 저하뿐만 아니라 큰 인명피해로도 이어지게 된다. 현재의 화생방 방호시설 설계기준은 공조시스템 등 특정 설비에 국한되어 있으며, 실제 화생방전 발생 시 실제 진입 소요시간을 고려한 설계기준이 부재한 실정이다.

본 연구에서는 화생방 방호시설 진입 소요시간에 크게 영향을 미치는 요소를 시뮬레이션에 반영하여 화생방 방호시설 진입 소요시간을 예측하는 시뮬레이션 모델을 개발하였다. 이를 위해 오염통제구역 및 무해구역에서 이루어지는 행동절차를 세분화하고, 각 행동절차에 소요되는 실제 시간을 측정하여 이를 시뮬레이션에 적용하였다. 또한 진입 소요시간에 영향을 미치는 요인들을 선정하여 이들의 조정을 통해 대안을 작성하고 각 대안별 진입

소요시간 및 전체결과에 미치는 영향을 분석하였다. 이 모델은 향후 화생방 방호시설 진입 시뮬레이터의 모듈로써 활용될 수 있으며 방호시설 설계 및 운용자의 의사결정 기초자료로 활용될 수 있다.

주요어: 화생방 방호시설, 진입 소요시간, 시뮬레이션,

행동 절차분석

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