Discussion on Destination Control System for Up-Peak Traffic with Non-Uniform Distribution of Passenger's Destination

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Abstract. Various policies are used by lift group control systems to provide good services to passengers on the main floor during up-peak traffic. One of those is the so-called destination control system, in which the destination floors covered by each car are dynamically decided based on the destination information entered by passengers at a lift hall. The destination control system is expected to improve round trip time and handling capacity. The degree of improvement depends on the distribution of passengers' destinations because the distribution affects sectoring which is the division of the building floors into groups of floors. In lift traffic design, designers usually evaluate the destination control system on only the uniform distribution. This paper shows the up-peak equations for the destination control system for non-uniform distribution. In the numerical experiments, the probability distribution is expressed as the cumulative distribution function of the truncated normal distribution with mean μ and standard deviation σ. Numerical results show that one method of sectoring is effective for uniform distributions but less effective for non-uniform distributions, and we discuss the implications of these result.

1 INTRODUCTION

Handling up-peak traffic has been a significant issue for group lift scheduling systems for a long time. This is because the passengers gather at the main floor such as an entrance floor at the same time, and queue in front of the lift in some cases. To solve this issue, the lift traffic designer uses an up-peak traffic calculation to design a lift whose handling capacity, which is the number of passengers transported by the lift, is more than the number of passengers occurring at the main floor. The handling capacity is calculated on the assumption that every car carries CAP passengers per round trip. CAP is usually the maximum number of passengers boarding a car. Thus, we can assume that $K \times CAP$ passengers occur per the round trip time, where K is the number of cars. Recently, the destination control system has been attracting attention as an advanced lift. The formulation for the destination control system is based on the conventional system and assumes to know the destination of the $K \times CAP$ passengers prior to them registering their destinations [1][2][3]. Hence, if the destination information changes, the handling capacity and round trip time for the destination control system will be affected. In practice, the probability distribution is not always uniform and changes over time due to tenants, flexes, etc. However, designers usually design based on a uniform distribution. This paper shows up-peak traffic equations for the destination control system for non-uniform distribution which is discussed based on numerical results.

2 FORMULATION FOR TRAFFIC CALCULATION

This section shows the up-peak traffic equations on the assumption that $K \times CAP$ passengers occur per the round trip time and the distribution of passengers' destinations is non-uniform.

2.1 Conventional system for arbitrary probability distribution

Barney and Al-Sharif introduce the round trip time and the handling capacity for the conventional collective control system for non-uniform distribution [2].

Let us assume that served floors above the main entrance are $\Phi = \{1,2, \ldots, N\}$, and the probability of getting off on the n-th floor is expressed as $P(n)$. The probability that nobody gets off on the n-th floor is $(1 - P(n))^{CAP}$, where CAP is the number of passengers boarding one car. Since the probability that somebody gets off on the n-th floor is $1 - (1 - P(n))^{CAP}$, the expected number of stops S is calculated as follows:

$$S = \sum_{n \in \Phi} \left(1 - \left(1 - P(n)\right)^{CAP}\right) \tag{1}$$

The probability that one passenger will get off on the 1-th, 2 -th, …, n-th floors is $\sum_{m \in \Phi(n)} P(m)$, where $\Phi(n) = \{m \in \Phi \mid m \leq n\}$. If there are CAP passengers in a car who will get off on the 1-th, 2 -th, …, n-th floors, the car travels no higher than n-th floor. The probability of the car travelling no higher than n-th is shown by:

$$Q(n) = (\sum_{m \in \Phi(n)} P(m))^{CAP}, \quad n \in \Phi. \tag{2}$$

The probability that the i-th floor is the reversal floor is $\left(Q(n) - Q(n-1)\right)$. The expected reversal floor (H) is calculated as follows:

$$H = \sum_{n \in \Phi} n\left(Q(n) - Q(n-1)\right), \ \mathrm{Q(0) := 0} \tag{3}$$

According to Barney and Al-Sharif [2], round trip time RTT and HC based on (1) and (3) are expressed as follows:

$$RTT = 2 \times H \times t_v + (S+1) \times t_s + 2 \times CAP \times t_p$$

(4)1

$$HC = \frac{K \times CAP \times 300}{RTT} \tag{5}$$

2.2 Destination control system

The destination control system is dynamic sectoring and dynamic allocation [1]. The sectoring is division of building floors into groups of floors, which are called sectors. The dynamic sectoring means that the size and composition of sectors change per lift round trip. Dynamic allocation refers to the lifts being allocated to different sectors in different round trips. There are several methods of sectoring, which affects the performance of the destination control system [1][3]. In this section, we formulate equations for the destination control system on i-th round trip after sectoring.

