# The Performance of Multi-Car Linear Motor Elevators

T. Sudo, S. Markon

*Fujitec Co., Ltd., Osaka, Japan*

**Key Words:** Simulation, linear motors, multi-car systems, hyper-building

**ABSTRACT**

Since a long time, ropeless linear motor elevators with several cars in each hoistway have been proposed as a way to increase the handling capacity, by allowing both vertical and horizontal movements, so that cars could circulate or bypass each other.
If horizontal movement is not needed, the multi-car system becomes more simple and feasible.However, in such a system there are many constraints on the car movements, so the performance gain is not evident.
We have developed a simulator system to analyze multi-car linear motor elevators.
Here we report on the results, which show that such systems would have clear advantages.

## 1. INTRODUCTION

In recent years, there are many reports about planned extra high-rise buildings.[1] In such buildings, the huge population would require very high levels of traffic handling capacity, and thus the large amount of space needed for elevators presents a serious problem.

For such cases, the use of ropeless linear motor elevators is considered as one possible solution. Ropeless linear motor elevators would offer some significant advantages:

1. Multiple cages could use the same elevator shaft
2. Elevators could provide horizontal as well as vertical transportation

There are several proposed operational modes that would make use of the above properties, to provide improved elevator solutions. Especially by allowing horizontal movements, the freedom of elevator operation is significantly increased, and it becomes possible to get much more efficient operation than with conventional elevators.[2) 3)]

However, horizontal movements would require special drive equipment, and the increased cost and complexity could be a disadvantage. Therefore we started to consider a relatively simple system, using multiple cars in the same hoistway but without using horizontal movements.

In this paper we report on the performance results obtained by simulating the operation of such single-shaft multi-car elevator systems.

## 2. THE PROPOSED MULTI-CAR SYSTEM

### 2.1 Outline of the Operation

The proposed multi-car system is shown in Fig.1. The main features are as follows:

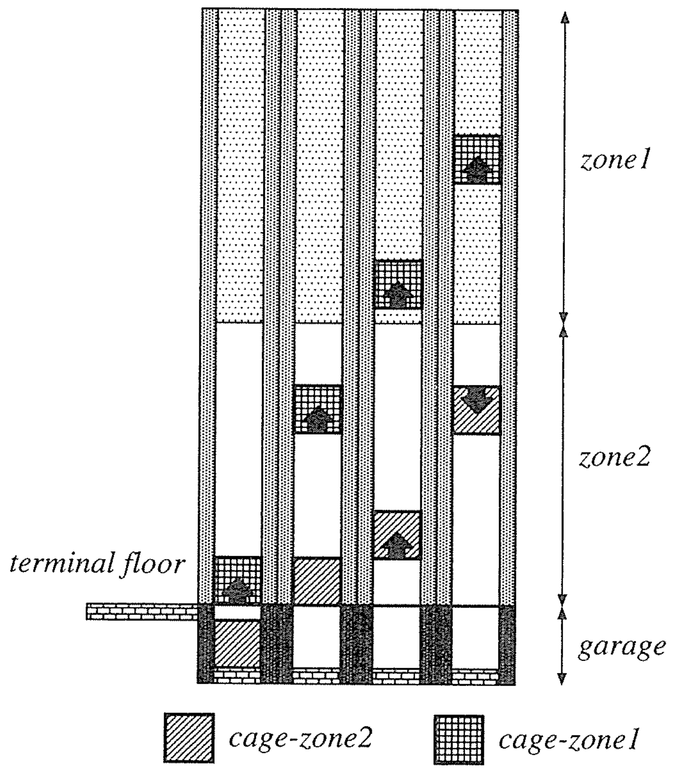


***Figure 1. Proposed Multi-car System***

**1. DRIVE**
Linear motors provide the vertical driving force for each car in the shaft. No horizontal driving devices are used.

**2. TERMINAL FLOORS**
We have considered the advantages and disadvantages of using multiple terminals, similarly to double-deck elevators. From the point of view of users, multiple terminals are not really convenient. Also, when the number of cars in each shaft increases, the number of terminals would also increase. Therefore, in this paper we consider only the case when there is a single lower terminal floor, where cars arrive one by one. Below the terminal floor, we provide a ‘garage’ space for the cars waiting to enter service.

**3. ZONING**
For the present analysis, we have used zoning operation, for the following reasons:

1. In a multi-car system, the most important requirement is the avoidance of the possibility of collision between cars. This is an especially serious problem in our case, since we don't use horizontal movements, which would allow cars to bypass each other. In zoning operation, the car movements are simple and predictable, thus collision avoidance becomes easier.

