Performance Comparison between Immediate and Nonimmediate Passenger Guidance in Group Control for a Multi-Car Elevator System

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ABSTRACT
A multi-car elevator system is such an elevator system that more than one car is installed in every elevator shaft. In this study we consider a call allocation problem in group control for a multi-car elevator system with nonimmediate passenger guidance. In nonimmediate passenger guidance the car allocated to a passenger is indicated to him/her just before the car arrives at the floor where he/she is waiting. On the other hand, in immediate passenger guidance the car is indicated immediately after a call is registered at an elevator hall. We will propose a simple call allocation algorithm by a local search for nonimmediate passenger guidance and compare its transportation capability with that of immediate passenger guidance by computer simulation.

Keywords: multi-car elevator system, nonimmediate passenger guidance, call allocation, local search

1. INTRODUCTION

Along with the increase of high-rise buildings, multi-car elevator systems have been attracting considerable attention (ThyssenKrupp Elevator 2005, Onat, et al. 2011, Valdivielso and Miyamoto 2011). A multi-car elevator system is such an elevator system that more than one car is installed in every elevator shaft (hoistway). Figure 1 shows a typical multi-car elevator system. In our previous studies (Tanaka and Watanabe 2009, 2010) we proposed an optimization-based collision avoidance algorithm for a realistic multi-car elevator system where floor stop time of a car cannot be known in advance by the system. It was shown by computer simulation that a simple call (passenger) allocation algorithm together with the proposed collision avoidance algorithm can improve the transportation capability of the system much compared to an ordinary single-car elevator system. In these studies immediate passenger guidance was assumed: The car that a passenger should board is indicated to him/her immediately after he/she pushes a button at an elevator hall and registers his/her destination floor. It is true that this is a user-friendly interface, but disadvantageous from the viewpoint of improving transportation capability because call allocation should be fixed early and hence its freedom is restricted. On the other hand, in nonimmediate passenger guidance the car is not indicated to a passenger until his/her car arrives at the floor. Compared to immediate passenger guidance, better transportation capability can be expected at the expense of user-friendliness.

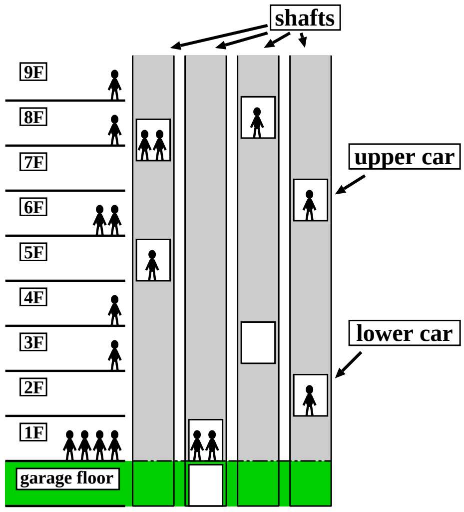


Fig. 1: Multi-Car Elevator System

The purpose of this study is to propose a simple call allocation algorithm for a multi-car elevator system with nonimmediate passenger guidance. Then, its transportation capability will be compared with that of a system with immediate passenger guidance by computer simulation.

2. SYSTEM CONFIGURATION

In this section we will describe the multi-car elevator system treated in this study.

Let us consider that an M-story building (the highest floor is the M-th floor) where a multi-car elevator system with two cars in every elevator shaft is installed. The entrance is the 1st floor and there is a garage floor under it where the lower car escapes to when the upper car is going to stop at the 1st floor (see Fig. 1). The hall call registration is destination-based. That is, a passenger who comes to an elevator hall at some floor registers his/her destination floor directly by pushing a button if it is not registered yet (Fig. 2(a)). The reason why such a destination hall call registration system is adopted in multi-car elevator systems is that the lower cars cannot go up to the highest (M-th) floor and hence destination floors of passengers are necessary for call allocation.

