Abstract
In this research study, the authors examined the behavioral characteristics of the evacuees who survived the Daegu subway fire on February 15, 2003, and matters related to evacuation were analyzed through interviews and questionnaires. The authors selected the Daegu subway fire survivors as their research subjects in order to understand human behavior concerning an underground emergency and to obtain "close-to-reality" data. Data, with regard to this research, is required in order to develop a method of minimizing life-threatening dangers and provide evacuation safety based directly on those who survived the actual evacuation process in the February 15, 2003 Daegu subway fire. This study found that the various spatial, environmental, and human factors made evacuation very difficult. When the fire broke out, 24.5% of the passengers reacted passively instead of instantly taking evacuation action; there is a statistical difference between the location of the carriage on the train and the factors that influenced each person's decision to take refuge ($x^2=34.186$, df=15, $p=0.003<0.05$). The greatest obstacles to evacuees were bad visibility (68.7%) due to smoke, and 93.3% of the subjects did not have significant help from the exit light they saw while evacuating. Finally, only 12% of the survivors evacuated through appropriate escape routes and exits.

Keywords: Daegu subway fire; evacuation; behavior and perception; fire safety; underground

1. Introduction
The ways in which a person perceives the space and objects in an emergency differ from the ways he or she behaves under normal conditions. For that reason, the evacuation passages and facilities that have been prepared in advance, regardless of these conditions, might become useless (Weyman et al., 2005). This statement has been verified to be true by the cases of fire that have broken out in Korea since the 1990s (Korean Fire Data, 2005). More people died of suffocation due to smoke and toxic gases than those who died from the effects of building collapse or spreading flames. Therefore, underground space design and facility installation should thoroughly consider not only human behavioral characteristics in general but also the perception patterns of evacuees in an emergency. In particular, we should know how people perceive and recognize the space and objects around them in a split second when suddenly confronted by an emergency.

In this paper, the authors examined the responses of people who survived the Daegu subway fire as well as their movements in the underground space. They analyzed the behavioral characteristics of the survivors and factors which influenced their evacuation behavior at the time of the fire. On the basis of their findings in this study, the authors developed a safe evacuation method in the case of a subway fire, by improving the current evacuation safety level in the underground passages connected to the subway station.

2. Daegu Subway Fire
The Daegu subway fire is the worst accident, claiming the highest number of lives in the history of the Korean subway since the opening of Subway Line 1 in Seoul on Aug. 15, 1974. The fire broke out in the 1st carriage of train 1079, which was stopping at the Jungangno station on the third underground level of the Daegu subway line 1 (Fig.1.) at 09:53 a.m., on Feb. 18, 2003. Train 1079 was bound for its next destination, Daegu Station, from the direction of Banwoldang station. The fire was set by a passenger (male, 56 years old) with 4ℓ of a volatile substance, who was riding in the 1st carriage of train 1079. Five minutes after the fire had started, Train 1080, bound for Banwoldang
The fire that had started in train 1079 then spread to train 1080, and both trains burned fiercely. It was 1:38 p.m. Feb. 18, 2003 by the time the fire had been completely extinguished (See Fig.2.). It has been estimated that approximately 640 passengers were aboard trains 1079 and 1080 at the time of the fire. The fire caused a total of 340 casualties - 192 dead and 148 injured. Among the dead, 142 persons were inside the train, 49 were outside the train, and 1 person was presumed dead. The presumed dead means that a person is presumed to be dead due to an incident, such as fire and flood) even though there is no proof of death. The presumed dead are recorded as deaths in the census register book by the Family Resister Law in South Korea. The age distribution of the 148 injured indicates that 29% were in their 20s, 26% were in their 30s, and 17% were their 40s (Fig.3.).
3. Method
3.1 Questionnaire and Subjects
In this study, the authors utilized a questionnaire to examine the behavioral types as well as the evacuation behaviors of the 146 survivors among the 148 persons who were injured in the Daegu subway fire. They administered the 1st questionnaire to 146 subjects and excluded 46 persons who were considered to lack consistency and objectivity due to the severity of their injuries. Then, the 2nd questionnaire and an interview were conducted with 100 injured persons. The items for the 2nd questionnaire consisted of 60 subjective and objective questions designed to find out the recognition characteristics, evacuation behaviors, evacuation methods, and the surrounding conditions.

Among the 96 injured persons, excluding the 4 subway station staff, the average age was 34.6 (Standard Deviation, SD=14.7, range=13~73); 61 (63.5%) were female and 35 (36.5%) were male. The position distribution of 100 persons in the trains at the time of the fire is shown in Table 1.

