DEVELOPMENT AND APPLICATION OF AUTOMATED DELIVERY SYSTEM FOR FINISHING BUILDING MATERIALS

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Abstract: The authors have developed an automated delivery system for finishing building materials with the aim of reducing delivery costs and improving efficiency. This system is composed of two kinds of automated equipment, and managed by a delivery scheduling system via the Internet. It has been applied to the construction of a high-rise building in Osaka City, where it performed all delivery tasks with high efficiency. Furthermore, the delivery scheduling system reduced the time spent by all foremen and managers on delivery work. This paper describes functions and features of the system and some application results.

Keywords: Automation; Delivery Schedule; Finishing Work; High-rise Building; Internet

1. INTRODUCTION

Delivery of finishing materials and equipment via a construction lift or elevator (henceforth, EV) is a bottleneck in construction of high-rise buildings. It is therefore very important to improve delivery performance. Moreover, transportation does not add value to a building, so it is important to evolve its mechanization and automation.

Therefore, an automated delivery system was developed for a 56-story high-rise building in 1995 [1]. As a result of its application, the following problems remained: 1) to enable the system's application to a smaller construction site in an urban area, 2) to reduce the number of temporary EVs by using the automated delivery system even at midnight, and 3) to reduce the manpower required to input data into the system.

Delivery efficiency would be increased by solving these problems. Furthermore, by reducing the number of installed EVs, it is possible to cut down delivery costs. We have been improving the automated delivery system since 1997. During this period, partially improved systems or individual pieces of automated equipment have been applied to more construction projects.

2. GENERAL STRUCTURE OF AUTOMATED DELIVERY SYSTEM

A new automated delivery system has been developed, and was applied to the construction of a 24-story high-rise building in Osaka City in 2000, as shown in Table 1. This new system is composed of two kinds of automated equipment: an automated device that can transfer materials to an EV (henceforth, Transfer Equipment) and an Automatic Guided Folk-lift (henceforth, AGF). It is managed by a web delivery scheduling system via the Internet (henceforth, WSS). Its structure is shown in Fig.1.

A multi-stage rack suitable for a narrow space was adopted that enabled materials to be easily removed from every rack. As a result, the area of the storage facility was decreased to about 30 percent that of the previous application. WSS can access the Internet, which enables the EV to be applied without an operator needing to visit the construction site. By sharing the schedule information among several sub-contractors, it is possible to allocate the EV's hours of use. The Internet was used to obtain the input from the sub-contractors' office, also achieving labor saving.

Table1 Specifications of The Applied Building

Location	Osaka Japan
Building Use	Office Building

Structure and Size	Steel-Frame B3F/25F/PH3F Total Floor Area: 64,621㎡
Construction Period	Mar.1998～Oct.2001

3. AUTOMATED EQUIPMENT

The authors planned to cut down the number of installed EVs by applying the automated delivery system. We estimated the overtime work at a maximum of 4 hours per a day during the height of finishing work. The automated equipment was mainly used for delivery during overtime work for basic materials such as gypsum plasterboard and lightweight steel.

The layout of the ground floor used as a storage facility is shown in Fig.2. Trucks carrying materials enter the building and the materials are unloaded onto the floor. The AGF operates automatically from its home position, and then unloads the materials onto the multi-stage rack. During the automated delivery work, the AGF automatically removes the materials from the multi-stage rack and conveys them to the front of the EV (HCE2800 in the figure). AGV's operations are repeated according to the operator's pre-inputted orders. After the automatic Transfer Equipment in the EV loads the materials, the EV is taken up to the delivery floor by an elevator operator. When it arrives at the delivery floor, the automatic Transfer Equipment automatically unloads the material from the EV.

