ABSTRACT

PARK, MINHYOUNG. A Research on the Republic of Korea Army Barracks Layout Design to Minimize the Maximum Egress Times Using Evacuation Planning Program (EVACNET) (Under the direction of Thom J. Hodgson).

A prompt evacuation from a military barracks is a crucial factor to preserve soldiers' lives in an emergency situation and to swiftly prepare combat readiness in an enemy surprise attack. The program 'EVACNET' may be the most widely used system to study evacuation time in various building designs. Relatively few studies, however, have been devoted to military barracks design. To present the best layout for military barracks with respect to the minimum evacuation time, three main steps are proposed as follows; First, generate a hypothetical outer building layout with a 'floor area criteria' that is used by the Republic of Korea Army construction design bureau. Second, recommend the best alternative inner room layout in light of the EVACNET results (minimized egress time and evenly usage of the each entrance). Third, derive general conditions for designing the best layout. Following this approach, the best layout for an independent platoon unit barracks is a one-floor double-loaded corridor, and the best option for an independent company unit barracks is a one-floor double-loaded corridor, or a two-floor with double-loaded corridors depending on land site limitations. We also found that a well-balanced allocation of the total initial capacity (number of soldiers housed in a barracks) for each entrance (destination (DS)) is important for reducing congestion. Another feature related to the conditions for the best layout is placing stockpile/maintenance rooms (i.e., rooms containing a large volume of material such as camouflage nets, tents.) as far as possible from the busiest DS. Notably, the busiest DS remains constant regardless of room location changes. It is necessary to consider the space division (block and separation) effect to enhance the area utilization; two adjacent rooms may be used as a larger single room by removing the common wall. This paper also addresses the preliminary results of

the most decisive factor regarding egress time in current barracks layouts. In every case, I found that the most sensitive factor from the EVACNET results is the dynamic capacity (persons / time period) of each DS. Consequently, I recommend an enlargement of door widths to reduce egress time because the dynamic capacity linearly dependent on the width of each door. Other factors do not appear to be as sensitive; such as hallways and stairwells.

A Research on the Republic of Korea Army Barracks Layout Design to Minimize the Maximum Egress Times Using Evacuation Planning Program (EVACNET)

by
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DEDICATION

I would like to thank and dedicate this work to my father, mother and country.

BIOGRAPHY

Minhyoung Park was born on July 21, 1985, in Gyeongju-si, Gyeongsangbuk-do, South Korea as the only child. In 2004, he entered the Republic of Korea Military Academy (KMA) to be an army officer. He received his bachelor's degree in civil engineering from the KMA in 2008. He has worked in an engineer battalion for five years. In August 2013, he joined North Carolina State University to pursue his Master of Science in Industrial Engineering (MSIE).

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1. Introduction

1.1Motivation

The Republic of Korea Army (ROKA) has sustained a local defense system since the end of the Korean War in 1953. This is a result of the intense confrontation with North Korea while the two countries remain in armistice status. In order to build a self-defense system, the ROKA has occupied key regions of the southern Korean Peninsula and kept a close watch to North Korea for suspicious movements. The majority of the facilities used by the ROKA, however, has been worn-down because it has been used over 60 years. For this reason, the ROKA plans to renovate the whole system. The ROKA expects the completion of this project within a decade. This project also related to the refurbishment efforts includes a change in the military unit scales and their locations. Thus, it is necessary to prepare for the renovations.

Figure 1. 1 The ROKA barracks before renovation (left) and after (right)

1.2Problem Description

The construction design bureau of the ROKA provides general criteria regarding building layout, which includes area per person, shape of structure, location of specific rooms, and so on. However, they do not provide the blueprint of every specific case. Since the ROKA does not design building layout itself, they contract third party professionals who have limited knowledge of military operations. The professionals take charge of design, and they must generate the 'best' blueprint in every case. Each case is characterized by land formation, feasible shape of area, unit size, special duties, and so on. Moreover, the professionals have deadlines to furnish blueprints that may limit interactions with end users to obtain their opinions. For this reason, facility users tend to encounter problems such as personnel traffic congestion, uneven use of entrances, and limited accessibility to arms room during combat employment readiness exercises. The main focus of this research is figuring out the egress time of unit personnel in emergency situations. Prompt evacuation time not only saves lives, but also increases the possibility of winning the battle. One of the principles of war says that "*The best way to grasp an initiative is a preemptive attack*," but the ROKA cannot use a preemptive attack due to Korean Constitution. Keeping this in mind, the ROKA evaluates the elapsed time of soldiers egress from their barracks during combat employment readiness exercises. The ROKA officers encourage their soldiers to move faster in order to reduce the elapsed time but hardly consider reducing the time by improving building design.

In this research, we suggest a way of improvement in the current barracks layout for minimizing egress time of a barracks under military combat operations. There are general constraints related to the location of command posts, the clustering similar operational rooms, and the shape of buildings. The location and circulation patterns for other rooms, however, are not considered, "Floor area criteria" [1]. Comments 1-5 explain the missing parts of the inner layout standard presented by the ROKA [1]:

1. The land use plan for vehicle and pedestrian movement is separate (room features

and living disturbance), and should take into account safety and security;

2. The personnel cross-circulation system within the building should be separated by function, and each function should be linked (block and separation);
3. The paths of travel should be coordinated to minimize the cross between the pedestrian and vehicle traffic and each should be correlated;
4. The design should consider ease of movement and congestion control for personnel;
5. The facility should be planned so that the appropriate path of travel is clear for each of the areas and rooms.

The proposed tool in this study can be helpful to the designers in providing guidelines for military barracks layout. This research will demonstrate the best layout for a military barracks in the context of the ROKA. The hypothetical sample case of building layout and optimal evacuation time will be useful for setting criteria for building design. Furthermore, the procedures of this research can be used to facilitate mission plans when a military unit transits to an unfamiliar building.

The three main steps of this research are as follows:

Step 1: Generate a hypothetical outer building layout;

Step 2: Compute the egress time and exit usage of each inner layout;

Step 3: Derive general conditions for the best layout.

2. Literature Review

2.1 Overview

Through literature review, there is a lack of research regarding, military barracks layout, which is concerned with the minimum egress time and entrance usage. It is necessary to review several issues separately as follows: 1) survey the facility layout optimization including military facilities; 2) examine the most recent estimation of evacuation time methodologies; 3) collect layout literature that considers evacuation time optimization.

2.2 General Facility Layout Optimization

Facility layout has an important impact on the overall operational efficiency of the facility, thus the facility layout problem (FLP) is widely studied as a combinatorial optimization problem [2]. The FLP, in general, is more difficult than the quadratic assignment problem (QAP). The QAP considers the problem of assigning equal-sized N departments to N pre-determined centroid locations, Koopmans, TC, Beckman, M [3]. Mathematically the QAP formulation in facility layout design is defined by two matrices of dimension n by n: Let, D = d(ij): the distance from location i to location j; F =f(ij): the flow of materials from facility i to facility j. Exact algorithms for solving the QAP include approaches based on cutting planes [4] and, branch and bound [5, 6]. Between those two, branch and bound algorithms are more successful. However, they are generally unable to solve problems of size larger than N =30 due to computational complexity. Heuristics or suboptimal algorithms are often used to estimate solutions for the QAP. These procedures can produce good answers within reasonable time and effort. Recently, attempts have been made to solve the QAP using heuristics. It addresses construction methods [7]; and limited enumeration methods [8], GRASP [9], simulated annealing [10], tabu search [11], genetic algorithms [12], and ant systems [13]. The QAP-type models, however, are not applicable for FLPs with unequal-sized departments [2].

In general, most work on the FLP has been aimed at finding good layouts using construction and improvement heuristics [14]. A noted exception is the exact mixed integer program (MIP) for the FLP (FLP1), due to Montreuil [15]. This MIP, however, is very difficult to solve problems of size with N = 5, despite the fact that it has 2n(n−1) binary variables. Many researchers have hence attempted to find 'good' feasible solutions to FLP1 by heuristically and then optimizing the resulting linear program (LP) [16-19].

Facility layout problem 2 (FLP2) [2], is a two-dimensional version of the widely-known linear ordering model for single machine scheduling problems. It is based on an acyclic sub graph structure. Some general classes of inequalities have been proposed to improve the LP lower bounds for the problem. Using these inequalities in a branch and-bound algorithm, the FLP2 offers the possibility of solving inequality problems without using a heuristic in the initial step. However, the FLP2 is restricted by CPLEX’s default branching scheme. It requires a profound understanding of the structure, and is essentially impossible to solve for over 25 departments.

2.3 Military Facility Layout Optimization

Not much has been done in a military facility layout optimization; especially in a barracks. There are several reasons for this. First, study can be limited due to military security issues. Second, the facility blueprints for concert hall, dining facility, and library might be similar to the public facility layout. Third, it is hard to get universal applications due to different branch features. However, research on military facility layout, virtual shop clustering for naval repair, and maintenance facilities does exist [20].

This study is based on cellular layout regarding to job shop problem. But, this assumes very specific conditions such as piping, re-threading, and welding jobs. Other approaches related to the military facility improvements are mostly about energy savings. A study for improving energy performance of Army dining facilities [21] offers the insight for the military facilities' problems although the study is based on simulation using 'Energy Plus Version 2.1 (DOE 2008)' is not helpful for this research. Deru, Michael, et al said, "Existing army dining facilities were not designed with energy and water efficiency as a primary objective. While minimizing construction cost has always been a goal of facility design [21]. " This definition can be also applied in this study if the word 'dining' changed into a 'barracks'.

2.4Methodologies of Evacuation Time Estimation

There are three major approaches considering evacuation time estimation methodologies; network models, simulation, and fast flow algorithms.

Francis [22, 23] contributed to the basic concept of building evacuation. He developed "EVACNET, " a program based on a network model. It is an interactive computer program that allows the modeling of emergency building evacuations, and the network flow is optimized using the network flow transshipment proposed by White [24]. This model handles a network consisting of a set of nodes connected by arcs. The nodes represent building components such as rooms, hallways, and stairwells. The arcs represent passageways between the objects represented by the nodes such as corridors or passageways. The EVACNET is easy to understand and more straightforward than other programs in this field. Based on network flows, the EVACNET can be easily adapted to military circumstances, and is expandable for other situations, such as the evacuation of vehicles from a parking lot or mobilization mission planning. University of Florida provides this program for free. The program's results can be visualized (i.e., number of evacuees from each egress point and congestion points over time) and run within the Matlab program [25]. For these reasons, the EVACNET program will be used in this study to evaluate the building layout relative to egress time and entrance usage.

Another methodology for evacuation time estimation is 'simulations', such as SIMULEX, EXIT89, EXODUS, SGEM, and EGRESS [26-30]. These models simulate the entire evacuation process and describe the behavior of each evacuee. Most simulation models use a fine network approach [31] such as considered behaviors of evacuees and internal environment of buildings (individual evacuees' situations like velocity and position by each time step). It is close to real environment and makes simulation models being highly accurate. However, it is an excessively time consuming process and does not lend itself to extensive experimental effort. Moreover, these programs are not available to public. Thus, SIMULEX, EXIT89, EXODUS, SGEM, and EGRESS are not used in this study as the universal tool for estimation.