3.2 Statistical analysis
The responses of 96 survivors were analyzed, excluding the 4 subway staff members who were working in the subway station at the time of the fire. The data was analyzed by means of descriptive statistics, a chi-square test and an independence t-test. In regards to the descriptive statistics, the authors used valid percentages with respect to the 96 subjects excluding missing values. The chi-square test and independence t-test were both conducted according to the type of variables. Either the chi-square test or independence t-test was used in order to analyze the relationship between personal variables (gender, age, position), experiential variables (frequency of use, knowledge of fire), recognition variables and evacuation behaviors. In addition, simulations were conducted by using the analysis program, known as SimuleX (Ver. 11.1.3), in order to calculate the time required for evaluation.

4. Results and Discussion
4.1 Experience and recognition of evacuees regarding use of the subway
Regarding usage frequency of the Daegu subway and the Jungangno station, more than half of the those surveyed responded that they used the Daegu subway line I more than once a day; most of those who used it more than once a day used the same subway more than twice for round trips. With respect to the Jungangno station where the accident occurred, almost half of the subjects responded that they had used that station more than once a day, as shown in Table 2. On average, they used the Daegu Subway 9.4 times a week (p-value = .961>\(\alpha\)=.05, standard error = 0.72), and the Jungangno station 6.5 times a week (p-value = .968>\(\alpha\)=.05, standard error = 0.72). Although there is no statistically significant difference between the respondents' gender and frequency of subway usage (t = 1.578, df = 89, p>0.05), the mean value was higher with regard to men (10.9 times, SD = 7.2) than with women (8.5 times, SD = 6.6).

Fig.4. presents the recognition level of the survivors regarding the evacuation passages in the Jungangno station. More than 70% responded that they could proceed to the ground level exit, regardless of the directional signs. As shown in Table 3., however, there is no statistically significant correlation between the Jungangno station passage recognition level and the usage frequency of the Jungangno station (x\(^2\) = 2.598, df = 8, p = 0.957>0.05). In addition, the gender difference shows no significant difference with regard to the passage recognition level at the Jungangno station (x\(^2\) = 2.862, df = 2, p = 0.239>0.05).

4.2 Evacuees' initial behavior and psychology
Despite the time difference regarding the fire occurrences between train 1079 and 1080, subjects...
responded that they had "waited (n = 47, 49%)" or "contacted someone outside (n = 19, 19.8%)" after they became aware of the subway fire. In other words, most of the passengers simply decided to wait, including about 20% of the passengers who requested help from the outside or reported using their cellular phones. Less than 30% of the subjects responded that they reacted immediately in order to initiate evacuation ("ran for safety instantly" = 6, "moved to another carriage" = 17). These respondents exhibited a tendency to merely observe the circumstances by moving into other carriages rather than taking refuge in a safe place. Additionally, the passengers inside the subway train carriage were unable to judge exactly what was going on outside due to the smoke from the fire. These environmental factors had an influence on delaying instant evacuation. There is a statistical difference between the initial evacuation behavior of the passengers in train 1079 and that of the passengers in train 1080, which had entered the station 5 minutes after the fire had occurred ($x^2 = 10.138$, df = 3, $p = 0.017 < 0.05$). Most passengers in train 1079 evacuated at the initial stage of the fire. On the other hand, the passengers in train 1080 tried to escape after the fire had advanced, and therefore had significantly aggravated the circumstances in comparison to the former. The degree of interest in the fire (interested = 15, thought that the fire has nothing to do with me = 74) made no significant difference in their initial evacuation behavior ($x^2 = 2.909$, df = 3, $p = 0.406 > 0.05$). However, those who had been interested in the fire represented a relatively higher percentage with respect to the fact that they escaped immediately (see Table 4.).

The factors which influenced the decision to take refuge after recognizing the life-threatening fire were smoke ($x^2 = 6.975$, df = 3, $p = 0.003 < 0.05$), or the degree of interest in the fire ($x^2 = 1.298$, df = 3, $p = 0.730 > 0.05$), as shown in Table 4. In addition, age groups, divided by 10 years, also do not represent a statistically significant difference.