2. In conventional elevator systems, high-rise buildings are normally divided into zones, each served by different elevator banks. In our system, we also use a similar method, but the zones can be created inside the same shaft, instead of needing separate shafts.

4. COLLISION AVOIDANCE

To ensure safe operation, we disallow cars running in different directions in the same shaft. For two adjacent cars, the only allowed simultaneous operation is to have both cars running in the same direction.

5. SYSTEM

The total system has several multi-car shafts,under common group supervisory control,using destination hall call registoration.

## 2.2 Method of Analysis

In the literature we find several reports about the performance of multi-car elevator systems. In our case, we have developed our original discrete event simulation system to simulate the operation of the proposed system.

### Execution of the simulation

The basic specifications of the simulated buildings and elevators is shown in Table 1. We have studied 3 versions of the building. For comparison, we also include simulation results for a conventional zoned elevator system for the same buildings. We compare the total required floor space of the proposed and the conventional elevator systems, for the same traffic handling capacity.
For each different values of passenger arrival rates, we have performed 5 runs of 60 minutes of simulation, and plotted the performance (waiting time) against the traffic level.

*Table 1. Specifications of the building and elevators*

| | |
|---|---|
| Number of shafts | 8 |
| Capacity (persons) | 16 |
| Rated speed (m/min) | 150 |
| Average floor distances (m) | 3.8 |
| Traffic | Up peak |
| Number of floors | 20 ,30 ,40 |

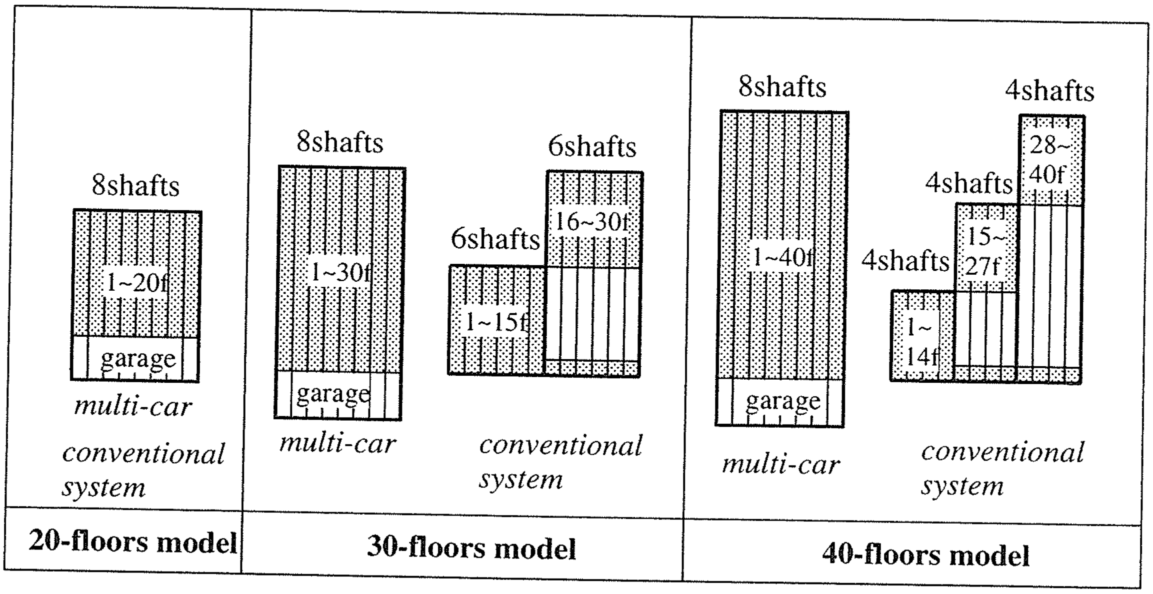


*Figure 2. 3 versions of the buildings*

## Results

For the case of the 20, 30, and 40-floor buildings, the results for each building are shown in Fig.3, 4, and 5, and in Table 2, 3, and 4. We can see that for the 30- and 40-floor buildings, the elevator space requirement is reduced in case of the proposed multi-car system.