Fast Flow Control Algorithm (FFCA) can be a different option [32]. This method can provide optimal evacuation profiles and make reasonable arrangements of the evacuation routes for each evacuee. In the FFCA, the evacuation problem is simplified and modeled as a multi-narrow door problem. Although the FFCA is appropriate for universal usage, this model is not very accurate and only can be applied to the case of single source node. In other words, when evacuees in a building are scattered in different source nodes, this algorithm is no longer appropriate. Wang and Liu [31] recently modified the FFCA to a recursive methodology to get an optimal evacuation profile. This recursive algorithm has low computational complexity and overcomes the limitation of the FFCA. Furthermore, it can be used in a multiple source-nodes situation. However, the algorithm requires coding in detail, and does not focus on the comparison of layout alternatives. For this reason, the FFCA and recursive algorithm are not used in this research.

2.5Layout Design considered Evacuation Time Optimization

The studies that evaluate layouts based on evacuation times mostly use EVACNET. The EVACNET reduces individual properties and approaches a more universal optimization than simulation programs. "Evacuation Analysis of a Commercial Plaza with Cafe Model" [33], "A Simulation Model for Emergency Evacuation Time of a Library Facility using EVACNET4" [34], and "Optimization Design to Evacuation in Reconstruction or Expansion Project" [35] are the most recent case studies using the "EVACNET".

All those reports use the following procedures;

1) Assume situation and derive related input values
2) Model the facility layout as a network flow model
3) Run and compare each alternative.

3. Problem Design and Experiment Implementation

3.1 Overview

In this chapter, a scenario is created in order to facilitate and justify assumptions of the model. Then, operational procedures within an independent platoon barracks (two floor double loaded corridor layout) are presented. Area data from the "Floor area criteria" is converted into a modular-form layout. All possible layout combinations are identified. Finally, an exhaustive search of inner layout combinations is performed, using EVACNET, in order to choose the best inner layout combination.

3.2 Create Scenario

From the ROKA "Floor area criteria" [1], they present classification of inner layout rooms and specific area per unit by the following criterion (see, Table 3.1).

In this chapter, independent platoon (PLT), which is the smallest unit size, will be explained with the ROKA "Floor area criteria." Other than the PLT unit barracks dealt with this chapter will be discussed in the next chapter following the same procedures. The "Floor area criteria" offers sample data relative to infantry PLT unit barracks that consists of 36 soldiers and 5 cadres (officer and non-commissioned officer). Table 3.2 shows this.

The ready for combat scenario is 1-5 as follows:

1) Enemy activity is distinct, Defense Readiness Condition 3 has been ordered;
2) The entire military unit is 'ready to combat action' (in full gear) and at stand-by at each soldier’s living space;
3) No soldier is disabled and can move individually, not by squad;

4) Each squad members knows the outside assembly point; and

5) Individuals have global situation awareness about the current situation to find their fastest way to the destination.

Table 3.1 "Floor area criteria" of the ROKA for infantry unit barracks

Classification	Room Name	BN	B	CO	PLT
Housing	Living room	O	O	O	O
Administration	Commander's office	O	O	O	O
	Personal office	O	O	O	O
	The staff	O	O	-	-
	Administration room	O	O	O	O
	Conference room	O	-	-	-
	Cadre study room	O	O	O	O
	Sensitive compartmented information facility	O	O	-	-
	Counseling room	O	O	O	O
Operation /Training	Tactical operations center	O	O	-	-
	Communication room	O	O	-	-
	Situation room	-	-	-	O
Sanitary/Meal	Dining facility	-	-	-	O
	latrine	O	O	O	O
	Washroom	O	O	O	O
	Laundry room	O	O	O	O
	Drying room	O	O	O	-
	Shower room	O	O	O	O
	Bathing house	O	O	O	-
	Mud room	O	O	O	O
Medical	Aid station	O	O	-	-
Stockpile /Maintenance	Supply room	O	O	O	-
	Training aids storage	O	O	O	-
	Arms room	-	-	O	O
	Records room	O	O	O	-
Education	Library in barracks	O	-	-	-
Morale/Welfare, & Recreation (MWR)	Barbershop for soldiers	O	O	O	-
	Barbershop for cadre	O	-	-	-
	Clothing maintenance shop	O	O	O	-
	P.X.	O	O	O	-
	Dayroom	O	O	O	-
	Billiard hall or pool hall	O	-	-	-
	Gym	O	O	O	O
	Computer room	O	O	O	-
	Multipurpose hall	O	O	O	-
	Female soldier convenience facilities	O	O	-	-
Others	Common space (corridor, hallway)	O	O	O	O
	Electrical Room	O	O	O	O

For Table 3.1, BN = Battalion, B = Brigade, CO = Independent company, PLT = Independent platoon. The Supply room is a place where the function is temporary storage and the dispensing of supplies for the troops. Training aids storage is a storeroom for various fixtures, camouflages, and supplies that are related to the education and training of soldiers. In smaller units this equipment may be stored in the unit administrative.

Table 3.2 PLT barracks area criteria

Classification	Room Name	Area (sq. m)
Housing	Living room	226.8
Administration	Commander's office	20.0
	The staff	17.0
Operation/Training	Situation room	38.5
Sanitary/Meal	Dining facility	82.8
	Latrine	31.0
	Wash room	9.7
	Laundry room	11.7
	Shower room	14.6
	Mud room	6.0
Morale/Welfare, & Recreation (MWR)	Computer room	16.0
	Gym	30.0
Others	Corridor single(Common space)	74.2
	Corridor double(Common space)	44.5
	Main entrance(Common space)	21.6
	Electrical room	18.6

3.3 Simplification as to a modular form structure

It is obvious that the area of each category is not an integer value (Table 3.2). In this case, it is hard to get a modular form layout. The most recommended case presented by the "Floor area criteria," it can be converted into an integer value based on a 9 soldier living room (width: 6.0m, length: 9.4m). It is necessary to divide the area of each room by the length of the living room (9.4m) to modify the width and length of the building.

The "Floor area criteria" requires a sustaining “block and separation” concept for users whenever designing the inner layout (section 1.2). Therefore, the width value of an individual room is added up by the classification. These values are divided by the width value of the living room (6.0m), and called as unit count. The value count of a unit is then adjusted to an integer value. Finally, the "Cell count" values from Table 3.3 are used to design a hypothetical structure layout. For instance of the "Administration", the "Area" total is 37 and divided by the length (9.4m). The "Width sum" is 3.94, then divided by the width (6.0m). The "Unit count" is 0.66 and this value is not an integer number. Hence, round off to make an integer which means "Cell count."

Table 3.3 PLT barracks area criteria cell counts

Classification	Room Name	Area	Width	Length	Width sum	Unit count	Cell count
Housing	Living room	226.80	24.13	9.40	24.13	4.02	**4**
Administration	Commander's office	20.00	2.13	9.40	3.94	0.66	**1**
	The staff	17.00	1.81	9.40			
Operation/ Training	Situation room	38.50	4.10	9.40	4.10	0.68	**1**
Sanitary/ Meal	Dining facility	82.80	8.81	9.40	16.58	2.76	**3**
	Latrine	31.00	3.30	9.40			
	Wash room	9.65	1.03	9.40			
	Laundry room	11.74	1.25	9.40			
	Shower room	14.63	1.56	9.40			
	Mud room	6.00	0.64	9.40			
Morale/Welfare, & Recreation (MWR)	Computer room	16.00	1.70	9.40	4.89	0.82	**1**
	Gym	30.00	3.19	9.40			
Others	Corridor single(Common space)	-	2.00	-	4.28	0.71	**1**
	Corridor double(Common space)	-	2.40	-			
	Main entrance(Common space)	21.60	2.30	9.40			
	Electrical room	18.60	1.98	9.40			
SUM	-	-	-	-	-	-	**11**

3.4Hypothetical structure of the outer layout

The PLT unit barracks are usually designed for up to two floors. The style of corridor, however, is not fixed to single or double-loaded (See Figure 3.1). Single-loaded corridor (single corridor) can obtain more natural sunlight and ventilation, but double cannot. On the other hand, double-loaded corridor (double corridor) can enhance space usability than single style. Due to the relatively small-scale structure, the PLT barracks have a long narrow outer layout (larger scale structures are more square for building site limitations). Four different possible hypothetic structure layouts are presented in Figures 3.2 to 3.5.

Figure 3. 1 Single-loaded corridor (left) and double-loaded corridor (right)