The shaft indicator panel and the destination-based

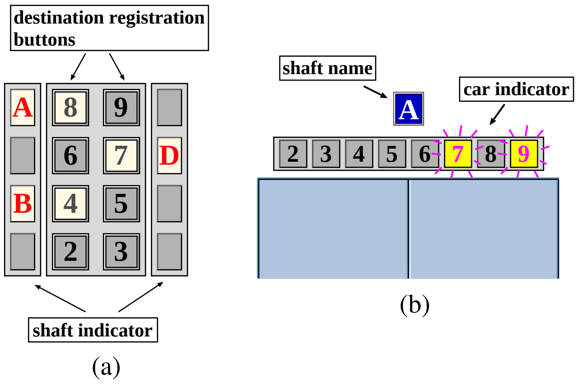


Fig. 2: (a) Destination Registration Buttons and Shaft Indicator, (b) Destination-Based Car Indicator

car indicator panel are used to guide passengers to the cars that they should board. The former is installed aside the destination registration buttons and the latter is above the door at each shaft (Fig. 2). In immediate passenger guidance (Tanaka and Watanabe 2009, 2010), the shaft indicator panel displays the shaft where he/she should wait for his/her car immediately after his/her destination floor is registered. The car indicator panel at that shaft displays the passenger's destination floor to urge him/her to board his/her car when the car stops at the floor (before the door opens). On the other hand, in the nonimmediate passenger guidance considered in this study, the shaft and the destination floor are displayed at the same time when the passenger's car stops at the floor.

The group control system for this multi-car elevator system is composed of a group controller and shaft controllers as shown in Fig 3. The group controller allocates calls to cars and generates car travel schedules by the selective-collective operation (Strakosch 1998), i.e. the ordinary elevator car operation, without considering collisions. Then, the shaft controllers control individual cars by modifying the travel schedules passed from the group controller so that collisions never occur. This study treats the call allocation algorithm in the group controller.

3. OPTIMIZATION-BASED COLLISION AVOIDANCE – AN OVERVIEW

Here, we will give a brief summary of the optimization-based collision avoidance for the shaft controllers proposed in our previous studies (Tanaka and Watanabe 2009, 2010).

Since passengers are assumed to push buttons at elevator halls only when their destination floors are not registered yet, the number of passengers corresponding to one call is unknown. Moreover, passenger boarding/leaving time varies in practice. It follows that the system cannot know in advance how long a car should stop at a floor. Therefore, in the proposed collision avoidance algorithm collisions are considered only until cars reach floors to be visited next, and the cars are assumed to stay there infinitely long. The collision avoidance algorithm is applied again when one of the cars finishes unloading passengers and becomes ready to start, This is repeated until all the passengers are served. To be

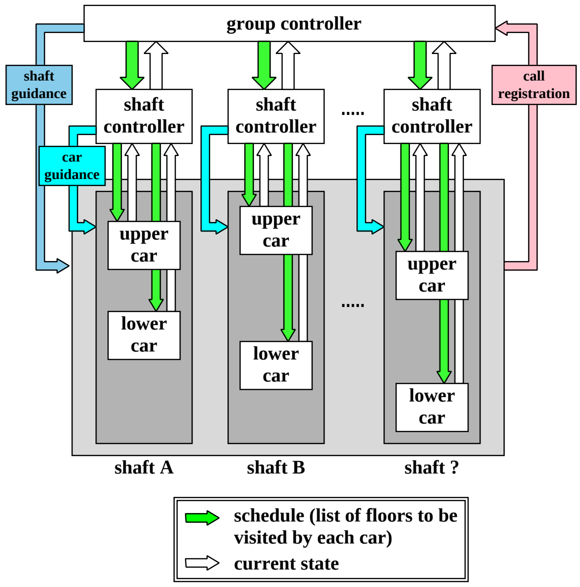


Fig. 3: Group Control System for Multi-Car Elevator

more precise, the collision avoidance algorithm is triggered when

(a) a new call is assigned to one of the cars in the shaft,
(b) a traveling car arrives at a floor,
(c) a car closes the door and becomes ready to start.

To determine floors to be visited next by cars, all feasible combinations are enumerated so that objective functions are minimized. In our first study (Tanaka and Watanabe 2009) an objective function to suppress reversal is adopted as the primary objective function, where reversal is such an undesirable car operation that onboard passengers travel in the opposite direction of their destination floors. However, in computer simulation reversal occurred frequently especially when passenger traffic is heavy. Moreover, a shaft could enter a livelock state and no call was served at all, although it was ensured that deadlock never occurs. Therefore, we improved the collision avoidance algorithm in the subsequent study (Tanaka and Watanabe 2010) so that reversal never occurs. For this purpose, suppressing reversal is regarded as a constraint instead of an objective function. It is also ensured that the system can always escape from a livelock state by switching the objective function when livelock is detected.