However, the position of the carriage on the train relating to the fire made a significant difference regarding the passengers in train 1080 in deciding to evacuate ($x^2 = 34.186$, df = 15, $p = 0.003 < 0.05$). The position of the carriages on train 1080 and the motive for evacuation showed a degree of correlation ($\lambda = 0.235$). Namely, the 9 passengers in the 5th and 6th carriage of train 1080, who were closest to the place where the fire originated (see Fig.1.), decided to evacuate due to toxic gases and smoke (44.5%) or heat (33.3%) from the fire, not due to the announcement...
(22.2%). On the other hand, 83.3% of the 12 passengers on the 1st carriage of train 1080, which was the farthest from the place where the fire broke out, decided to evacuate after listening to the announcement 3 times.

4.3 Route selection of evacuees

Borgers (1986) and Seneviratne (1985) have reported that distance is the most important single factor in regards to the selection and restriction of a route for a pedestrian in ordinary circumstances. However, there are changes in their psychological and physiological reactions when people evacuate (Sime et al., 1994). The evacuation behavioral features in an underground space are different from those who escape from a building on the surface.

Since the Daegu subway fire occurred in an underground space and there was no emergency shelter, people were required to move to exits on the ground level. Therefore, smoke and the evacuees both moved in the same direction, from the underground to the ground level, as in most cases of an underground fire. In the underground, smoke movement and the lack of a location index make it difficult for people to select the evacuation route, or find the location of their position (Kwon, 2000; Lee 1997).

With regards to the Jungangno station, there were four valid exits to the ground surface at the time the fire occurred as illustrated in Fig.1. A total of 54.3% of the 94 subjects evacuated through exit 2, 11.7% through exit 1, 7.4% through exit 4 and 3.2% through exit 3. The remaining 23.4% of the evacuees did not remember which exit they used to exit to the open ground.

The distribution of evacuation exits shows that only 12% of the survivors evacuated through appropriate escape routes and exits. This figure, 12%, is considered to be low when considering that most of the evacuees had used the station often (mean frequency of use = 6.5 times/week), were aware of the passages (see Fig.4.) and more than 60% of the survivors had a planned evacuation route.

Only 15 subjects evacuated through the evacuation route as they had planned at the initial stage in the evacuation process, while 44 subjects had behaved differently and deviated from their planned evacuation routes. Moreover, 11 subjects had no planned route. With respect to the passengers of train 1080, the mean value of the carriage number was 1.7 in the case of passengers whose evacuation route coincided with the planned route as shown in Table 5. In cases in which the actual evacuation route differed from the planned one, the mean value was 3.1. This difference of the mean value in regards to the carriage number is considered to be statistically significant (t = -3.028, df = 46, p = 0.004<0.05). The difference in the frequency of usage of the Jungangno station, according to the coincidence of the evacuation route, was approximately 2 per week (see Table 5.), but this was not considered to be statistically significant (t = 1.046, df = 53, p = 0.300>0.05).

Respondents who had no planned route either only sought the stairs while they were evacuating, or were pushed out by the onrushing crowd. Those who responded that the actual evacuation route was different from the planned one encountered an evacuation obstacle more than once during the evacuation process: Smoke from the fire made it impossible to follow the planned route, thus forcing them to take an alternate route (74.6% of 59 subjects answered "yes" or "no"). Namely, evacuees could not find their planned evacuation routes and had to follow different routes for three main reasons. First, they were pushed from behind by the crowd and had no choice. Secondly, they were unable to see and lost their sense of direction due to poor visibility conditions. Thirdly, the evacuation guide facilities, such as the exit signs, did not work effectively. This has been confirmed, both by the survivors’ direct statements and in their responses to the questionnaire.

A total of 43 evacuees (49.4% of 87 subjects) had to repeatedly traverse the same passage due to the impaired vision caused by smoke, the unclear location of stairs, separation from the person who was leading the way, as well as blocked passages. They experienced this most frequently on the second underground level (especially before passing the ticket gate) and also on the platform of the 3rd underground level.

4.4 Evacuation method and perception of the circumstances

When people move as individuals, the characteristics of behavioral features can be classified into several types. First, people tend to move to the shortest linear route (Bovy and Stern, 1991; Seneviratne and Morrell, 1985). People also attempt the most simple way that has fewer direction changes, even if it is not the shortest route (Marchand, 1974). The other factors are the preference of a brighter route to a darker one (Kim, 1992), as well as following the movement of the crowd stream (Kim, 1992).