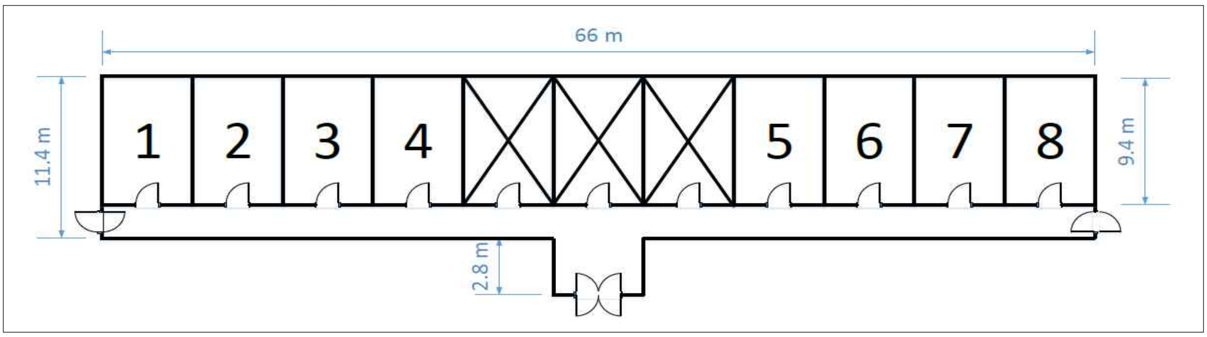


Figure 3. 2 1-floor single-loaded corridor

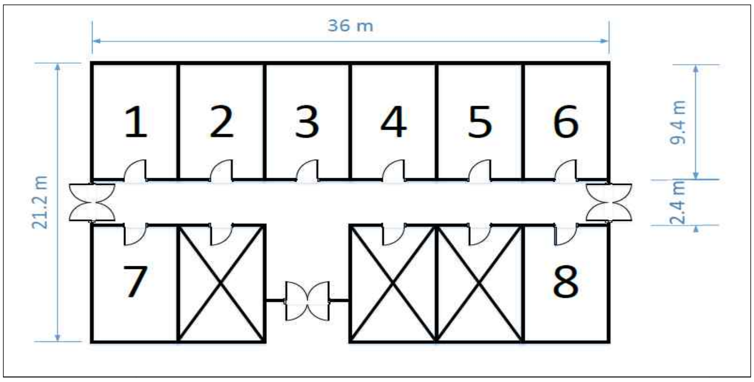


Figure 3. 3 1-floor double-loaded corridor

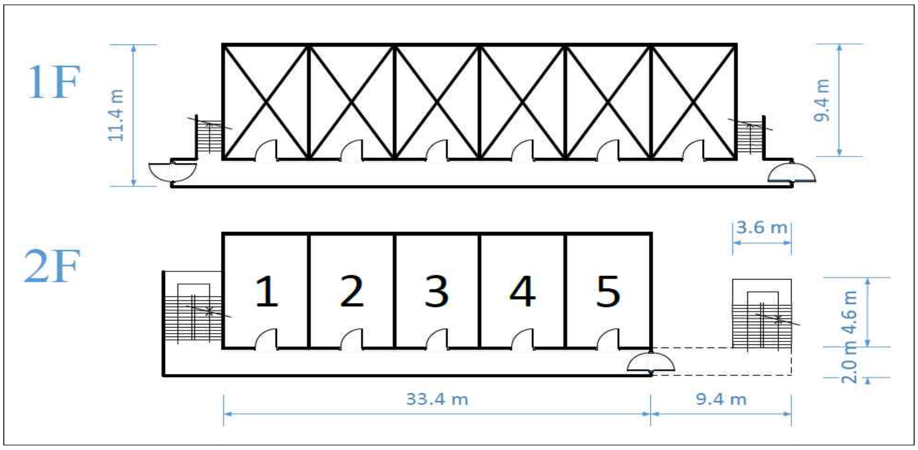


Figure 3. 4 2-floor single-loaded corridor

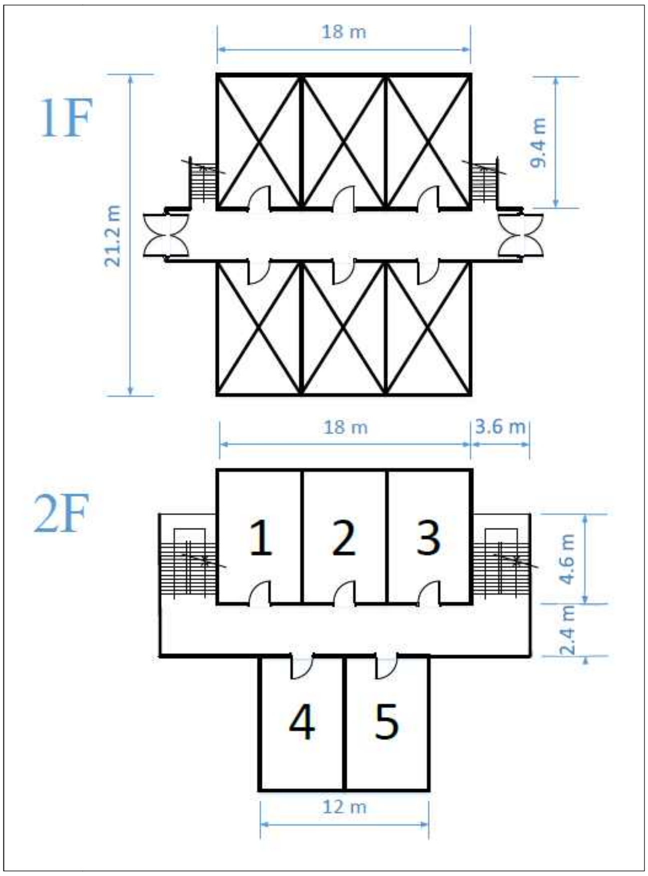


Figure 3. 5 2-floor double-loaded corridor

3.5Node specification and requirements

A node represents a user-defined component of the building of interest in a network model [36]. Defining a node helps break the building into distinct sections in order to represent the building spaces where occupants might be at the time of evacuation. A node specification scheme is required to recognize a specific node on the blueprint of the building. A node has three attributes in an EVACNET model: Node Capacity (NC), Initial Capacity (IC) and priority. The NC is the restraint of the maximum number of person in a space which is allocated to a node (maximum number of IC). The NC depends on the area and the maximum assumed density of occupants in the node at the starting time of egress. Three kinds of data are required to calculate the NC: Useable

Area (UA, sq. ft), Average Pedestrian Area Occupancy (APAO, sq. ft/person) and Level Of Service (LOS, A-F). The UA is a floor area minus obstacles. Assuming no obstacles, 1 foot is subtracted from each width and length because person does not move along the sidewall. The APAO depends on LOS. This LOS concept also can be expressed as level of congestion or level of traffic. The NC can then be calculated as: NC = UA/APAO. In this study assumed LOS = B, APAO = 13, entrances or destinations (DS) have no upper bound limitation. Those values were estimated in light of empirical experience. In this study, those assumed values are relatively unimportant because this research objective is to find the best relative alternative among several options rather than comparing estimated time or real time. The verification of the assumed values relative to LOS [36] and APAO remain for further research.

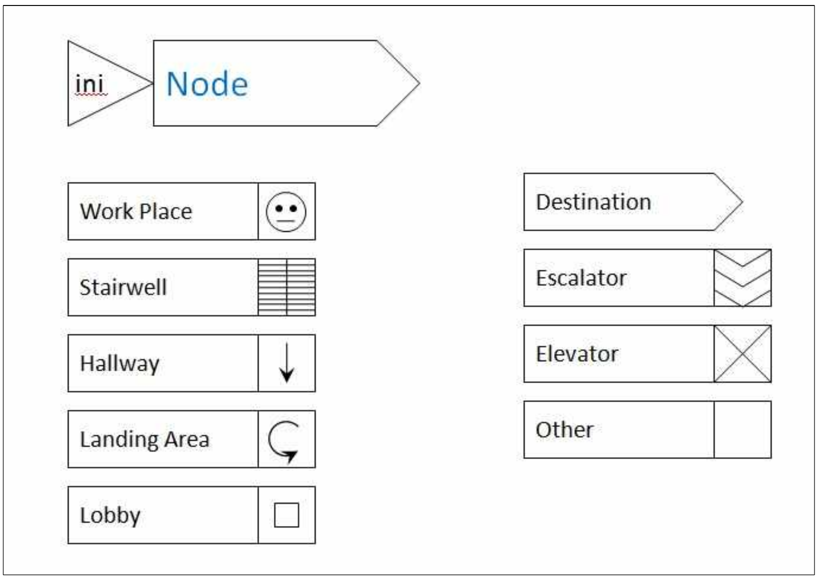


Figure 3. 6 Network model node data legend

Table 3.4 Node information for 2-floor double-loaded corridor PLT barracks

Node	Location	Floor	Description	UA	LOS	APAO	NC	IC	Priority (H=3, L=0)
WP	1	2	MWR	575.7	B	13	44	0	0
WP	2	2	Living 1	575.7	B	13	44	9	1
WP	3	2	Living 2	575.7	B	13	44	9	1
WP	4	2	Living 3	575.7	B	13	44	9	1
WP	5	2	Living 4	575.7	B	13	44	9	1
HA	1	2	HA 1	133.0	B	13	10	0	0
HA	2	2	HA 2	133.0	B	13	10	0	0
HA	3	2	HA 3	133.0	B	13	10	0	0
LA	1	2	LEFT	72.1	B	13	6	0	0
LA	2	2	RIGHT	72.1	B	13	6	0	0
LA	1	1	LEFT	32.9	B	13	3	0	0
LA	2	1	RIGHT	32.9	B	13	3	0	0
SW	1	2	LEFT	173.3	B	13	13	0	0
SW	2	2	RIGHT	173.3	B	13	13	0	0

3.6Arc specification and requirements

An arc represents passageways between the defined nodes [37]. To specify an arc, a "from" node and a "to" node are requisite. Dynamic Capacity (DC, person / time period) and Traversal Time period (TT, unit time) are two attributes of an arc leading out of nodes. DC is the maximum number of person that can pass through an arc in a given time. It is determined by a restraining factor which affects the flow from one node to another. Widths of doorways or stairways between any two nodes are usually identified as the minimum passageway width. To confirm the DC of an arc, Average Flow Volume (AFV, person/ft-min) that based on walkway Level Of Service (LOS), and Width Restriction (WR, in) are demanded. The WR is typically a doorway or a passageway between any two nodes of an arc. It is considered to be 12 inches less than the actual minimal width when a door or other obstacles exist. Second Per Time Period for a unit time assumed by the program user (SPTP). In this research, the SPTP set as 1 second / period for calculation issue, then considered as a unit time after this step. The DC can then be calculated as follows:

$$DC = WR \times (1/12 \text{ ft/in}) \times AFV \times (1/60 \text{ min/sec}) \times SPTP$$

Traversal Time (TT) is the number of time periods required to flow through the length of an arc. The EVACNET assumes that time can be broken down into a number of finite uniform lengths known as time periods. The data required to calculate the TT are distance (Dist, ft) and Average Speed (AS, ft/min). The Dist is the rectilinear distance (center to center) that person need to travel while passing from one node to another. The AS depends on the walkway Level of Service (LOS). Once AS and WR are known, the TT can be calculated as follows:

$$TT = (Dist / AS) \times 1 / SPTP.$$

In this study assumed LOS = C, AFV = 10 (7 for stairwells), Time period = 1 second, AS = 300 (150 for stairwells).

Figure 3. 7 Network model arc data legend

Table 3.5 Arc information for 2-floor double-loaded corridor PLT barracks

Begin	loc#	fl#	End	loc#	fl#	LOS	AFV	DC	Adj. DC	DIST	AS	TT	Adj. TT
WP	1	2	HA	1	2	C	10	0.3	**1**	19.0	300.0	4.0	**2**
WP	2	2	HA	2	2	C	10	0.3	**1**	19.0	300.0	4.0	**2**
WP	3	2	HA	3	2	C	10	0.3	**1**	19.0	300.0	4.0	**2**
WP	4	2	HA	1	2	C	10	0.3	**1**	29.0	300.0	6.0	**3**
WP	5	2	HA	3	2	C	10	0.3	**1**	29.0	300.0	6.0	**3**
HA	1	2	LA	1	2	C	10	1.3	**4**	16.0	300.0	3.0	**3**
HA	3	2	LA	2	2	C	10	1.3	**4**	16.0	300.0	3.0	**3**
HA	1	2	HA	2	2	C	10	1.3	**4**	20.0	300.0	4.0	**4**
HA	2	2	HA	1	2	C	10	1.3	**4**	20.0	300.0	4.0	**4**
HA	2	2	HA	3	2	C	10	1.3	**4**	20.0	300.0	4.0	**4**
HA	3	2	HA	2	2	C	10	1.3	**4**	20.0	300.0	4.0	**4**
LA	1	2	SW	1	2	C	7	0.6	**2**	22.7	150.0	9.1	**9**
LA	2	2	SW	2	2	C	7	0.6	**2**	22.7	150.0	9.1	**9**
SW	1	2	LA	1	1	C	7	0.6	**2**	22.7	150.0	9.1	**9**
SW	2	2	LA	2	1	C	7	0.6	**2**	22.7	150.0	9.1	**9**
LA	1	1	DS	1	1	C	10	0.6	**2**	3.0	300.0	1.0	**1**
LA	2	1	DS	2	1	C	10	0.6	**2**	3.0	300.0	1.0	**1**

3.7Modification of input values

Two additional concepts are applied. One is an "Adjusted Dynamic Capacity (Adj. DC)" and the another is "Adjusted Travel Time period (Adj. TT)". First, the Adj. DC is used to make a difference between two corridor styles. In fact, the calculated DC value of a single corridor is 1.1 and a double is 1.3. However, the EVACNET only can accept integer value, thus they would be the same value as one. In a similar way, the DC of entrance (destination: DS) has the same problem (single door DS is 0.3 and double is 0.6). To make a significant difference between under the value of one, added the Adj. DC concept that measuring the value of 0.3 into one unit. Second, the Adj. TT is related to the scattered starting point (living space) of the soldiers (Table 3-5). The final result of "Traversal Time" period affected by living room area and door's effective width that located between the living room and the adjacent hallway. The resulting value, however, is hardly accepted in a real situation. In this study, it is assumed that all soldiers are ready to leave immediately (Figure3-8). From practical experiments, the value is closer to 2 unit times (seconds) in emergency situations (the calculated value was 4 unit times).