4. CALL ALLOCATION ALGORITHM FOR NONIMMEDIATE PASSENGER GUIDANCE

In this section we will first describe the call allocation algorithm in our previous studies for immediate passenger guidance. Then, we will propose a simple algorithm for nonimmediate passenger guidance.

In the case of immediate passenger guidance, a call is allocated to a car of some shaft immediately after it is registered at an elevator hall. Therefore, the optimal (in the sense that some objective function is minimized) allocation of the call can be easily obtained by enumerating all the possible allocations because the number of allocations that should be considered is at most the number of cars in the system. In our previous studies, which car

Table 1: Car Allocation by Zoning

direction	call type origin floor	call type destination floor	allocation
up	—	lower half	lower car
	—	upper half	upper car
down	lower half	—	lower car
	upper half	—	upper car

(upper or lower) should be used in a shaft is determined by zoning (Strakosch 1998) (see Table 1) and only the shaft is determined by such an enumerative approach.

On the other hand, in nonimmediate passenger guidance, we allocate a new call tentatively to a car of some shaft by the same method as that for immediate passenger guidance. Then, this allocation is repeatedly modified at every instant when the state of the shaft changes. These timings are the same as those when the optimization-based collision avoidance is triggered (see Section 3.). It is obvious that a simple enumerative approach is too time-consuming and hence intractable in this case, because allocations of several calls should be optimized at every time instant of the modification. To overcome this, a local search is employed to obtain a near-optimal allocation. It only searches for shaft allocation, and car allocation in the selected shaft is always determined by zoning as in the algorithm for immediate passenger guidance. The neighborhood in this local search is a combination of insertion and interchange. That is, the neighborhood of the current allocation (solution) is defined by all the solutions obtained by moving one call from the allocated car to another or by interchanging two calls allocated to different cars.

5. CALCULATION OF OBJECTIVE VALUE

To perform the local search in the preceding section, it is necessary to evaluate each allocation of calls. The optimization-based collision avoidance also requires to evaluate each combination of next visited floors. These evaluations are based on the passenger waiting time or service time. Here, the waiting time of a passenger is the time from when he/she appears at an elevator hall until when he/she boards a car. On the other hand, the service time of a passenger is the time from when he/she appears at an elevator hall until when he/she leaves a car at his/her destination floor. It is natural to use these for the evaluation of elevator operation because to transfer passengers as soon as possible is the primary purpose of elevator systems. However, their exact values are unknown from the elevator control system and hence should be estimated by some method. One reason of it is that the number of passengers that correspond to one call is unknown. Another reason is that car travels in the future are unknown even if no call is registered in the future because the collision avoidance algorithm only determines next visited floors and car travels after arriving there are not fixed at the current moment. It is true that car travel schedules after arriving the next visited floors are given by the group controller, but they are subject to modifications if collisions occur.

To calculate the passenger waiting/service time, it is assumed that only one passenger corresponds to a call and car travels after arriving next visited floors are estimated by a simple collision avoidance rule, as in our previous study (Tanaka and Watanabe 2009). There are two types of collisions: a collision when the cars of the shaft travel in the same directions, or, that when the cars travel in the approaching directions. In the former case, the rule makes one of the cars wait at some floor so that it does not catch up with the other. In the latter case, the rule makes one of the cars wait or evacuate.

Several types of objective functions in terms of the passenger waiting time and service time are examined in computer simulation.