In regards to the Daegu subway fire, 49.4% of the 85 subjects used the method of "moving forward by touching the wall (see Fig.5.")", and 30.6% exhibited

Table 5. Subjects’ frequency of use and their location on the trains according to coincidence between the planned evacuation route and the actual evacuation route. Passengers in train 1079 were excluded as they didn’t remember the carriage number. If the carriage number was close to 6, subjects in that carriage were close to the place where the fire originated as shown in Fig.1.

| Coincidence of the evacuation route | Yes | No |
|------------------------------------|-----|----|
| Frequency of the Jungangno station usage per week (Mean value / Standard Deviation) | 10.3 / 8.2 | 8.0 / 6.3 |
| Carriage number (Mean value / Standard Deviation) | 1.7 / 1.4 | 3.1 / 1.3 |
follow-the-others type of behavior, moving along with others by holding on to their clothes or parts of the body. 3.5% of evacuees moved forward by grasping a handrail. This means that the handrails had not been installed to be used easily by evacuees during an emergency. As shown in Table 6., there was a statistically significant difference between the movement method and gender ($\chi^2 = 18.757$, df = 3, $p = 0.000<0.05$). However, the separate analysis of those in their 30s ($\leq 30$ or $>30$), 40s and 50s found no statistically significant difference between age and the movement method regarding the evacuation process.

Light was the most helpful factor for the evacuees while they were evacuating (54.0% of 87 subjects); various light sources, such as evacuation guide lights, advertisement lights, and the rescue crew's flashlights. Following the person who was familiar with the passages (20.7%), and following the voice of the person who was familiar with the passages (13.8%) in that order. Other responses (11.5%) included survivors who did not answer the question or were non-respondents, and 2 persons who had responded by writing "the wall" for an answer. For successful evacuation to have occurred, as described earlier, most subjects would have searched for stairs that led to the upper levels and moved to their desired location by touching the wall and relying on it as a guide.

On the other hand, the greatest obstacles to evacuees were bad visibility (49.3% of 67 subjects), smoke (19.4%) and staircases (13.4%), irrespective of gender and age. That is, poor visibility as well as vision impaired by smoke caused evacuees to lose their respective sense of direction. Especially, a large-sized underground space, such as the Jungangno subway station, requires long horizontal movements for evacuation purposes. Therefore, poor visibility and impaired vision would make it extremely difficult for evacuees to select an evacuation route, forcing them to slow down. In addition, the ticket gates, the fire shutters, the pillars, and the presence of other evacuees were factors that interfered with, and obstructed safe and quick evacuation. A total of 48% of the subjects had difficulties in walking on the stairs that they had to climb several times to escape to the ground; this result was higher than those of evacuees who responded "No" (37%) (Blake et al., 2004). In addition, the height (280mm) of the staircases, with too many steps, had caused more difficulty than their width (3,200mm) with respect to the evacuees.

The obstacles on the platform are exhibited in Table 7. The platform is the farthest place from a ground exit and was in the worst condition in terms of evacuation. When the passengers on the platform moved from the 3rd basement level to the 2nd, they had difficulty in seeing and determining the width of the platform. The difficulty was aggravated further by the dense smoke and the blackout caused by the power failure. The smoke density and air temperature were highest on the platform because fires had broken out on the same floor. Additionally, when all the passengers rushed out of the carriages on to the platform, shocked by the fire, bumping and colliding into one another en masse at once, they had an even a greater difficulty in escaping to safety (Yang, 2005). This is what is often referred to as a panic situation in an emergency. On the platform of the Jungangno station, it is possible for 10 persons (9.8 men or 11.3 women) to stand still side-by-side considering the average human shoulder breadth. If people move about rather than stand still, far fewer numbers of people can move on the platform at the same time. However, the result of the SimuleX analysis indicated that no valid difference was observed in regards to the duration of evacuation according to the width of the platform (see Fig.6.). In addition, the pillars on the platform blocked the movement of evacuees and caused them to lose their sense of direction. In ordinary circumstances, an array of pillars as shown in Fig.7. could indicate a specific direction to help the evacuees. But in the case that evacuees can

![Fig.5. Evacuee Moving by Groping the Wall in the Evacuation Experiment Conducted after the Daegu Subway Fire](image)

Table 6. The Method of Moving Forward

| Method                                      | Male     | Female   | Overall  |
|---------------------------------------------|----------|----------|----------|
| Moved by relying on the wall                | 18 (60.0%) | 24 (43.6%) | 42 (49.4%) |
| Moved by grasping the person's clothes ahead| 1 (3.3%)  | 25 (45.5%) | 26 (30.6%) |
| Moved according to the person's own decision| 9 (30.0%) | 5 (9.1%)  | 14 (16.5%) |
| Moved by grasping a handrail                | 2 (6.7%)  | 1 (1.8%)  | 3 (3.5%)  |
| Valid subjects in total                     | 30        | 55        | 85        |

Table 7. Factors Concerning Obstacles to Evacuation on the 3rd Underground Level (77 Valid Subjects)

| Factor                                | Percentage |
|---------------------------------------|------------|
| Poor visibility                       | 40.3%      |
| The width of the platform             | 33.8%      |
| People around                         | 6.5%       |
| Installations like newspaper stands   | 3.9%       |
| Others                                | 15.5%      |
see no further than the inter-pillar distance, as was the case in this accident, these pillars can be significant obstacles to movement. Therefore, in order to remove this type of obstacle factor, it is necessary to install a luminescent apparatus at the bottom part of a pillar while considering people's movement posture and sight direction.