Let us assume that the destination group control system knows in advance the destination floor probability distribution $P(n)$ for $K \times CAP$ passengers on the i-th round trip, where $i = 1,2, \ldots$. The destination control can perform sectoring based on the prior information before the passengers register. Here, we set $\Omega_k^{(i)}$ as the sector allocated to car k on i-th round trip, noting the number of sectors is equal to the number of cars. Then, car k only carries passengers destined for floors included in the sector $\Omega_k^{(i)}$. Thus, the probability distribution of one passenger in the car k will get off on n-th floor is expressed by

$$\hat{P}_k^{(i)}(n) = \frac{\alpha_k^{(i)}(n)\, P(n)}{\sum_{m \in \Omega_k^{(i)}} \alpha_k^{(i)}(m) P(m)}, \tag{6}$$

where $\alpha_k^{(i)}(n)$ is a parameter for cases where one or more floors overlap, and satisfying $0 < \alpha_k^{(i)}(n) \leq 1$ and $\sum_{k=1}^{K} \alpha_k^{(i)}(n) = 1$. If only one car stops on the n-th floor, $\alpha_k^{(i)}(n) = 1$. When multiple cars stop on the n-th floor, the sum of $\alpha_k^{(i)}(n)$ for these multiple cars becomes 1.

The expected number of stops $\hat{S}_k^{(i)}$and the expected reversal floor $\widehat{H}_k^{(i)}$ is derived from using $\hat{P}_k^{(i)}(n)$ for the process similar to Section 2.1.

$$\hat{S}_k^{(i)} = \sum_{n \in \Omega_k^{(i)}} \left(1 - \left(1 - \hat{P}_k^{(i)}(n)\right)^{CAP_k^{(i)}}\right) \tag{7}$$

$$Q_k^{(i)}(n) = \left(\sum_{m \in \Omega_k^{(i)}(n)} \hat{P}_k^{(i)}(m)\right)^{CAP_k^{(i)}} \tag{8}$$

$$\widehat{H}_k^{(i)} = \sum_{n \in \Omega_k^{(i)}} n \left(Q_k^{(i)}(n) - Q_k^{(i)}(n-1)\right) \tag{9}$$

where $\Omega_k^{(i)}(n) = \left\{m \in \Omega_k^{(i)} \,\middle|\, m \leq n\right\}$. Please note here that if $K \times CAP$ passengers hope to use the lift on the i-th round trip and $\sum_{n \in \Omega_k^{(i)}} \alpha_k^{(i)}(n) P(n) > 1/K$, $K \times CAP \times \sum_{n \in \Omega_k^{(i)}} \alpha_k^{(i)}(n) P(n)$ passengers greater than CAP hope to ride on the car k however, the car is only capable of transporting CAP passengers. On the other hand, if $\sum_{n \in \Omega_k^{(i)}} \alpha_k^{(i)}(n) P(n) \leq 1/K$, the car transports only $K \times CAP \times \sum_{n \in \Omega_k^{(i)}} \alpha_k^{(i)}(n) P(n)$ passengers lower or equal to CAP. Therefore, the number of passengers boarding the car k on i-th round trip is calculated as follows:

$$CAP_k^{(i)} = \min\left(K \times CAP \times \sum_{i \in \Omega_k^{(i)}} \alpha_k^{(i)}(n) P(i), CAP\right) \tag{10}$$

The round trip time for the destination system with respect to the car k and i-th round trip is obtained by substituting (7) and (9) for S and H in (4), respectively.

$$\widehat{RTT}_k^{(i)} = 2 \times \widehat{H}_k^{(i)} \times t_v + \left(\hat{S}_k^{(i)} + 1\right) \times t_s + 2 \times CAP_k^{(i)} \times t_p \tag{11}$$