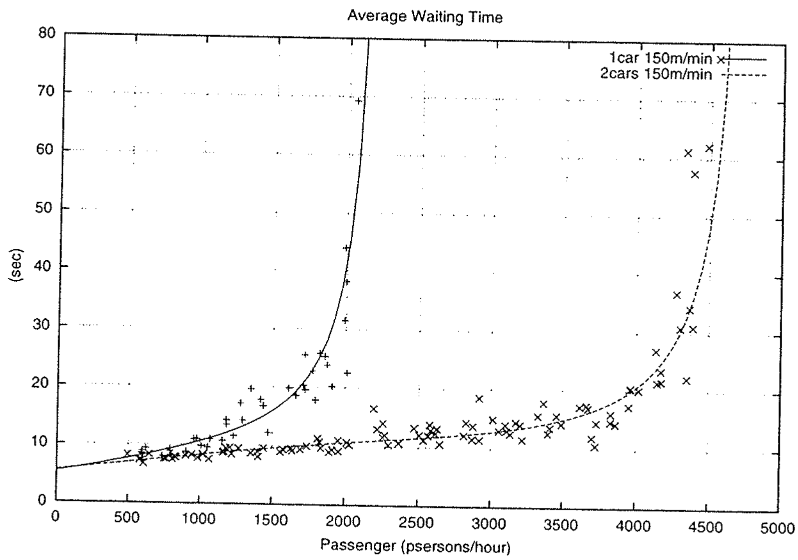


*Figure 3. Results for 20-floor building*

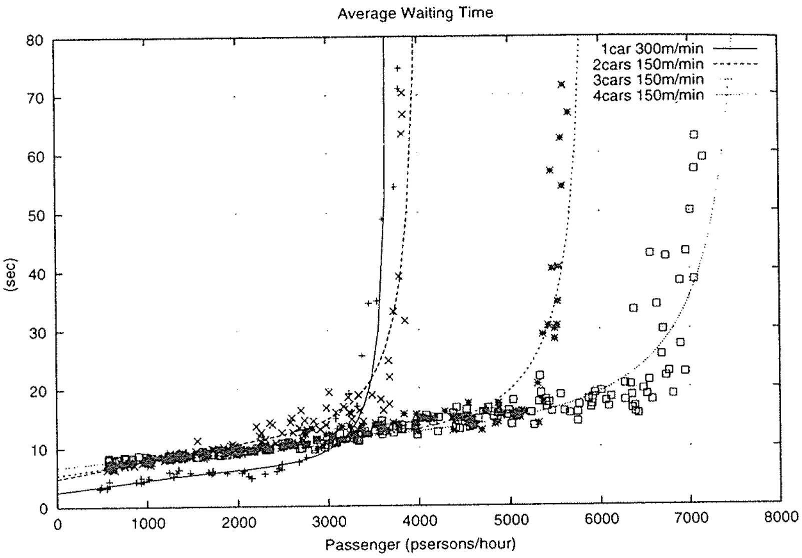


*Figure 4. Results for 30-floor building*

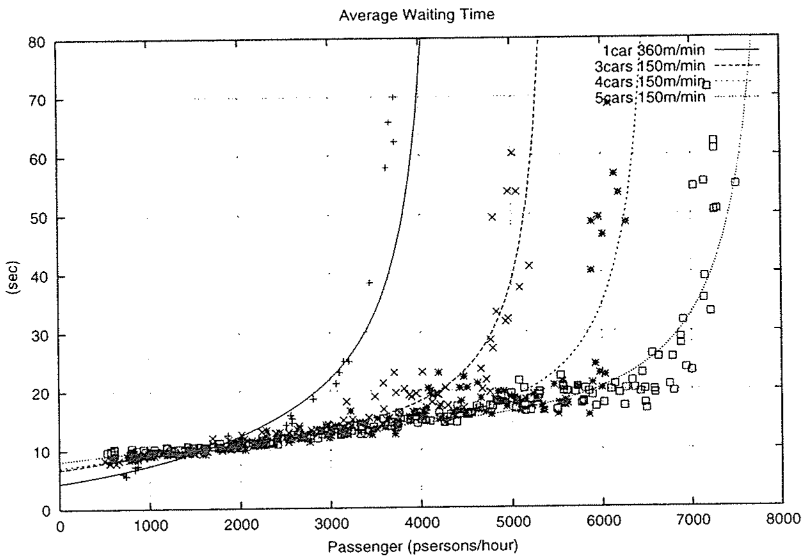


*Figure 5. Results for 40-floor building*

*Table 2. Performance for 20-floor building*

| Number of cars Per shaft | Persons/hour | Space usage efficiency |
|---|---|---|
| 1 | 1700 | 1.00 |
| 2 | 4000 | 2.35 |

*Table 3. Performance for 30-floor building*

| Number of cars per shaft | Persons /hour | Space requirement | Space usage efficiency |
|---|---|---|---|
| 1 | 3400 | 324 | 1.00 |
| 3 | 4800 | 336 | 1.36 |
| 4 | 5800 | 344 | 1.61 |
| 5 | 6800 | 352 | 1.84 |