4.5 Evacuation guide light

Most of the survivors responded that, in the process of their evacuation, they did not see any evacuation guide lights that pointed to the direction of the emergency exit after they had made up their minds to escape to safety (see Fig.8. and 9). In addition, they responded that the evacuation guide lights they found did not help with their evacuation. A total of 94.4% of the respondents, 89 subjects, responded that they did not see a guide light while evacuating, and 93.3% of the survivors, 90 subjects, responded that the guide light they found was of no help. This indicates that the previously installed guide lights were not able to serve their originally intended functions due to smoke from the fire as well as various other obstacles. If we take into consideration those reported behavioral patterns of "moving by leaning against the wall", "moving by following the persons ahead", and "moving with the body lowered to the floor", the locations and distances of previously installed guide lights should be readjusted for more effective evacuation purposes. Since it has been proven that the previously installed guide lights do not work effectively in a fire, improved devices, such as those the authors recommend, should be installed in large underground facilities. Improved guidance devices should provide effective lifesaving information to evacuees regardless of visibility issues due to fires. The devices, which utilize either audible sense or tactile sense, are not influenced by smoke or impaired vision.

5. Conclusions and Recommendations

The Daegu subway fire, as noted, claimed the highest number of casualties in the history of subway use in South Korea. In regards to this research, the authors examined and analyzed the evacuation behavior, as well as the evacuees' perception characteristics in the Daegu subway fire, in order to draw their conclusions on the basis of the actual and empirical data sources. The authors findings with regard to this study led them to draw the following conclusions in order to improve evacuation safety in an underground emergency.

Although about one half of survivors are usually able to proceed through the desired exit without the aid of a directional sign, only 12% of the evacuees could exit through an appropriate escape route at the time of the fire. Moreover, when the fire broke out, the passengers reacted passively by either waiting for help or by contacting someone outside for help instead of instantly initiating evacuation actions for themselves. Therefore, in order to reduce the incidence of
casualties with regard to a similar underground fire, it is necessary to make announcements that can minimize panic and, at the same time, give passengers clear evacuation instructions, telling them what they should do instantly in order to save themselves. In addition, since crowd psychology conditions are liable to cause passengers to react to an emergency rather passively, the general public should be provided with systematic education and drilling that would teach them how to escape actively and safely in the case of an emergency.

It is necessary to develop and install evacuation guide lights which are easier to recognize and can give practical help to evacuees. In addition, it is necessary to develop emergency guide devices that can also make use of hearing and tactile senses as well as vision. Most survivors responded that they did not recognize the guide lights while evacuating, nor did the guide lights help their evacuation. Under these circumstances, evacuees tended to move by touching the wall, lowering their bodies to the floor in order to breathe less polluted air. Therefore, for a fast and safe evacuation to occur, besides installing guide lights to secure visibility enabling the evacuees to see where they are going, it is necessary to install evacuation guide lines on the walls and the surfaces of the passages. Additionally, in a large-scale underground facility, pillars can make it difficult for people to egress. Thus, luminescent devices are recommended on the bottom part of a pillar in order to prevent the blocking of an evacuee's course or causing the evacuee to lose direction.

In general, the last place for safe evacuation with regard to an underground fire is the ground surface. However, the initial evacuation was delayed because most of the evacuees waited for the announcements, and initiated actions only when forced by the smoke from the fire to do so. By the time the evacuees started to escape, the fire had quickly advanced and the surrounding conditions were negatively aggravated for safe evacuation. According to this research, more than one half of the evacuees followed an actual evacuation route that was different from the planned one. Therefore, it is necessary to consider an underground square as a temporary evacuation space in an underground location, as well as post clear directions suit the characteristic features of the specific underground facility. Additionally, it is recommended that evacuation experts, who are qualified to lead and guide in the event of an evacuation, be trained and dispatched. Plans for evacuation passages should incorporate an effective system that plans, manages, and guides the smooth and safe movement of a large number of people.

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