Table 2: System Specifications

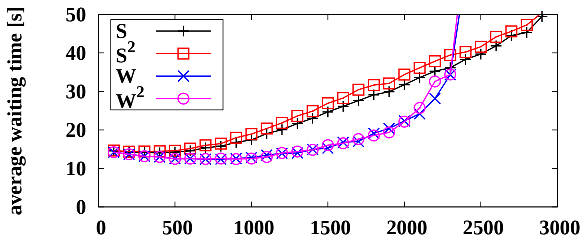
number of floors	30
number of shafts	5
interfloor distance	4.33m
passenger boarding/leaving time	1.2s/person
passenger response time	2.0s
door opening time	1.8s
door closing time	2.4s
maximal speed	6m/s
maximal acceleration	1.1m/s^2
jerk	2.0m/s^3
car capacity	20 persons

6. COMPUTER SIMULATION

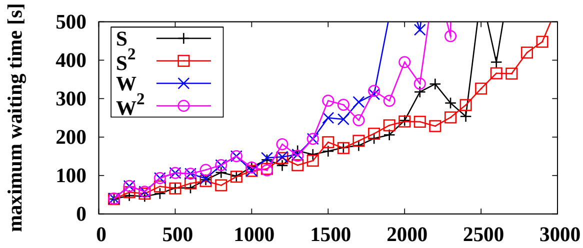
In this section the transportation capability is compared by computer simulation between immediate and nonimmediate passenger guidance. The specifications of the system follow our previous studies (Tanaka and Watanabe 2009, 2010), which are summarized in Table 2.

Data sets of passengers are generated as follows. Passenger arrival times at elevator halls are generated from the uniform distribution $[0, 7200)$ (in seconds). Their origin and destination floors are randomly generated to simulate two types of passenger traffics, uppeak and downpeak traffics, and the ratios among
(1) the number of passengers from the 1st floor,
(2) the number of passengers to the 1st floor,
(3) the number of upward passengers that travel between floors other than the 1st floor,
(4) the number of downward passengers that travel between floors other than the 1st floor,
are set to (1):(2):(3):(4)=19:1:1:1 and 1:19:1:1, respectively. For each setting of the passenger arrival rate (the number of passengers per one hour), and the type of passenger traffic, 10 data sets are generated. To examine stationary performance, the average and maximum waiting/service times of passengers whose arrival times are in the interval $[1800, 5400)$ are evaluated.

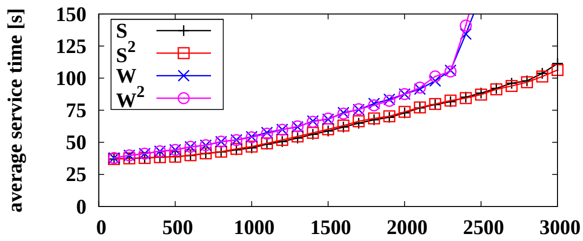
First, the objective function for the collision avoidance and the call allocation is examined. The results in uppeak traffic are shown in Figs. 4 and 5, and those in downpeak traffic are shown in Figs. 6 and 7. In these figures, the average or the maximum waiting/service time



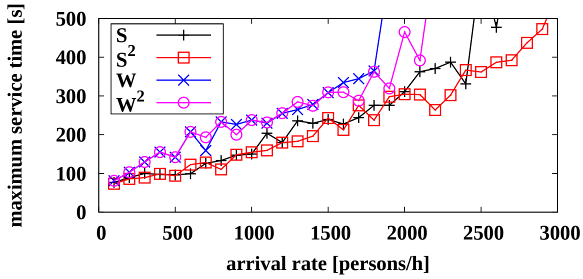
(a) average waiting time



(b) maximum waiting time

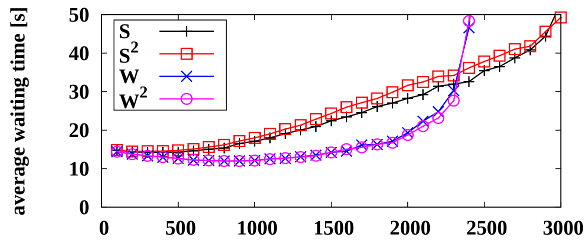


(c) average service time

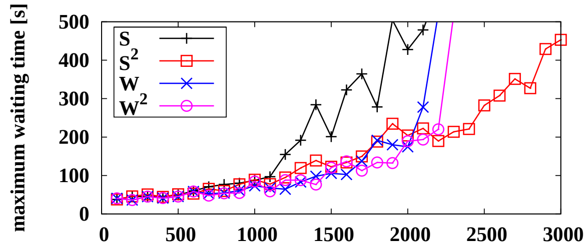


(d) maximum service time

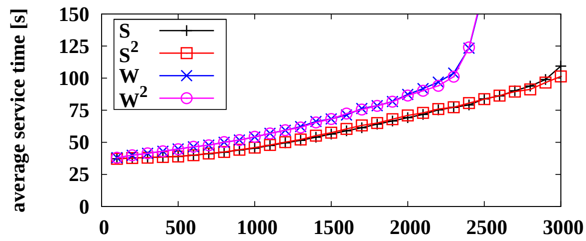
Fig. 4: Comparison of Objective Functions for Immediate Guidance (Uppeak Traffic)