Since the destination control system is dynamic allocation, the average round trip time for the lift on i-th round trip is written by

$$\widehat{RTT}^{(i)} = \frac{\sum_{k=1}^{K} \widehat{RTT}_k^{(i)}}{K} \tag{12}$$

K cars per one round trip carry $\sum_{k=1}^{K} CAP_k^{(i)}$ passengers during $\widehat{RTT}^{(i)}$. Here, let us define that I is the number of rounds within 5 min, which is satisfying $\sum_{i=0}^{I} \widehat{RTT}^{(i)} \leq 300$, $\widehat{RTT}^{(0)} := 0$. Then, the lift carries $I \times \sum_{k=1}^{K} CAP_k$ passengers by I round trips, and as many passengers as it can carry during $300 - \sum_{i=0}^{I} \widehat{RTT}^{(i)}$ on $I+1$ -th round trip. Therefore, the handling capacity for the destination control system is follows as:

$$\widehat{HC} = \sum_{k=1}^{K} CAP_k^{(i)} \times \left(I + \frac{\left(300 - \sum_{i=0}^{I} \widehat{RTT}^{(i)}\right)}{\widehat{RTT}^{(I+1)}}\right) \tag{13}$$

3 NUMERICAL EVALUATION

In this section, we calculate the round trip time and the handling capacity while changing the standard deviation for the probability distribution. Firstly, we set an example of calculated building information and the probability distribution given by the truncated density function. Next, we simplify numerical evaluation. By regarding the destination control system as static sectoring and dynamic allocation, we rewrite (12) and (13). In a numerical experiment, we calculate the conventional system and the destination control system with two types of sectors.

3.1 Example of building information

We set each car as $\mathrm{K} = \{1,2,3,4\}$ and floors above the main floor as $\Phi = \{2,3,\ldots,17\}$. Table 1 is the required parameters for the calculations not yet shown above.

Table 1 Definition of parameter

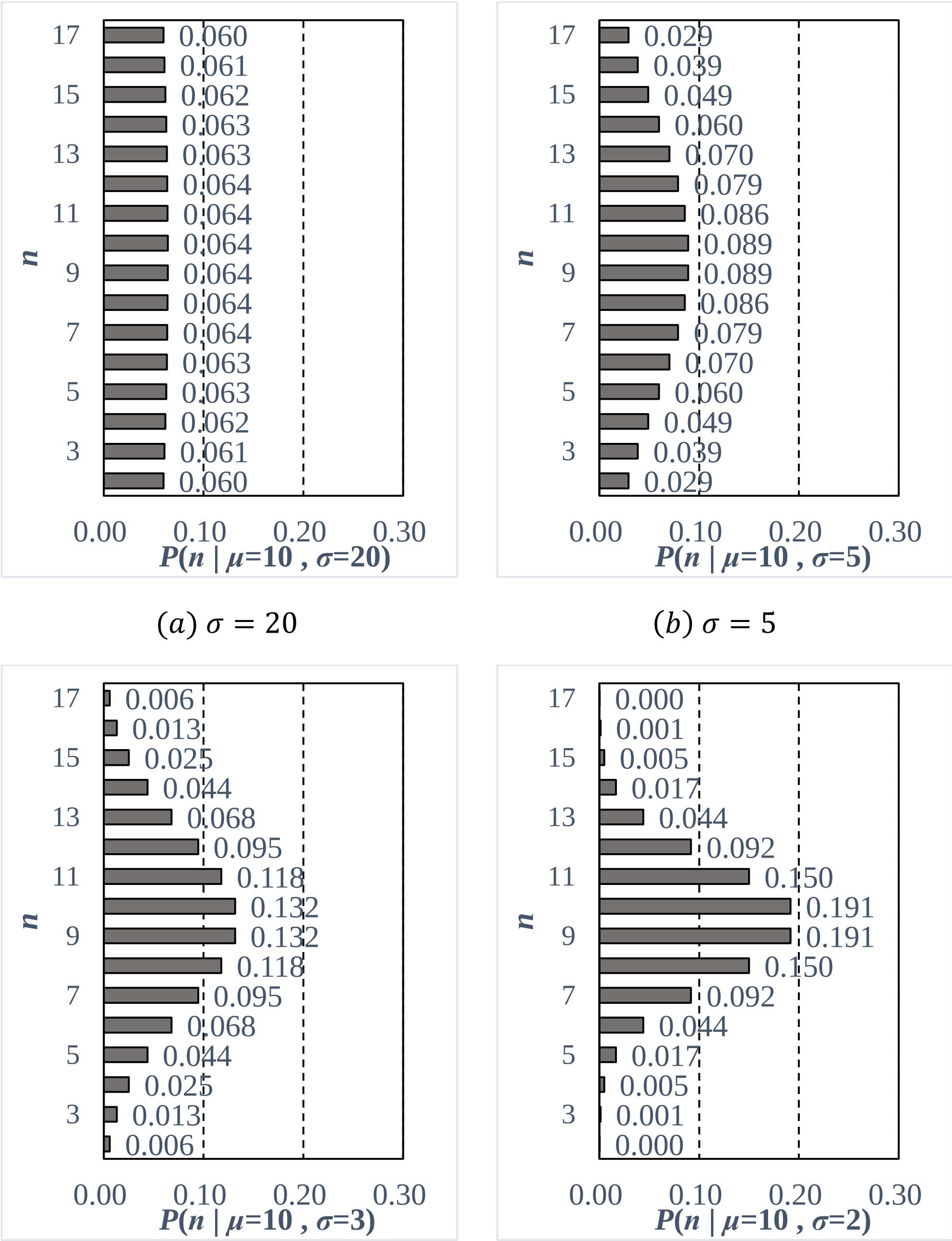
Parameter	Symbol	Value
Average interfloor distance	D_f	4000mm
Maximum number of passengers in car	CAP	20
Rated velocity	V	1.5m/sec.
Acceleration and deceleration	acc	0.8m/sec^2
Door opening time + Door closing time	t_{door}	4.3sec.
Average one-way passenger transfer time	t_p	1.0sec.