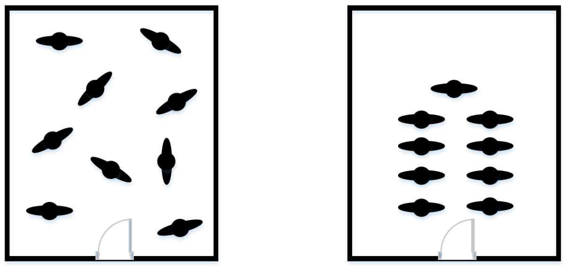


Figure 3. 8 Non-specific situation of IC (left) and military situation of IC (right)

3.8Make a Network Flow Model

In this section, two-floor double-loaded corridor hypothetical layouts (Figure 3.5) will be discussed. This design is the most representative and widely used in the real world.

Related regulations for barracks layouts from the "Floor area criteria" are as follows [1]:

1) Within the same classification of rooms, they should be adjacent (share positive length) due to enhancement of area usability.
2) Commander's office and other administrative offices should be at the center of the building.
3) Sanitary / meal (S/M) rooms should be positioned on the first floor due to everyday food supply movement and water leak risk.

Based on these regulations, the two-floor double-loaded corridor layout is completed; 1st floor has no vacancies because all six rooms are occupied – three for administrative and three for S/M functions.

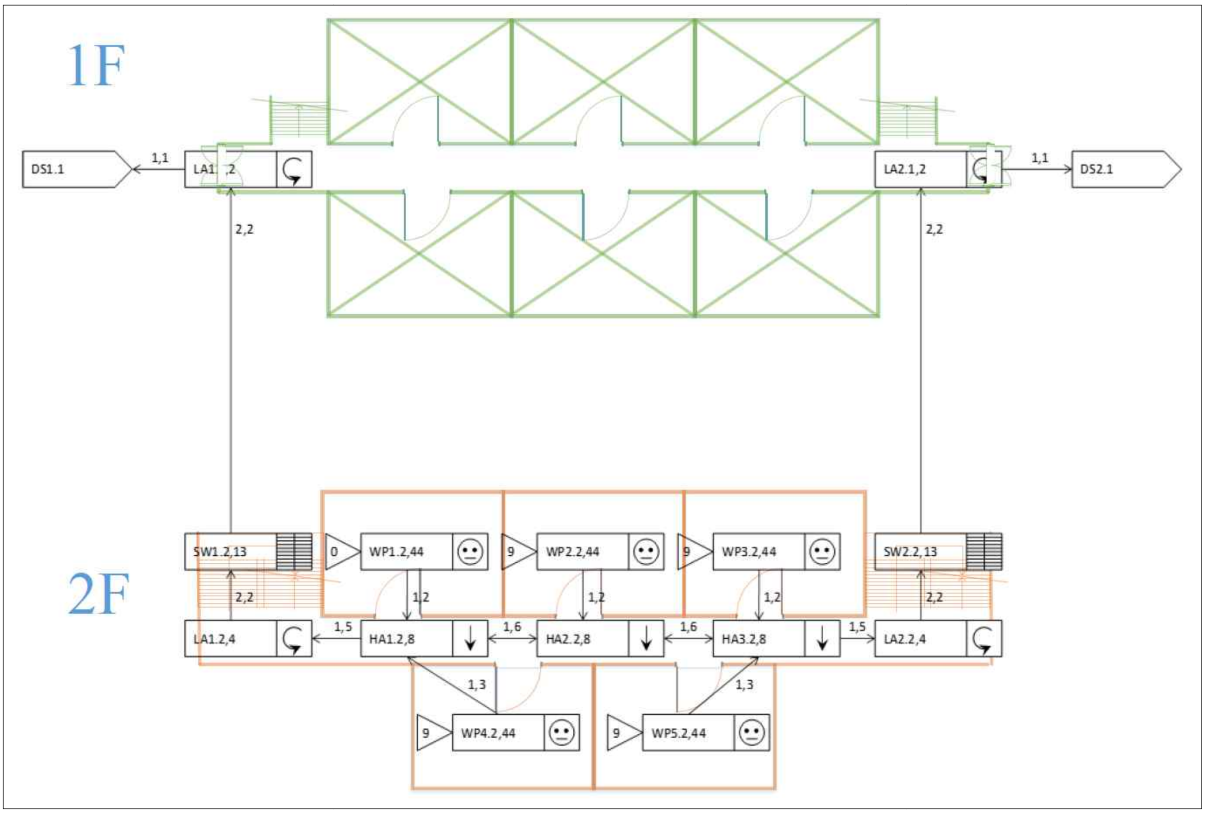


Figure 3. 9 Network flow model (black) overlay of 2-floor double-loaded corridor PLT unit barracks layout

3.9 Exhaustive search to find the best inner layout

By "Graph theoretic heuristics for layout problem" [37], if M of nodes exist, the possible maximum number of combination is

$$\frac{M(M-1)}{2}.$$

The sample data, which is used in section 3.7 has 5 nodes for living rooms (WP1.2 to 5.2, see Figure 3.9). The possible maximum number of combination is 10 (upper bound).

Based on the upper bound, initiate an exhaustive search process. According to Figure 3.10, providing graphical illustration of exhaustive search, the search can be reduced to five combinations since the 2nd floor has only two group classifications: one for the morale, welfare, & recreation (MWR) room (blue filled box) and four for living rooms (white filled box). The location of MWR rooms is considered as symmetric when it located number 1 or 3 and 4 or 5. Furthermore, the final number of possible combinations is reduced to 3-cases. Table 3.8 is the all possible combinations within two-floor double-loaded corridor of infantry PLT unit barracks layout and the results of EVACNET (DS*X* stands for the number of soldiers that using each entrance (DS1; left, DS2; right, DC3; center of the layout)).

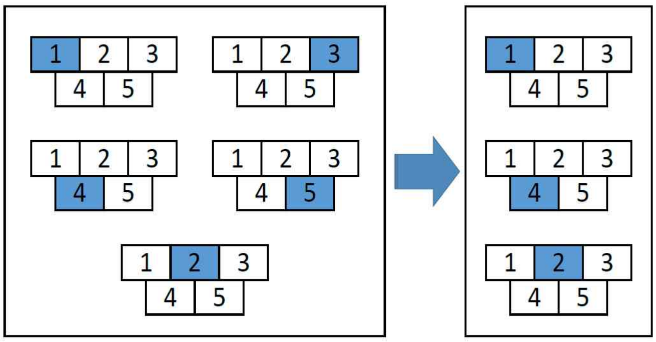


Figure 3.１０ Graphical illustration for inner layout combination

Table 3.6 EVACNET summary of results for 2-floor double-loaded corridor PLT barracks, the MWR room located in cell number 1

```
EVACNET+ SUMMARY OF RESULTS FOR MODEL ID 'PARK THESIS'

    36  TIME PERIODS TO EVACUATE BUILDING (   36 SECONDS)

    28  TIME PERIODS FOR UNCONGESTED BUILDING EVACUATION (  28 SECONDS)

   1.3  CONGESTION FACTOR (RATIO OF BUILDING EVACUATION TIME TO
        UNCONGESTED BUILDING EVACUATION TIME)

  29.5  AVERAGE # OF PERIODS FOR AN EVACUEE TO EVACUATE (  30 SECONDS)

   1.0  AVERAGE NUMBER OF EVACUEES PER TIME PERIOD

    36  NUMBER OF SUCCESSFUL EVACUEES

    60  MAXIMUM # OF TIME PERIODS ALLOWED FOR EVACUATION (  60 SECONDS)

    24  UNNECESSARY TIME PERIODS (  24 SECONDS)
```

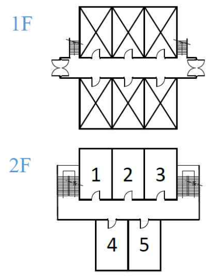
Table 3.7 EVACNET DS allocations for 2-floor double-loaded corridor PLT barracks, the MWR room located in cell number 1

```
                 DESTINATION ALLOCATION:
              NUMBER OF EVACUEES BY DESTINATION
              FOR MODEL ID 'PARK THESIS'

            # OF        EACH * REPRESENTS   1 PERSON(S)
DESTINATION  EVACUEES----|----|----|----|----|----|----|----|----|----|

DS01.001       18   ******************
DS02.001       18   ******************
```

Table 3.8 2-floor double-loaded corridor PLT unit barracks possible layouts and EVACNET results

Possible Layout					EVACNET Result			
Class	**Layout**	**Sanitary Meal**	**MWR**	**Living**	**Egress Time**	**Entrance Allocation** DS1 (Left)	DS2 (Right)	DS3 (Center)
2floor -double		1st floor fixed	1	2,3,4,5	36	18	18	-
			2	1,3,4,5	33	18	18	-
			4	1,2,3,5	33	17	19	-

4. Experiment Results and Interpretations

4.1 Overview

In this chapter, organize conditions for the best layout. Generate layouts for the each barracks unit size using the method of the previous chapter. Analysis the EVACNET result data for each layout, choose the best one using the best layout conditions, interpret, and generalize.

4.2 Conditions for the Optimal Layout

In this research, five major conditions for an optimal layout are considered in sequence:

1. Minimize the completion time of egression from barracks;
2. Develop a well-balanced allocation of the total number of soldiers that represent the initial capacity (IC) for each entrance (destination: DS) to reduce the possibility of congestion and enhance the effectiveness of circulation;
3. Place stockpile/maintenance (ST) rooms as far as possible from the busiest DS. The busiest DS remains constant regardless of room location changes. The ST rooms contain a large volume of materials such as camouflage nets, tents for outpost, etc. These materials may cause a bottleneck and reduce the average speed of soldiers exiting the building (no ST rooms in the PLT unit barracks);
4. Consider the block and separation effect. Two adjacent rooms may be used as a larger single room by removing the common wall to utilize the space more efficiently (Figure 4.1); and
5. Minimize the sum of total distance (accessibility) from each living room to common use rooms such as; MWR, ST, sanitary / meal (S/M).