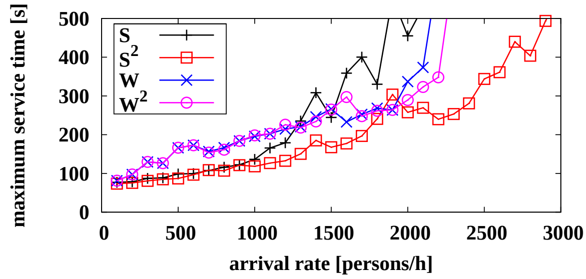
(a) average waiting time



(b) maximum waiting time



(a) average service time



(b) maximum service time

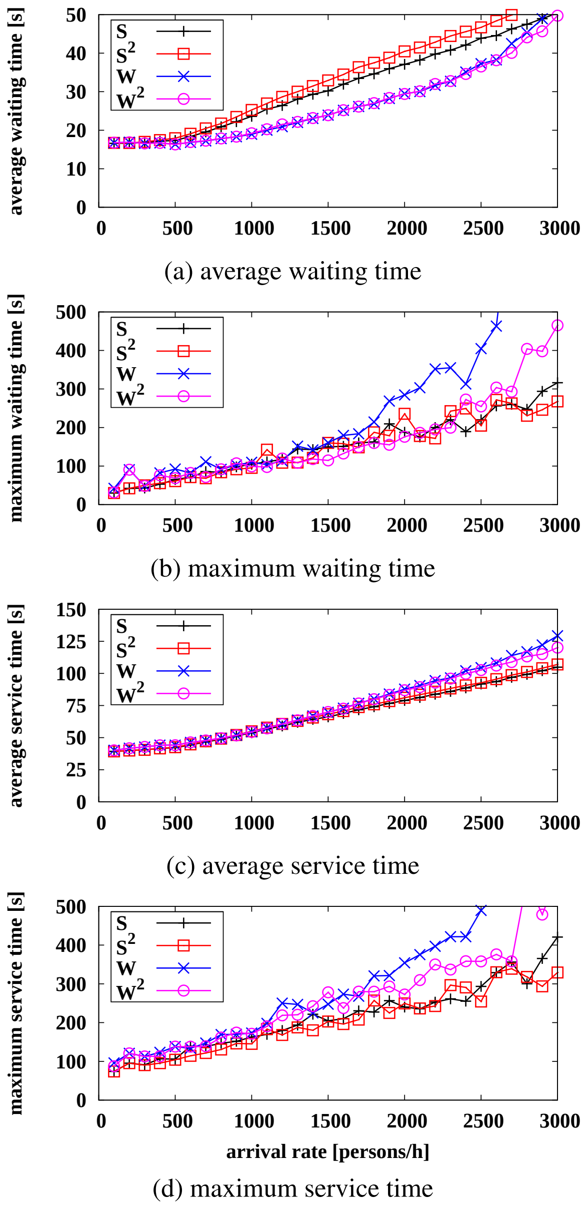
Fig. 5: Comparison of Objective Functions for Nonimmediate Guidance (Uppeak Traffic)

over 10 instances is depicted against the passenger arrival rate. Each line corresponds to a setting of the objective function: S and S^2 denote the sum and the square sum of service times, respectively, and W and W^2 the sum and the square sum of waiting times, respectively. We can see from Figs. 4 and 6 that the objective functions based on weighting times (W and W^2) work well for suppressing the average waiting time in light uppeak traffic and downpeak traffic, when immediate passenger guidance is adopted. However, the average waiting time diverges in heavy uppeak traffic (more than about 2200 persons/h). Moreover, the average and maximum service times of W and W^2 are worse than those of S and S^2.