3.2 Distribution of destination floor

If the cumulative distribution function of the truncated normal distribution with mean μ and standard deviation σ is defined as $F(n|\mu, \sigma, 1 \leq n \leq N)$, the probability $P(n)$ of getting off on the n-th floor is expected to be as follows:

$$P(n|n \in \mathbb{Z}, 2 \leq n \leq N) = F(n) - F(n-1) \tag{14}$$

Figure 1 shows the distribution of the destination for $\mu = 10$ and $\sigma = 20, 5, 3, 2$. It can be seen that the lower the standard deviation σ is, the more the destination floor is clustered around the mean μ.



$(c)\ \sigma = 3$ $(d)\ \sigma = 2$

Figure 1 Distribution of destination floor

3.3 Destination control system for static sectoring

In lift traffic design, the handling capacity and the round trip time for the destination control system are usually calculated on the assumption that sectoring is static. Static sectoring refers to the composition of the sector as fixed on every round trip.

By static sectoring, where all sectors on the first round trip are equal to the sectors on subsequent round trips, we obtain relationships (15)

$$\Omega_k^{(i)} = \Omega_\ell^{(1)}, \quad k, \ell \in \{1,2,\dots,K\} \tag{15}$$

From (15), (12) is rewritten as follows:

$$\widehat{RTT} = \frac{\sum_{k=1}^{K} \widehat{RTT}_k^{(1)}}{K} \quad (16)$$

, where $\widehat{RTT} = \widehat{RTT}^{(i)}$. Substituting (12) as (14), we obtain

$$\widehat{HC} = \frac{\sum_{k=1}^{K} CAP_k^{(1)} \times 300}{\widehat{RTT}} \quad (17)$$

In this numerical experiment, we set two types of sectors as follows:

$$\Omega_1^{(1)} = \{2,6,10,14\}, \Omega_2^{(1)} = \{3,7,11,15\}, \Omega_3^{(1)} = \{4,8,12,16\}, \Omega_4^{(1)} = \{5,9,13,17\} \quad (18)$$

$$\Omega_1^{(1)} = \{2,3,4,5\}, \Omega_2^{(1)} = \{6,7,8,9\}, \Omega_3^{(1)} = \{10,11,12,13\}, \Omega_4^{(1)} = \{14,15,16,17\} \quad (19)$$

3.4 Numerical result

The round trip time and the handling capacity for the conventional system and destination control system with the two types of sectors are calculated based on sections 3.1, 3.2 and 3.3.