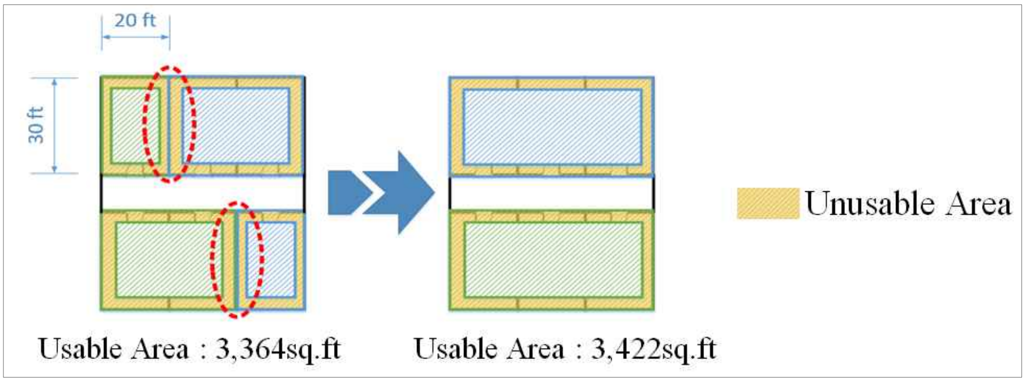
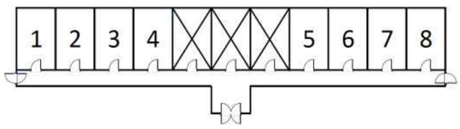
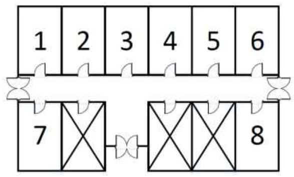
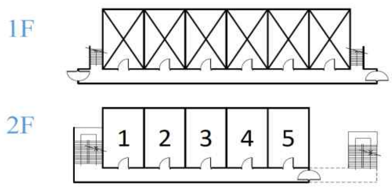
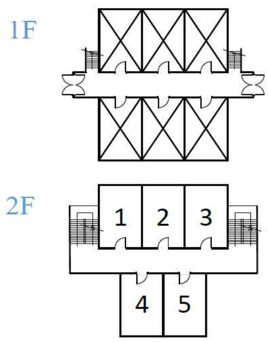


Figure 4. 1 Block and separation effect

4.3Experimental results for the Independent Platoon (PLT) Unit Layout

The one-floor single corridor layout is long and narrow (see Table 4.1). The three center rooms are assigned to administration. Other rooms are labeled as one to eight. This layout is symmetric so only one side of the building is actually modeled. Based on the conditions for the optimal layout (section 4.1), the best option has the living rooms located at room {1, 5, 6, 8}and has 21 time units for the egress time (highlight in Table 4.1). The amount of time is the same as the case of living room located at room {1, 6, 7, 8}. However, the center entrance (DS3) has larger dynamic capacity (DC) than other two entrances, thus locating more IC near the DS3 is a better option in terms of effective circulation. In the case of one-floor double corridor design, three adjacent rooms need to be occupied for the same reason as the one-floor single corridor design. The best layout in this case is to assign living rooms in location number {1, 6, 7, 8} and there are two cases highlighted in Table 4.1. It is obvious that one should evenly allocate the ICs and locate them at the nearest DS to minimize the egression time. Other characteristics can be seen from other room layout combinations. One has 19 time units of egress with the case of living rooms located in room {4, 6, 7, 8}. The change of the location from

Table 4.1 PLT unit barracks possible layouts and EVACNET results

Possible Layout					EVACNET Result				
Class	Layout	Sanitary Meal #	MWR #	Living #	Egress Time		Allocation		
					Units	Difference	DS1	DS2	DS3
1floor -single		1,2,3	4	5,6,7,8	26	117%	0	23	13
			5	4,6,7,8	24	100%	4	21	11
			6	4,5,7,8	23	92%	6	20	10
			7	4,5,6,8	23	92%	7	18	11
			8	4,5,6,7	24	100%	8	17	11
		2,3,4	1	5,6,7,8	26	117%	0	23	13
			5	1,6,7,8	23	92%	9	20	7
			6	1,5,7,8	21	75%	9	18	9
			7	1,5,6,8	21	75%	9	18	9
			8	1,5,6,7	23	92%	9	16	11
1floor -double		1,2,3	4	5,6,7,8	20	67%	9	27	0
			5	4,6,7,8	19	58%	9	18	9
			6	4,5,7,8	20	67%	9	18	9
			7	4,5,6,8	20	67%	0	27	9
			8	4,5,6,7	20	67%	9	18	9
		2,3,4	1	5,6,7,8	20	67%	9	27	0
			5	1,6,7,8	12	0%	18	18	0
			6	1,5,7,8	20	67%	18	18	0
			7	1,5,6,8	20	67%	9	27	0
			8	1,5,6,7	20	67%	18	18	0
		3,4,5	1	2,6,7,8	16	33%	18	18	0
			2	1,6,7,8	12	0%	18	18	0
			6	1,2,7,8	16	33%	24	9	3
			7	1,2,6,8	16	33%	18	18	0
			8	1,2,6,7	16	33%	24	9	3
		4,5,6	1	2,3,7,8	18	50%	18	9	9
			2	1,3,7,8	15	25%	18	9	9
			3	1,2,7,8	16	33%	24	9	3
			7	1,2,3,8	16	33%	18	9	9
			8	1,2,3,7	16	33%	26	0	10
2floor -single		1floor fixed	1	2,3,4,5	45	275%	18	18	-
			2	1,3,4,5	43	258%	20	16	-
			3	1,2,4,5	43	258%	20	16	-
			4	1,2,3,5	43	258%	20	16	-
			5	1,2,3,4	45	275%	22	14	-
2floor -double		1floor fixed	1	2,3,4,5	36	200%	18	18	-
			2	1,3,4,5	33	175%	18	18	-
			4	1,2,3,5	33	175%	17	19	-

number six to five, however, leads to an increase in egress time by one unit, regardless of the same usage of each DS. It is evident that the same usage of the DSs does not always mean the same egress time.

In the two-floor single corridor design, six rooms on the 1^{st} floor are already fully used, three for administration and three for sanitary / meal (S/M) that should be located on the 1^{st} floor, see section 3.7). The five rooms on the 2^{nd} floor can be modified. As long as those living rooms are not concentrated in one side, they have the same result in terms of egress time (43 units) and DS {20, 16} allocations. In addition, different allocations of living rooms do not affect the total usage of each DS. That is because of bottleneck problems at the right entrance of the 2^{nd} floor. To make the best layout relative to the block and separation effect, MWR should be located in room {3}. This is highlighted in Table 4.1.

In the same vein, with the two-floor single corridor layout, only the 2^{nd} floor is considered for the two-floor double corridors. Five rooms consist of two classes. Well-balanced allocation of the Initial Capacity (IC) can reduce the maximum egress time. It is evident that living room location at number {1, 3, 4, 5} is the best layout. However, there exist two options that have the same egress time of 33 units even if one of the living room locations is changed from 3 to 2. Thus, the hallway distance of 3 meters affects the one solder difference usage of each destination.

Another important feature of the experimental data is the relative difference of the egress time from the best layout ('Difference' in Table 4.1).

$$Relative \quad difference = \frac{X - X_{reference}}{X_{reference}} \tag{4.1}$$

In equation (4.1), X is the value of egress time units of each layout and $X_{reference}$ is the best layout's egress time. The best layout is one-floor single corridor and has the minimum egress time 12 unit times ($X_{reference}$). Hence, the smallest relative difference of one-floor single is 75%, two-floor single is 258%, and two-floor double is 175% in light of egress time.

4.4Experimental results for the Independent Company (CO) Unit Layout

The one-floor single corridor design is too wide and inefficient in terms of land usage. This is an issue in the ROKA. For this reason, the one-floor single corridor configuration is not considered. Clearly, allocating IC symmetrically and evenly to each DS can lead to an optimal layout. The minimum egress time for one-floor double layout is 29 time units (see Table 4.2). There are five different optimal layouts for the ST room. An ST room contains 12 soldiers and has the highest priority (3). All the results are independent of the ST room location. This indicates that the DC value of each DS is the determining factor for egress times and DS allocations. Once the first soldier arrives at a DS, bottleneck problems will continue until the last soldier's evacuation, and the remaining soldiers would choose the best way out. Among those five layouts, however, the best option is the ST located in room 12 (highlight Table 4.2) as it satisfies the blocking and separating effect.

From Figure 4.3, the two-floor single corridor style is symmetric, thus only one side is considered. The procedures for drawing layouts are as follows; First, allocate all of the inner room combinations for the 1st floor. Second, set the S/M rooms of the 2nd floor in the same column location in the 1st floor (building construction and management issue). Third, locate the remaining rooms. The minimum egress time for two-floor single layout is 45 time units and the best DS allocation is 36, 40 and 62 (highlight in Table 4.3). There are two cases that satisfies the minimum egress time of 45 units. Within those two options, consider the block and separation effect. The case of living room location {5,6,7,8,9,10,11,12,13,14,17,18,19,20} is a better option than the last two rooms located in {25,26}.

In Figure 4.4, the two-floor double corridor layout is not symmetric. Every possible case should be considered. The best model has 36 time units of egression {[S/M; 1, 2, 3, 14, 15], [W; 21, 22, 23, 24, 25, 26], [ST; 6]}. Living rooms are located in the remaining spaces (highlight Table 4.4). The purpose of reducing possible congestions by heavy item moving from the ST rooms, allocate ST rooms as far from the busiest entrance (DS2) as possible. There are two cases of 36 unit egression time with their ST location as one or six. When the two cases (i.e., living room in {2, 3, 9} and {7, 8, 9}) are compared, the latter is more suitable due to the potential for blocking and separating.

Relate to the relative difference ('Difference' of the Table 4.2-4) of one unit of time for egress is similar to as mentioned in the PLT unit. The best independent company (CO) unit barracks layout (one-floor double) has the minimum 29 unit times (Table 4.2). Hence, the two-floor single is 55%, the two-floor double is 36% relatively differ to the best layout in light of egress time.

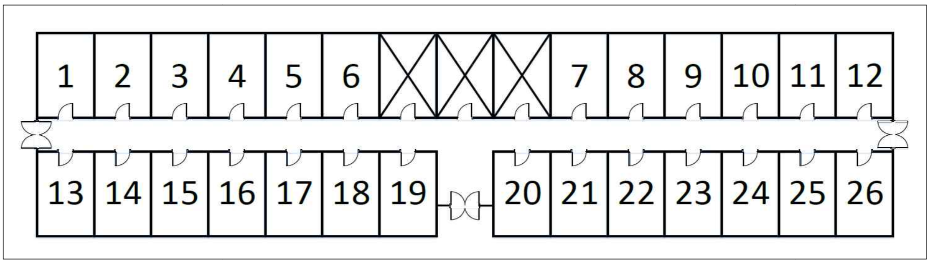


Figure 4. 2 CO barracks possible layout (1-floor double corridor)

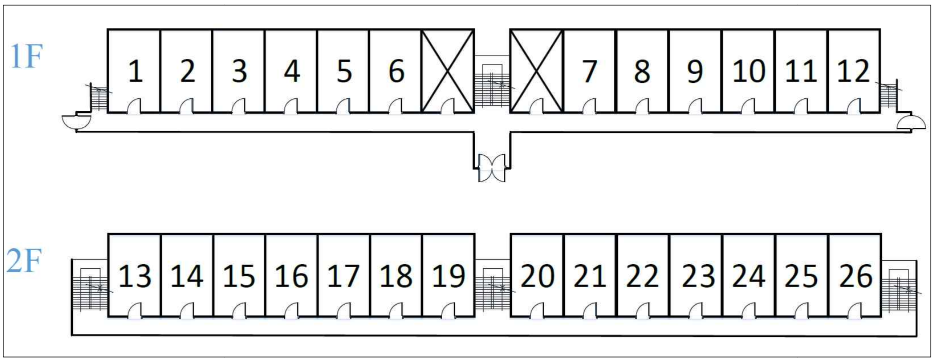


Figure 4. 3 CO barracks possible layout (2-floor single corridor)

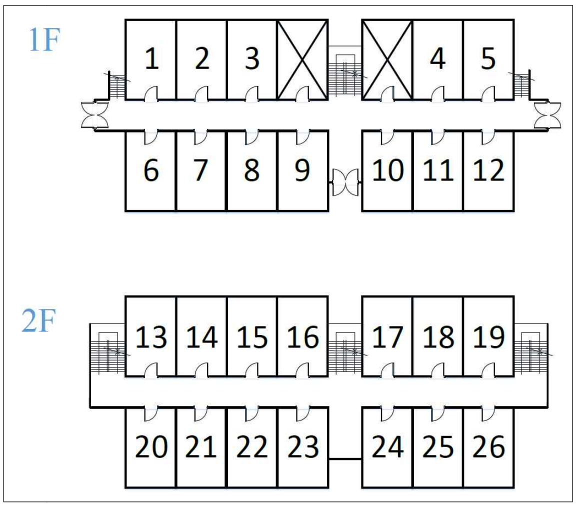


Figure 4. 4 CO barracks layout possible (2-floor double corridor)