These results are natural because only waiting times are considered in W or W^2. Unlike single-car elevator systems, it is possible that passengers should stay long in cars until they reach their destination floors due to collision avoidance. However, the objective functions W and W^2 do not take such a situation into account. Thus it seems more appropriate to adopt S or S^2 as the objective function.

With regard to the performances of S and S^2 for immediate passenger guidance, the average waiting/service time of S^2 is worse than that of S while the reverse is true for the maximum. However, the differences are small.

Similar results are observed for nonimmediate passenger guidance in Figs. 5 and 7, but the differences between S and S^2 are larger: The maximum waiting/service time of S is much worse than that of S^2 especially in uppeak traffic. Hence the best objective function among the four is S^2 for nonimmediate passenger guidance. The reason why S deteriorates the maximum waiting/service time would be that a specific call may



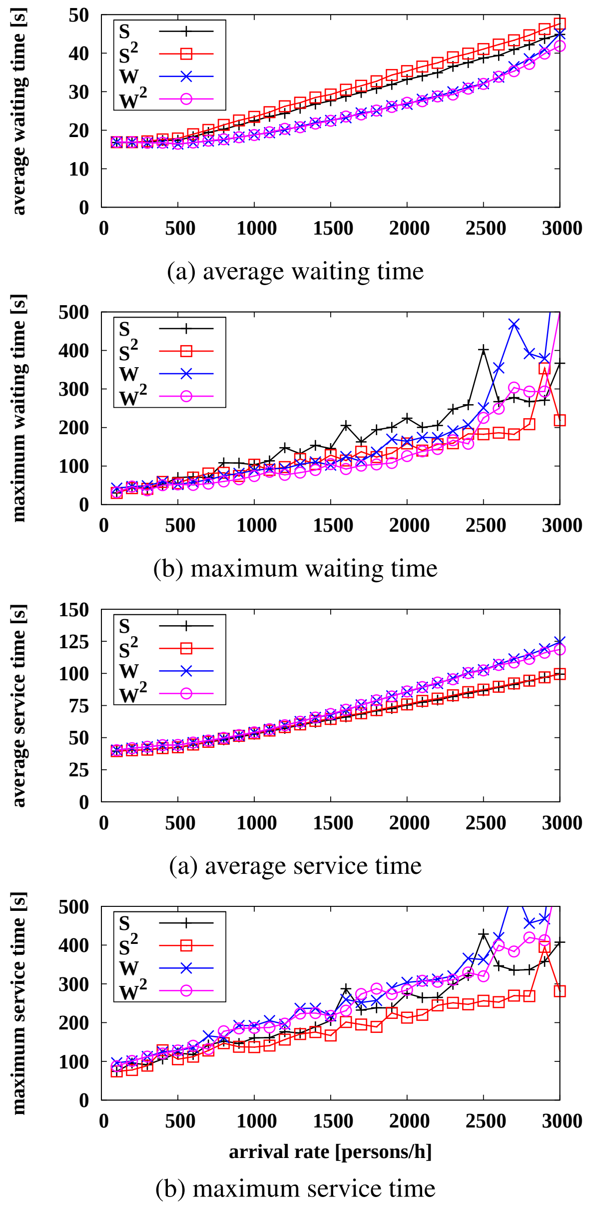
(a) average waiting time

(b) maximum waiting time

(c) average service time

(d) maximum service time

Fig. 6: Comparison of Objective Functions for Immediate Guidance (Downpeak Traffic)



(a) average waiting time

(b) maximum waiting time

(a) average service time

(b) maximum service time

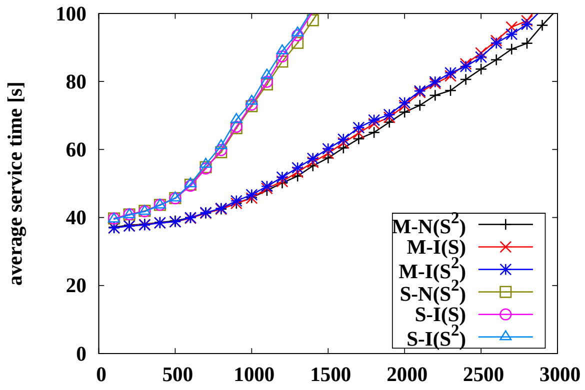
Fig. 7: Comparison of Objective Functions for Nonimmediate Guidance (Downpeak Traffic)

be delayed again and again by reallocating it from one car to another. Since service times of calls (passengers) equally contribute to S, a call may be delayed to improve service times of other calls when it leads to the improvement of the total service time. On the other hand, this is less likely to happen for S^2 because the square sum will increase if a call with a large waiting/service time is delayed.