Tables 2 and 3 show the round trip time and handling capacity, respectively, when there are $K \times CAP$ passengers per each round trip. With the uniform probability distribution $\sigma = 20$, the destination control system with (19) has the best round trip time and the best handling capacity. However, as σ becomes smaller, the handling capacity becomes smaller even though the round trip time of the destination control system with (19) becomes smaller. The reason is that the round trip time and the handling capacity are calculated for the cars allocated $\Omega_1^{(1)} = \{2,3,4,5\}$ and $\Omega_4^{(1)} = \{14,15,16,17\}$ running with less than CAP passengers because of $\sum_{n\in\Omega_k^{(1)}} P(n) < 1/K, k = 1,4$. On the other hand, there are more than CAP passengers who hope to board the cars allocated $\Omega_2^{(1)} = \{6,7,8,9\}$ or $\Omega_3^{(1)} = \{10,11,12,13\}$ because of $\sum_{n\in\Omega_k^{(1)}} P(n) \geq 1/K, k = 2,3$. Thus, left-behind passengers occur.

Table 2 Round trip time

	RTT (sec.)			
	20.00	5.00	3.00	2.00
Conventional system	218.97	213.13	195.36	172.24
Destination control system with (18)	158.35	157.31	148.68	132.91
Destination control system with (19)	134.03	133.93	116.66	102.75

Table 3 Handling Capacity

	HC (persons/5min.)			
	20.00	5.00	3.00	2.00
Conventional system	109.60	112.61	122.85	139.34
Destination control system with (18)	151.48	151.96	161.20	179.75
Destination control system with (19)	177.28	152.82	139.09	127.40

The round trip time and the handling capacity of the destination control system with (18) improve as σ is small. The improvement in the round trip time is due to the lower reversal floor. Moreover, the destination control system with (18) satisfies $\sum_{n\in\Omega_k^{(1)}} P(n) \approx 1/K$, $k = 1,2,3,4$, for $\sigma = 20, 5, 3, 2$ so that the cars carry about CAP when they leave the main floor. Therefore, the handling capacity of the destination control system with (18) increases as σ is small.

In general, the distribution of the destination floor $P(n)$ can be calculated from the population on each floor. The population on each floor is roughly estimated on the basis of the floor space at a design time of a new building. Since the same number of people are supposed to live in the equivalent floor space, the distribution of the destination floor often looks uniform. However, in practice, the distribution is not always uniform. There is a possibility that the distribution changes with tenant replacement. Even if the distribution calculated from the population is uniform, the distribution of the passengers transported in the round trip is not always uniform, and $P(n)$ will be defined as a function of time. Furthermore, tenants often introduce flexible working time, which affects the distribution.

Although the destination control system is robust to handle the change in the distribution, if the handling capacity is insufficient, there is a possibility that a change of sectoring might reduce the line of passengers. On the other hand, if the lift traffic has been designed on the assumption of the one type of sectoring with uniform distribution in the first place, it is difficult to reduce the waiting line later, when it includes more than the expected number of passengers and the unexpected distribution of the destination floor.

In this paper, we assume that passenger destinations are known prior to the passengers registering for the lift, although in reality their destination is unknown until they register. Even if the destination control system (19) is actually applied by predicting in real time that the distribution of passenger destination is uniform, if the prediction is wrong, the performance will be degraded as well as the numerical result.

In lift traffic design, it is important to totally evaluate calculations for several types of sectors and for several probability distributions.

4 CONCLUSION

In this paper, we formulate up-peak traffic equations for the destination control system on the non-uniform distribution of passenger destination. In a numerical experiment, we calculate the round trip time and the handling capacity using the formulation on the assumption that the probability distribution $P(n)$ is the cumulative distribution function of a truncated normal distribution with mean μ and standard deviation σ and the destination control system is static sectoring. Numerical results show that even for the one type of sector with the best handling capacity in uniform distribution, it deteriorates in non-uniform distribution. This suggests that the lift traffic design with the destination control system which can be applied to several types of sectors is more robust.

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