*Table 4. Performance for 40-floor building*

| Number of cars per shaft | Persons /hour | Space requirement | Space usage efficiency |
|---|---|---|---|
| 1 | 3600 | 270 | 1.00 |
| 2 | 3700 | 248 | 1.12 |
| 3 | 5400 | 256 | 1.58 |
| 4 | 6600 | 264 | 1.88 |

From the results, we can conclude the following:

*20-floor building:*

If the conventional elevator system does not use zoning, we get 2.35 times higher handling capacity with the proposed system.

*30-floor building:*

There is no advantage in using 2-car multi-car systems; however, for 3- and 4-car systems, we get 1.58 and 1.88 times higher handling capacities.

*40-floor building:*

For all studied cases, the multi-car system is significantly better than the conventional elevator system.

When we have started this research, we were concerned that the loss time of cars entering and leaving the terminal space would be a serious problem. However, from the simulation results we can see that this loss time is significant only when we look at the cars one by one. For the total system, this time will help to keep the cars moving in a regular way, preventing 'bunching'.

## 3.Application to an Existing Building

In the previous section, we have studied the general performance of the proposed multi-car system. Here we consider the application of the system to an actual building, which has been designed with conventional elevators. The building is shown in Fig.6, and the specifications are given in Table 5 and 6.

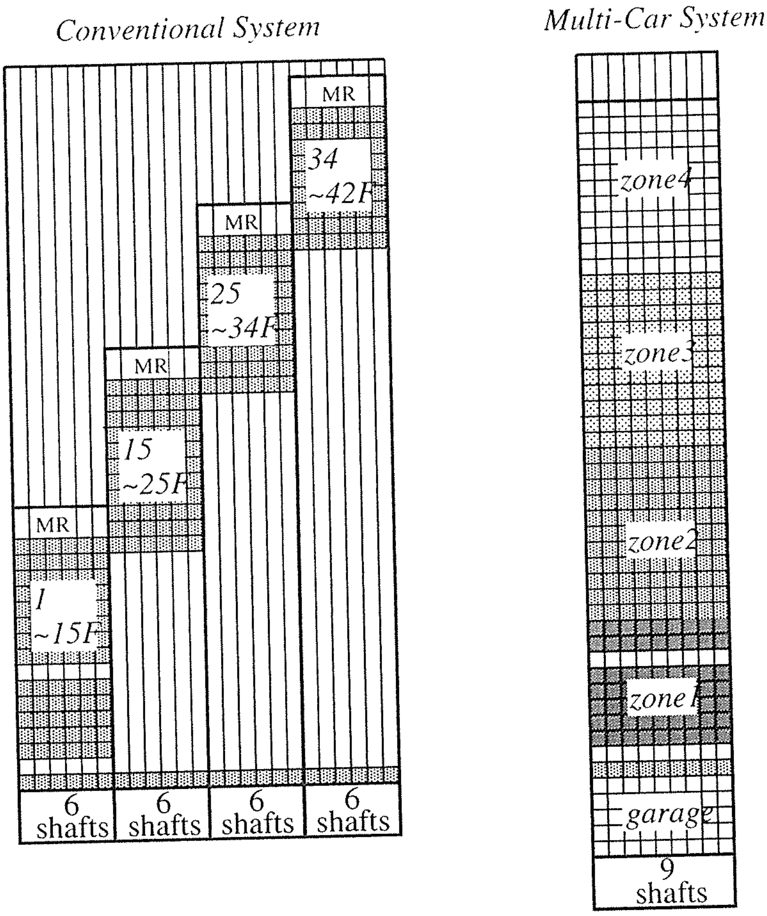


*Figure 6. Existing Elevators and Multi-car System*

*Table 5. Specifications of the Zoning*

| Zone | Low rise | Low mid rise | High mid rise | High rise |
|---|---|---|---|---|
| Population | 1892 | 1941 | 1805 | 1661 |
| Passengers/ hour | 3407 | 3488 | 3254 | 2989 |
| Number of cars | 6 | 6 | 6 | 6 |
| Rated speed | 240 | 360 | 360 | 360 |
| Stopping floors | G, 6-15 | G,15-25 | G, 25-33 | G, 33-42 |
| Capacity | 26 | 26 | 26 | 26 |

*Table 6. Specifications of the building*

| | |
|---|---|
| Population | 7299 |
| Number of floors | 43 |
| Average floor distances (m) | 4.34 |
| Persons/hour | 13138 |
| Rated speed (m/min) | 360 |
| Traffic | Up peak |
| Capacity | 9, 26 |
| Number of cars per shaft | 4, 5, 6 |

We have calculated the number of multi-car shafts needed to replace the conventional elevator banks. For the case of 4,5,6-car shafts, the result is shown in Table 7.