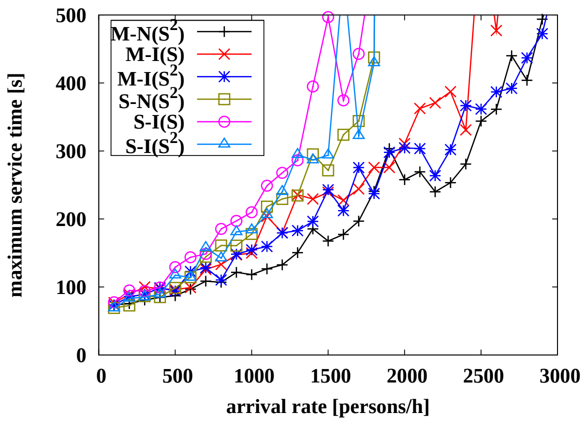
Next, the transportation capability is compared between immediate and nonimmediate passenger guidance. The average and maximum service times are shown in Figs. 8 and 9. In these figures, "M–" and "S–" denote the multi-car system and the single-car system (with five shafts), respectively, and "N" and "I" after them denote nonimmediate passenger guidance and immediate passenger guidance, respectively. The objective function used is given in parentheses. From these figures, we can verify that nonimmediate passenger guidance can decrease both the average and maximum service times compared to immediate passenger guidance. We can also see that the improvement is not significant for the single-car elevator system. In other words, reallocation of calls in the single-car elevator system does not affect much on the transportation capability at least when the proposed allocation method is employed.

7. CONCLUSION

In this study we proposed a simple call allocation algorithm for multi-car elevator systems with nonimmediate passenger guidance. Then, computer simulation was conducted to examine the most appropriate objective function and to show the effectiveness of the proposed method. As a result, it was verified that nonimmediate passenger guidance can improve the transportation

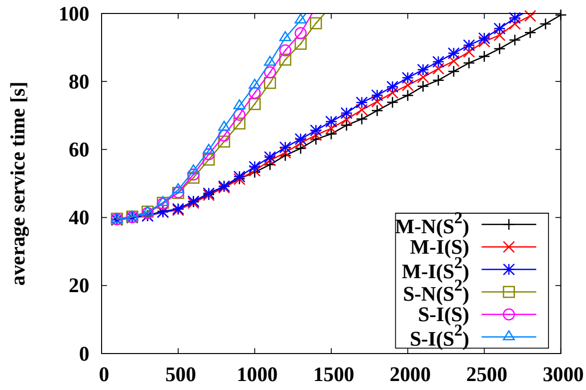


(a) average service time

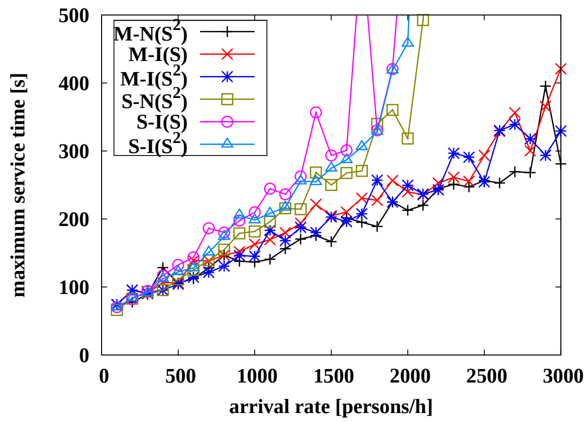


(b) maximum service time

Fig. 8: Comparison between Immediate and Nonimmediate Passenger Guidance (Uppeak Traffic)



(a) average service time



(b) maximum service time

Fig. 9: Comparison between Immediate and Nonimmediate Passenger Guidance (Downpeak Traffic)

capability compared to immediate passenger guidance. However, more intelligent algorithms would be able to improve the transportation capability further. Therefore, it is worthwhile to investigate it in the future study. It will also be necessary to treat systems with more than two cars.

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