Table 4.2 CO unit barracks possible layouts and EVACNET results (1-floor double-loaded corridor)

Possible Layout				EVACNET Result				
MWR #	Sanitary / Meal #	Stockpile #	Living #	Egress Time		Allocation		
				Units	Difference	DS1	DS2	DS3
1,2,3,4,5,6	13,14,15,16,17	7	8,9,10,11,12,18,19,20,21,22,23,24,25,26	38	31%	14	70	54
		12	7, 8,9,10,11,18,19,20,21,22,23,24,25,26	38	31%	14	70	54
		18	7, 8,9,10,11,12,19,20,21,22,23,24,25,26	37	28%	17	68	53
		20	7, 8,9,10,11,12,18,19,21,22,23,24,25,26	38	31%	14	70	54
		26	7, 8,9,10,11,12,18,19,20,21,22,23,24,25	38	31%	14	70	54
	15,16,17,18,19	7	8,9,10,11,12,13,14,20,21,22,23,24,25,26	38	31%	18	68	52
		12	7,8,9,10,11,13,14,20,21,22,23,24,25,26	38	31%	18	70	50
		13	7,8,9,10,11,12,14,20,21,22,23,24,25,26	36	24%	18	62	46
		20	7,8,9,10,11,12,13,14,21,22,23,24,25,26	37	28%	18	63	48
		26	7,8,9,10,11,12,13,14,20,21,22,23,24,25	37	28%	18	63	48
	20,21,22,23,24	7	8,9,10,11,12,13,14,15,16,17,18,19,25,26	30	3%	48	54	36
		12	7,8,9,10,11,13,14,15,16,17,18,19,25,26	30	3%	48	54	36
		13	7,8,9,10,11,12,14,15,16,17,18,19,25,26	30	3%	48	54	36
		19	7,8,9,10,11,12,13,14,15,16,17,18,25,26	30	3%	48	54	36
		26	7,8,9,10,11,12,13,14,15,16,17,18,19,25	30	3%	50	54	34
	22,23,24,25,26	7	8,9,10,11,12,13,14,15,16,17,18,19,20,21	30	3%	48	50	40
		12	7,8,9,10,11,13,14,15,16,17,18,19,20,21	30	3%	48	50	40
		13	7,8,9,10,11,12,14,15,16,17,18,19,20,21	30	3%	49	50	39
		19	7,8,9,10,11,12,13,14,15,16,17,18,20,21	30	3%	50	48	40
		20	7,8,9,10,11,12,13,14,15,16,17,18,19,21	30	3%	48	50	40
	7,8,9,10,11	12	13,14,15,16,17,18,19,20,21,22,23,24,25,26	29	0%	48	52	38
		13	12,14,15,16,17,18,19,20,21,22,23,24,25,26	29	0%	48	52	38
		19	12,13,14,15,16,17,18,20,21,22,23,24,25,26	29	0%	48	52	38
		20	12,13,14,15,16,17,18,19,21,22,23,24,25,26	29	0%	48	52	38
		26	12,13,14,15,16,17,18,19,20,21,22,23,24,25	29	0%	48	52	38
	8,9,10,11,12	7	13,14,15,16,17,18,19,20,21,22,23,24,25,26	30	3%	48	50	40
		13	7,14,15,16,17,18,19,20,21,22,23,24,25,26	30	3%	50	48	40
		19	7,13,14,15,16,17,18,20,21,22,23,24,25,26	30	3%	48	50	40
		20	7,13,14,15,16,17,18,19,21,22,23,24,25,26	30	3%	48	50	40
		26	7,13,14,15,16,17,18,19,20,21,22,23,24,25	30	3%	48	50	40

Table 4.3 CO unit barracks possible layouts and EVACNET results (2-floor single-loaded corridor)

Possible Layout				**EVACNET Result**				
MWR #	**Sanitary / Meal #**	**Stockpile #**	**Living #**	**Egress Time**		**Allocation**		
				Units	**Difference**	**DS1**	**DS2**	**DS3**
1,2,3,13,14	15,16,17,18,19,20	4	5,6,7,8,9,10,11,12,21,22,23,24,25,26	48	66%	26	43	69
		6	4,5,7,8,9,10,11,12,21,22,23,24,25,26	48	66%	26	43	69
		7	4,5,6,8,9,10,11,12,21,22,23,24,25,26	49	69%	23	43	72
		12	4,5,6,7,8,9,10,11,21,22,23,24,25,26	49	69%	23	44	71
	17,18,19,20,21,22	4	5,6,7,8,9,10,11,12,15,16,23,24,25,26	47	62%	28	42	68
		6	4,5,7,8,9,10,11,12,15,16,23,24,25,26	47	62%	28	42	68
		7	4,5,6,8,9,10,11,12,15,16,23,24,25,26	47	62%	29	42	67
		12	4,5,6,7,8,9,10,11,15,16,23,24,25,26	47	62%	29	42	67
	18,19,20,21,22,23	4	5,6,7,8,9,10,11,12,15,16,17,24,25,26	47	62%	29	41	68
		6	4,5,7,8,9,10,11,12,15,16,17,24,25,26	47	62%	30	42	66
		7	4,5,6,8,9,10,11,12,15,16,17,24,25,26	47	62%	29	42	67
		12	4,5,6,7,8,9,10,11,15,16,17,24,25,26	47	62%	30	42	66
	19,20,21,22,23,24	4	5,6,7,8,9,10,11,12,15,16,17,18,25,26	47	62%	29	42	67
		6	4,5,7,8,9,10,11,12,15,16,17,18,25,26	47	62%	29	42	67
		7	4,5,6,8,9,10,11,12,15,16,17,18,25,26	47	62%	29	42	67
		12	4,5,6,7,8,9,10,11,15,16,17,18,25,26	47	62%	29	42	67
2,3,4,15,16	17,18,19,20,21,22	1	5,6,7,8,9,10,11,12,13,14,23,24,25,26	47	62%	32	42	64
	19,20,21,22,23,24	1	5,6,7,8,9,10,11,12,13,14,17,18,25,26	45	55%	36	40	62
	21,22,23,24,25,26	1	5,6,7,8,9,10,11,12,13,14,17,18,19,20	45	55%	35	39	64
3,4,5,16,17	18,19,20,21,22,23	6	1,2,7,8,9,10,11,12,13,14,15,24,25,26	47	62%	41	42	55
	21,22,23,24,25,26	6	1,2,7,8,9,10,11,12,13,14,15,18,19,20	47	62%	41	36	61
4,5,6,17,18	19,20,21,22,23,24	1	2,3,7,8,9,10,11,12,13,14,15,16,25,26	47	62%	42	36	60
		3	1,2,7,8,9,10,11,12,13,14,15,16,25,26	47	62%	42	36	60
		7	1,2,3,8,9,10,11,12,13,14,15,16,25,26	47	62%	42	36	60
		12	1,2,3,7,8,9,10,11,13,14,15,16,25,26	47	62%	42	36	60
	21,22,23,24,25,26	1	2,3,7,8,9,10,11,12,13,14,15,16,19,20	47	62%	42	32	64
		3	1,2,7,8,9,10,11,12,13,14,15,16,19,20	47	62%	42	32	64
		7	1,2,3,8,9,10,11,12,13,14,15,16,19,20	47	62%	42	35	61
		12	1,2,3,7,8,9,10,11,13,14,15,16,19,20	47	62%	42	35	61

Table 4.4 CO unit barracks possible layouts and EVACNET results (2-floor double-loaded corridor)

Possible Layout				EVACNET Result				
MWR #	Sanitary / Meal #	Stockpile #	Living #	Egress Time		Allocation		
				Units	Difference	DS1	DS2	DS3
1,2,3,13,14	20,21,22,23,24,25	5	4,6,7,8,9,10,11,12,15,16,17,18,19,26	40	38%	34	59	45
		6	4,5,7,8,9,10,11,12,15,16,17,18,19,26	40	38%	36	58	44
		9	4,5,6,7,8,10,11,12,15,16,17,18,19,26	40	38%	32	59	47
		10	4,5,6,7,8,9,11,12,15,16,17,18,19,26	40	38%	33	59	46
1,2,3,14,15	21,22,23,24,25,26	5	4,6,7,8,9,10,11,12,13,16,17,18,19,20	36	24%	45	51	42
		6	4,5,7,8,9,10,11,12,13,16,17,18,19,20	36	24%	47	50	41
		9	4,5,6,7,8,10,11,12,13,16,17,18,19,20	36	24%	44	51	43
		10	4,5,6,7,8,9,11,12,13,16,17,18,19,20	36	24%	45	50	43
6,7,8,20,21	13,14,15,16,17,18	1	2,3,4,5,9,10,11,12,19,22,23,24,25,26	40	38%	34	59	45
		5	1,2,3,4,9,10,11,12,19,22,23,24,25,26	40	38%	32	60	46
		9	1,2,3,4,5,10,11,12,19,22,23,24,25,26	40	38%	31	58	49
		10	1,2,3,4,5,9,11,12,19,22,23,24,25,26	40	38%	32	59	47
6,7,8,21,22	14,15,16,17,18,19	1	2,3,4,5,9,10,11,12,13,20,23,24,25,26	36	24%	47	50	41
		5	1,2,3,4,9,10,11,12,13,20,23,24,25,26	36	24%	45	51	42
		9	1,2,3,4,5,10,11,12,13,20,23,24,25,26	36	24%	45	50	43
		10	1,2,3,4,5,9,11,12,13,20,23,24,25,26	36	24%	45	50	43
7,8,9,21,22	14,15,16,17,18,19	5	1,2,3,4,6,10,11,12,13,20,23,24,25,26	36	24%	49	50	39
		6	1,2,3,4,5,10,11,12,13,20,23,24,25,26	36	24%	49	50	39
		10	1,2,3,4,5,6,11,12,13,20,23,24,25,26	36	24%	50	50	38
7,8,9,22,23	13,14,15,16,17,18	5	1,2,3,4,6,10,11,12,19,20,21,24,25,26	36	24%	49	56	33
		6	1,2,3,4,5,10,11,12,19,20,21,24,25,26	36	24%	49	56	33
		10	1,2,3,4,5,6,11,12,19,20,21,24,25,26	36	24%	50	56	32
	14,15,16,17,18,19	5	1,2,3,4,6,10,11,12,13,20,21,24,25,26	36	24%	57	50	31
		6	1,2,3,4,5,10,11,12,13,20,21,24,25,26	36	24%	57	50	31
		10	1,2,3,4,5,6,11,12,13,20,21,24,25,26	36	24%	55	44	30
10,11,12,24,25	13,14,15,16,17,18	1	2,3,4,5,6,7,8,9,19,20,21,22,23,26	40	38%	56	36	46
		6	1,2,3,4,5,7,8,9,19,20,21,22,23,26	40	38%	56	36	46
		9	1,2,3,4,5,6,7,8,19,20,21,22,23,26	40	38%	56	36	46
	14,15,16,17,18,19	1	2,3,4,5,6,7,8,9,13,20,21,22,23,24	40	38%	64	20	54
		6	1,2,3,4,5,7,8,9,13,20,21,22,23,24	40	38%	64	20	54
		9	1,2,3,4,5,6,7,8,13,20,21,22,23,24	40	38%	64	20	54

4.5 Overall shape of the Structures

In the independent platoon (PLT) unit barracks layout, double corridor style can reduce the maximum egress time from a single corridor style for PLT unit barracks. The experimental result provides that the one-floor single corridor takes 9 time units more in egress time than one-floor double corridor. Similarly, the two-floor single corridor takes 10 time units longer than the two-floor double corridor. However, it is not recommended for PLT unit barracks to add one more floor, because a two-floor structure dramatically increases the egress time in both single and double corridor styles. Furthermore, one-floor structure is better than two-floor, considering construction simplicity. As a result, when it comes to PLT unit barracks layout, one-floor double corridor is the most appropriate structure style.