*Table 7. Results*

| Capacity | Number of Cars in a Shaft | Number of Shafts | Number of Cars | Space requirement | Space reduction |
|---|---|---|---|---|---|
| 9 | 4 | 24 | 96 | 514 | 0.69 |
| | 5 | 20 | 100 | 438 | 0.59 |
| | 6 | 19 | 114 | 425 | 0.57 |
| 26 | 4 | 12 | 48 | 552 | 0.74 |
| | 5 | 10 | 50 | 470 | 0.63 |
| | 6 | 9 | 54 | 432 | 0.58 |

The original design used elevators with a capacity of 26 persons. For the multi-car case, we considered both the same capacity, and also the case of smaller, 9-person cars.

For the conditions of Table 7, we have determined the number of multi-car shafts to provide the same elevator performance like the conventional design. The criterion was that for the same traffic rate, the average waiting time in both cases should be under 30 seconds. From the number of shafts, we have calculated the total floor space (for the 9-person cars, the shaft area was assumed to be 0.47 times smaller). For simplicity, we have used the same parameters (speed, acceleration, door times etc.) both for the ropeless linear motor cars and the conventional elevators.

From the results we can see that even for such a medium-scale building, we can expect very substantial reduction in the elevator hatch space requirements. On the other hand, the number of elevator cars would increase, at the rate between 2.5 - 6. Further studies will be needed to determine if the overall effect will be a net cost reduction or not.

## 4. CONCLUSIONS

In the present report, we have analyzed the case of replacing the conventional elevator system with multi-car ropeless linear motor elevators, for the case of existing buildings. In the future,

this research should be extended to the case of extra large scale buildings, like e.g. the 1000 m high 'HyperBuilding' which is being proposed in Japan. A further topic for future studies is the development of efficient group control algorithms for multi-car systems.
However, since the number of cars to be controlled becomes much larger than in the conventional case, new methods become necessary.

At the present, we are considering the possible application of the methods used by Kita et al. in the study of autonomous decentralized transportation systems for large-scale buildings[4]. In particular, the method of cooperation between agents by using the 'Contract-Net Protocol' (CNP), and the idea of using genetic algorithms for optimal cooperative control, could be applied to the multi-car system, too. We discuss the reasons in some detail below.

### Problems of Group Control of Multi-Car Systems

In the present study, we have considered only the case of pure up-peak traffic. For this case, a simple zoning control provides sufficient performance. In practice, however, all kinds of uneven and changing traffic patterns will occur, and some kind of high-performance group control algorithm becomes necessary. There are some difficulties, however:

1. *Loss times*
   In a multi-car system, sometimes a car will need to move in order to provide space for another car, thus not all car movements are directly connected with carrying passengers. Also, in our system we pass cars to the lower terminal one by one, and there will be a time loss for the 'parking' of the other cars. A group control algorithm should be able to reduce such loss times.
2. *Car movements are inter-dependent*
   In a conventional system, the allocation of a car or a shaft to a call has the same meaning. In the multi-car system, however, there are several cars in the same shaft; thus the controller has to select a shaft, then select a car in that shaft. We can consider this system as a hierarchical structure, consisting of the shafts as subsystems, and the shafts consisting of cars as further subsystems.
   In such a hierarchical system, some kind of cooperative control will be needed between the subsystems. This is where we expect the CNP cooperation method, as proposed by Kita, to be useful.

## REFERENCES

1) Hyper-Building Research Group (1996, in Japanese). Report of the Hyper-Building Research
2) M.Miyatake, et al. (1995). Experimental and Operational Study on Vertical Transportation System Driven by a Linear Synchronous Motor Using Permanent Magnets, Proc. LDIA95, pp.73-76
3) M.Miyatake, et al. (1996). Rational Scheduling for High Density Transport in Ropeless Lift System Using Multiple Cars with Transfer-ability between Shafts, Proc. COMPRAIL'96, Vol.2, pp.375-384
4) H.Kita, Y.Komoriya, S.Markon and Y.Nishikawa (1999). On Adaptive Cooperation of AGVS and Elevators for Material Handling Systems In High-rise Buildings, Proc. IWES'99, pp.139-144