For the independent company (CO) unit design, it is not desirable to build one-floor single corridor structure. Thus, comparison between two corridor styles is the only viable option in the two-floor structures. The two-floor double structure takes 6 time units less than two-floor double structure. Therefore, it is also reasonable to use a double corridor for CO unit barracks. With regard to the number of floors in the CO unit barracks layouts have different features to the PLT unit. In the CO case, when the corridor is same as double, adding one more floor increases 7 unit times. This amount is significantly smaller than the PLT unit case (increase 21 time units). As a consequence, as for the best CO barracks layout, one-floor double corridor style is recommended, but also two-floor double is an alternative option if there exist building site limitations.

4.6 Modifications of DS

From the PLT and CO layout results above, the most sensitive factor is the Dynamic Capacity (DC) of each entrance (DS). As discussed above, the value of every arc's DC connected to DS is overestimated due to measuring a decimal place (see, section 3.6). Nonetheless, every layout is affected by the DC of the DS. It means that every soldier waiting in line in front of the entrance needs not to know which path they have used. In other words, the DC of each room door or hallways is not a constraint factor (does not affect the path of the initial starting point to the each DS). That means if there exists a need for reducing a total construction cost, reducing the width of each room door and hallways are considerable.

The key point in minimizing egress time is to increase the dynamic capacity at entrances or to add more entrances (DS). These two options need further consideration for their structures and cost such as widening the door width. The separation of left and right side stairwells, however, is advisable in any situation (see Figure 4.5). By doing this, soldiers (IC) of the 2nd floor will not use the same left and right side of the entrance (DS1, DS2). In some cases such as medical facilities, it is necessary to keep stairwells inside of the buildings, but as for facilities as the military barracks, it is recommended to separate the left and right side stairwells.

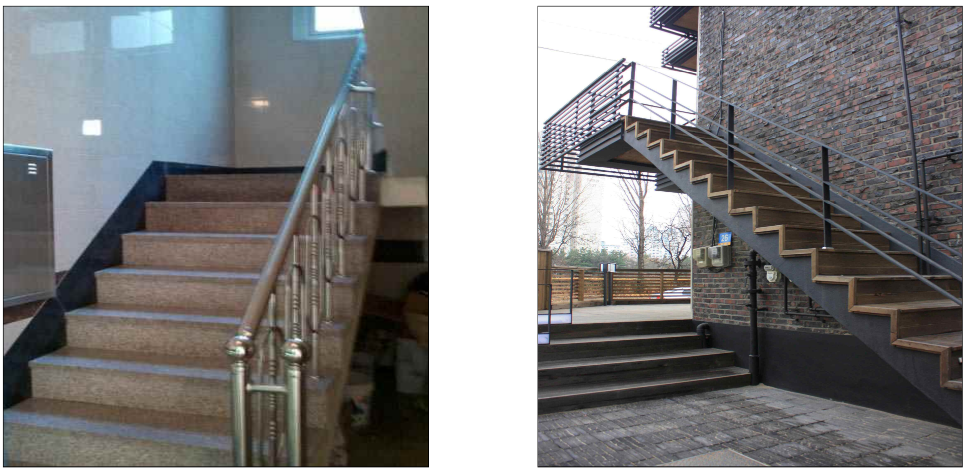


Figure 4. 5 Building including stairwell (left) and separating stairwell (right)

5. Conclusion

5.1 Summary

The Republic of Korea Army (ROKA) has sustained a local defense system since the end of the Korean War in 1953 and remains in armistice status. Over the 60 years of armistice, the importance of peacetime operations has increased. In peace time operations, most of the commanders in charge of barracks layout emphasize the wellbeing and/or hygiene of the soldiers. Even though commanders encourage their soldiers to evacuate the barracks as quickly as possible in emergency situations, they have little knowledge about how the building design can reduce the actual distances to the entrance. The ROKA should prepare for every possible scenario. This research originates from the awareness of potential wartime operations, especially in a barracks design. The main purpose of this study is to find the best layout of a barracks to minimize the maximum egress time in an emergency situation. This reduces the time for combat preparations and raises the probability of saving more lives. To address this goal, the three main steps are as follows:

> Step 1: Generate a hypothetical outer building layout with 'area criteria' that provided by the ROKA construction manual;
>
> Step 2: Recommend the best alternative inner room layout in light of the EVACNET results (egress time and each entrance usage); and
>
> Step 3: Derive general conditions for designing the best layout

The experimental results are shown in Table 5.1 and 5.2. EVACNET can determine maximum egress unit times. DS*X* stands for the number of soldiers that using each entrance (DS1; left, DS2; right, DC3; center of the layout).

5.2Limitations and Further Research

While this thesis provides meaningful implications to offer ways of improvement for the best barracks layouts, several limitations of this study should be considered. One of the limitations is simplified outer layouts. In this research, we mainly considered a simple barracks shape such as a long, narrow shape. In reality, however, there can be a box shape and an 'L' shape, and so on. In a case of an 'L' shape, the size of the center entrance would be larger than the long, narrow style (see Table 5.3). This layout has the same egress time units (29) with the long, narrow one. In the meantime, it has same result when the stockpile room located in the right next to left entrance or center entrance. Thus, due to congestion possibility of large items from the stockpile rooms, locating that room near to center entrance is recommended (larger area may reduce congestion).

As mentioned already, the main objective of this research is to investigate egression procedures in an infantry unit barracks. Combat support units such as combat engineer unit, chemical biological radiological nuclear (CBRN) unit, and logistics unit can be another realm of future research. Each army branch has a different concept of missions accompanied by their inherent properties; different types of rooms, equipment, and handling restrictions. Thus, to apply this research procedure to other than combat units, certain modifications to account for different equipment and missions will need to be made. For instance, the CBRN units wear anti-contamination clothing that reduces their average speeds (AS). The combat engineers move construction materials such as lumber (that needs at least two soldiers to carry) that reduces the average flow volume (AFV) of hallways.

Another limitation is not taking into account of individual attributes during egression operations. Due to the limitations of the network flow model, it is difficult to describe

Table 5.1 The best layouts for PLT unit barracks and results of the EVACNET

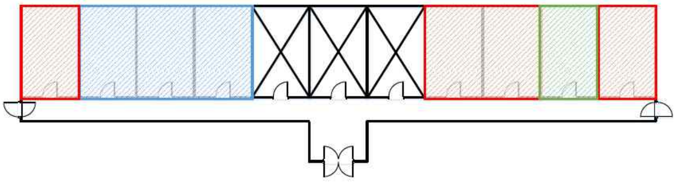
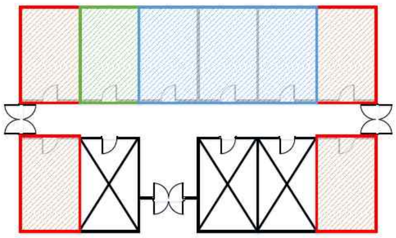
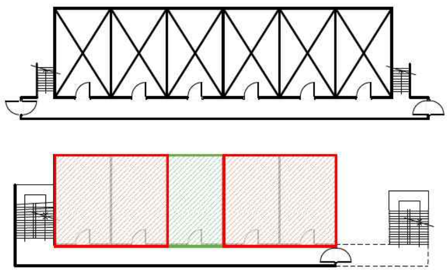
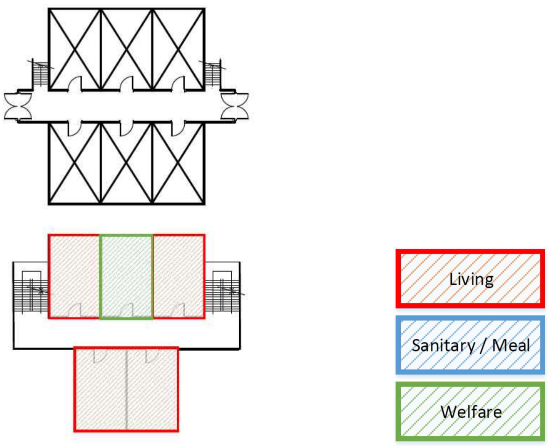
Class	Layout	EVACNET Result			
		Egress Time	Allocation		
			DS1	DS2	DS3
1 floor-single		21	9	18	9
1 floor-double		12	18	18	0
2 floor-single	1F 2F 	43	20	16	-
2 floor-double	1F 2F 	33	18	18	-

Table 5.2 The best layouts for CO unit barracks and results of the EVACNET

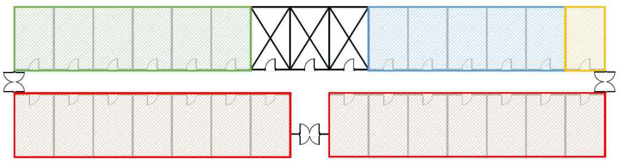
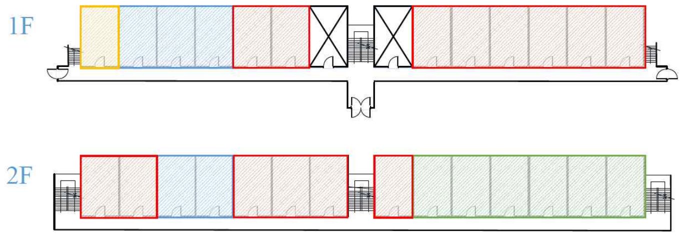
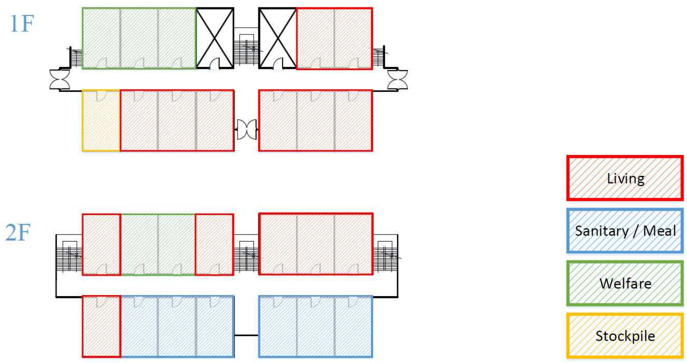
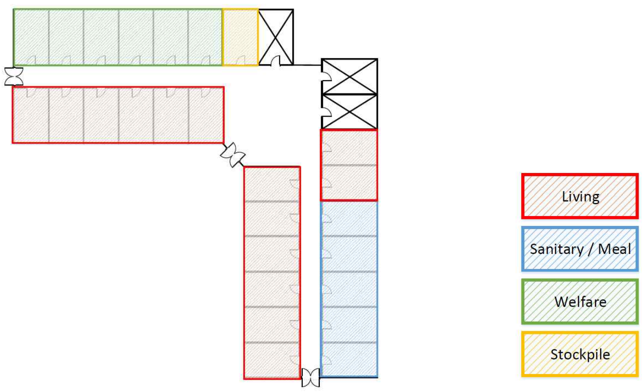
Class	Layout	EVACNET Result			
		Egress Time	Allocation		
			DS1	DS2	DS3
1 floor-double		29	48	52	38
2 floor-single		45	35	39	64
2 floor-double		36	47	50	41

Table 5.3 The best layouts for CO unit 'L' shape barracks and results of the EVACNET

Class	Layout	EVACNET Result			
		Egress Time	Allocation		
			DS1	DS2	DS3
1 floor-double-'L' Shape		29	48	48	42

more than two dynamic capacities (DC) and different properties of individual soldiers such as AFV and AS. Soldiers who carry heavy items would have slower movement and occupy a larger area of the hallways than ordinary soldiers. They should share hallways and stairwells to go out of the barracks, possibly affecting the DC of each hallway and stairwell, as well as congestion (reducing AFV and AS). To handle this problem, using simulation programs such as SIMULEX, EXIT89, EXODUS, SGEM, and EGRESS [26-30] can be potential alternatives.

Although this study offered an initial contribution to the egression mission in small size barracks such as independent platoon (PLT) or company (CO), more research on larger size barracks is needed. Related to the exhaustive search method, units larger than the CO unit barracks layouts are intentionally left out due to the computational complexity. The most reasonable method to solve this problem can be heuristics with local search technique like the pair wise comparisons [39]. Conditions for the best layout (Section 4.2) can help to generate a Brigade (B) and Battalion (BN) size barracks as close as possible to the best layout. Once prototype layouts made for the B or BN unit size, then find a better layout with the pair wise comparisons by changing the rooms' locations.

At the very least, this military barracks layout problem should be pursued to the point where it links up with peace time usage of barracks. Thus, it is desirable to consider the utility of barracks layout of a peace time operation as well as a wartime operation. One possible method is the facility layout problem (FLP). The FLP concentrates on designing facility layout in order to minimize the total weighted flow cost [2]. To provide valid experimental results for this problem, actual data such as circulation time for patrols, distance to latrines, accessibility of recreation rooms, and evacuation operation exercises on several scenarios are needed. Once the FLP based layout is produced, it could be combined with the egress time analysis studied in this research. That is a methodology of solving multi-objective optimization problems [40]. The result of this study can be used as a preemptive layout (minimizing time), while the peace time layout can be considered as a secondary objective (minimizing flow cost).

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APPENDIX

Appendix A. Example for 2-floor double corridor PLT barracks

This document presents instructions and scripts to run the EVACNET program example for 2-floor double corridor PLT barracks, the MWR room located in 1 case.

Script Preparation

!UG_C_RUN.IN - Users guide Appendix C Example 2
! Defines nodes and arcs, runs the model and EXAMs summary of results
SYS
1
60
3
1
5
Park Thesis
6
0
7
EXUG.MOD
8
EXUG.RES
END
EN
WP1.2,44,0,0
WP2.2,44,9,1
WP3.2,44,9,1
WP4.2,44,9,1
WP5.2,44,9,1
HA1.2,10,0,0
HA2.2,10,0,0
HA3.2,10,0,0
LA1.2,6,0,0
LA2.2,6,0,0
LA1.1,3,0,0
LA2.1,3,0,0
SW1.2,13,0,0
SW2.2,13,0,0
DS1.1
DS2.1
END
EA
WP1.2-HA1.2,1,2
WP2.2-HA2.2,1,2
WP3.2-HA3.2,1,2

WP4.2-HA1.2,1,3
WP5.2-HA3.2,1,3
HA1.2-LA1.2,4,3
HA3.2-LA2.2,4,3
HA1.2-HA2.2,4,4
HA2.2-HA1.2,4,4
HA2.2-HA3.2,4,4
HA3.2-HA2.2,4,4
LA1.2-SW1.2,2,9
LA2.2-SW2.2,2,9
SW1.2-LA1.1,2,9
SW2.2-LA2.1,2,9
LA1.1-DS1.1,2,1
LA2.1-DS2.1,2,1
END
RUN
EXAM
1
END
EXAM
2
END
QUIT
BYE

Execution

!EVACNET4 /READ UG_C_RUN.IN RESULTS.OUT (enter)

Result

MASTER OPTION MENU SUPPRESSED FOR BATCH MODE
ENTER CODE OF REQUESTED ACTION: !UG_C_RUN.IN - Users guide Appendix C Example 2

MASTER OPTION MENU SUPPRESSED FOR BATCH MODE
ENTER CODE OF REQUESTED ACTION: ! Defines nodes and arcs, runs the model and EXAMs summary of results

MASTER OPTION MENU SUPPRESSED FOR BATCH MODE
ENTER CODE OF REQUESTED ACTION: SYS

SYS MENU SUPPRESSED FOR BATCH MODE
ENTER CODE OF REQUESTED ACTION: 1

ENTER NEW VALUE FOR MAXIMUM NUMBER OF EVACUATION PERIODS
60

```
SYS MENU SUPPRESSED FOR BATCH MODE
 ENTER CODE OF REQUESTED ACTION:  3
 ENTER NEW VALUE FOR THE LENGTH OF A TIME PERIOD (IN SECONDS)
1

SYS MENU SUPPRESSED FOR BATCH MODE
 ENTER CODE OF REQUESTED ACTION:  5

 ENTER THE NAME OF THE BUILDING OR MODEL
OR 'END' TO RETURN TO ATTRIBUTES LIST OR 'HELP' IF YOU HAVE
QUESTIONS
PARK THESIS

SYS MENU SUPPRESSED FOR BATCH MODE
 ENTER CODE OF REQUESTED ACTION:  6

ENTER '1' TO DISPLAY SUMMARY,OR '0' TO SUPPRESS SUMMARY
0

SYS MENU SUPPRESSED FOR BATCH MODE
 ENTER CODE OF REQUESTED ACTION:  7

ENTER NEW DATA SET NAME FOR MODEL
OR 'END' TO RETURN TO ATTRIBUTES LIST OR 'HELP' IF YOU HAVE
QUESTIONS
EXUG.MOD

SYS MENU SUPPRESSED FOR BATCH MODE
 ENTER CODE OF REQUESTED ACTION:  8

ENTER NEW DATA SET NAME FOR RESULTS DATA SET
OR 'END' TO RETURN TO ATTRIBUTES LIST OR 'HELP' IF YOU HAVE
QUESTIONS
EXUG.RES

SYS MENU SUPPRESSED FOR BATCH MODE
 ENTER CODE OF REQUESTED ACTION:  END

MASTER OPTION MENU SUPPRESSED FOR BATCH MODE
 ENTER CODE OF REQUESTED ACTION:  EN

ENTER 'NODE SPECIFICATIONS,CAPACITY,INITIAL CONTENTS,PRIORITY'
E.G. 'WP1.3,20,15'
OR 'HELP' IF YOU HAVE ANY QUESTIONS OR 'END' WHEN COMPLETED
(REMEMBER THAT DS AND EL TYPE NODES HAVE SPECIAL FORMATS)
WP1.2,44,0,0
WP2.2,44,9,1
```

WP3.2,44,9,1
WP4.2,44,9,1
WP5.2,44,9,1
HA1.2,10,0,0
HA2.2,10,0,0
HA3.2,10,0,0
LA1.2,6,0,0
LA2.2,6,0,0
LA1.1,3,0,0
LA2.1,3,0,0
SW1.2,13,0,0
SW2.2,13,0,0
DS1.1
DS2.1
END

MASTER OPTION MENU SUPPRESSED FOR BATCH MODE
ENTER CODE OF REQUESTED ACTION: EA

ENTER 'ARC SPECIFICATION,DYNAMIC CAPACITY,TRAVERSAL TIME'
E.G. 'HA1.3-SW2.3,7,2 '
OR 'HELP' IF YOU HAVE QUESTIONS, OR 'END' WHEN COMPLETED
(REMEMBER THAT ARCS FROM EL NODES HAVE SPECIAL FORMATS)
WP1.2-HA1.2,1,2
WP2.2-HA2.2,1,2
WP3.2-HA3.2,1,2
WP4.2-HA1.2,1,3
WP5.2-HA3.2,1,3
HA1.2-LA1.2,4,3
HA3.2-LA2.2,4,3
HA1.2-HA2.2,4,4
HA2.2-HA1.2,4,4
HA2.2-HA3.2,4,4
HA3.2-HA2.2,4,4
LA1.2-SW1.2,2,9
LA2.2-SW2.2,2,9
SW1.2-LA1.1,2,9
SW2.2-LA2.1,2,9
LA1.1-DS1.1,2,1
LA2.1-DS2.1,2,1
END

MASTER OPTION MENU SUPPRESSED FOR BATCH MODE
ENTER CODE OF REQUESTED ACTION: RUN

BEGIN EXECUTION
FOR MODEL ID 'PARK THESIS'

THE EXECUTION OF THE MODEL IS SUCCESSFUL
MASTER OPTION MENU SUPPRESSED FOR BATCH MODE
ENTER CODE OF REQUESTED ACTION: EXAM

EXAM MENU SUPPRESSED FOR BATCH MODE
ENTER CODE OF REQUESTED ACTION: 1

EVACNET+ SUMMARY OF RESULTS FOR MODEL ID 'PARK THESIS'

36 TIME PERIODS TO EVACUATE BUILDING (36 SECONDS)

28 TIME PERIODS FOR UNCONGESTED BUILDING EVACUATION (28 SECONDS)

1.3 CONGESTION FACTOR (RATIO OF BUILDING EVACUATION TIME TO UNCONGESTED BUILDING EVACUATION TIME)

29.5 AVERAGE # OF PERIODS FOR AN EVACUEE TO EVACUATE (30 SECONDS)

1.0 AVERAGE NUMBER OF EVACUEES PER TIME PERIOD

36 NUMBER OF SUCCESSFUL EVACUEES

60 MAXIMUM # OF TIME PERIODS ALLOWED FOR EVACUATION (60 SECONDS)

24 UNNECESSARY TIME PERIODS (24 SECONDS)

EXAM MENU SUPPRESSED FOR BATCH MODE
ENTER CODE OF REQUESTED ACTION: END

MASTER OPTION MENU SUPPRESSED FOR BATCH MODE
ENTER CODE OF REQUESTED ACTION: EXAM

EXAM MENU SUPPRESSED FOR BATCH MODE
ENTER CODE OF REQUESTED ACTION: 2

DESTINATION ALLOCATION:
NUMBER OF EVACUEES BY DESTINATION
FOR MODEL ID 'PARK THESIS'

```
            # OF         EACH * REPRESENTS   1 PERSON(S)
DESTINATION  EVACUEES----|----|----|----|----|----|----|----|----|----|
```

```
DS01.001        18   ******************
DS02.001        18   ******************
 EXAM MENU SUPPRESSED FOR BATCH MODE
 ENTER CODE OF REQUESTED ACTION:  END

MASTER OPTION MENU SUPPRESSED FOR BATCH MODE
 ENTER CODE OF REQUESTED ACTION:  QUIT


 CODE    REQUESTED ACTION
 ----    ----------------
SAVE   - SAVE CURRENT MODEL
RETURN - RETURN TO MASTER OPTION LIST
BYE    - END EXECUTION OF EVACNET

ENTER CODE OF REQUESTED ACTION:  BYE
```