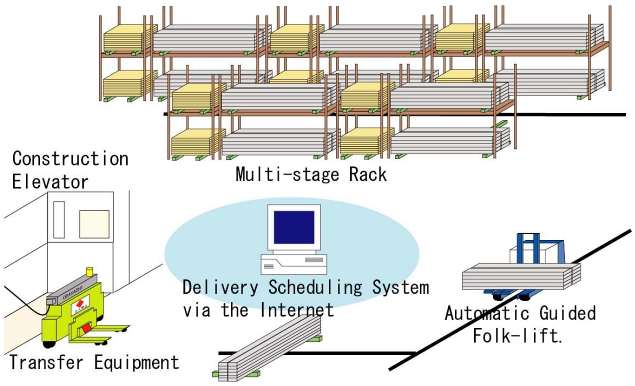

Fig.1 The Structure of Automated Delivery System

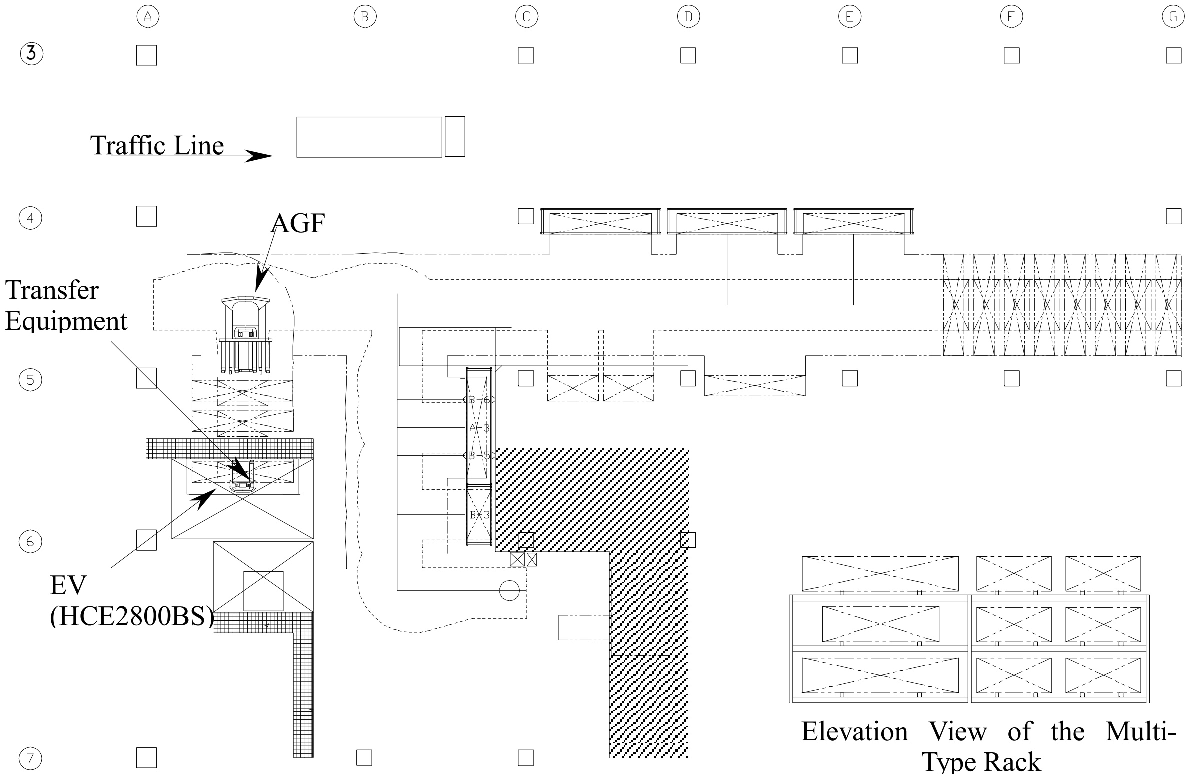

Fig.2 The Layout of Ground Plan of The Automated Delivery System

3.1 AGF and Multi-stage Racks

The AGF's rated capacity is 1500 kgf. It runs along an electromagnetic guide wire. This guidance system is more reliable than others such as light reflex or magnetic tape. An AGF removing material from a multi-stage rack is shown in Fig.3. We reduced development costs by adapting a standard machine to an AGF by attaching a sensor and radio equipment needed for construction work. If the AGF detects any obstacles in the traveling direction with its photosensors or supersonic sensors, it begins to slow down to avoid contact with them. Moreover, the AGF and Transfer Equipment have a collision avoidance system that utilizes radio signal communication. The AGF can deliver materials safely and efficiently in a narrow space. We applied 2m- and 4m-wide racks adapted to the form of object materials. An address number was set for each rack. After the operator inputs the address number into the AGF's control panel, it continuously delivers materials up to 99 times.

3.2 Automatic Transfer Equipment

The Transfer Equipment shown in Fig.4 is attached to an EV. Materials are loaded and unloaded automatically by an elevator operator. By automating the unloading work, it is possible to reduce delivery time and achieve labor saving. The Transfer Equipment is as light as 800 kgf, whereas its rated capacity is 2000 kgf. It is supplied power directly from the EV via a flexible cord, so it does not need to carry a heavy battery. Moreover, when an EV is used to transport workers or lightweight materials, the Transfer Equipment can be easily removed from it in order to maximize its capacity.

4. WEB DELIVERY SCHEDULING SYSTEM

4.1 Structure of Web delivery scheduling system

Fig.3 Automatic Guided Folk-lift

The structure of the Web delivery scheduling system (WSS) is shown in a Fig.5. It is composed of three kinds of hardware: a TA-terminal for application; a WS-Web shared server; a TM-terminal for management. The TA is a computer installed in each subcontractor's office, which accesses the Internet and processes several assignments: new reservations, deletions, modifications, and confirmations for use of an EV. The WS implements script in response to requests from the TA. Since a CGI pearl is used for script, a hosting service provided by a general Internet service provider can be used. The TM is a computer installed in a construction office, which downloads data for a definite period and makes a schedule based on a predetermined algorithm and uploads these data to the WS as fixed information. Moreover, the TM is operated by the EV's manager and makes EV regulations such as holidays and regular services, and uploads these data to the WS. Consequently, an EV reservation can be restricted. In addition, the TC can indicate past records of an EV in contrast to plans. Fig.6 is a calendar indication that shows application conditions. Detailed application conditions obtained from the bar chart can be confirmed by choosing the reservation day (Fig.7).

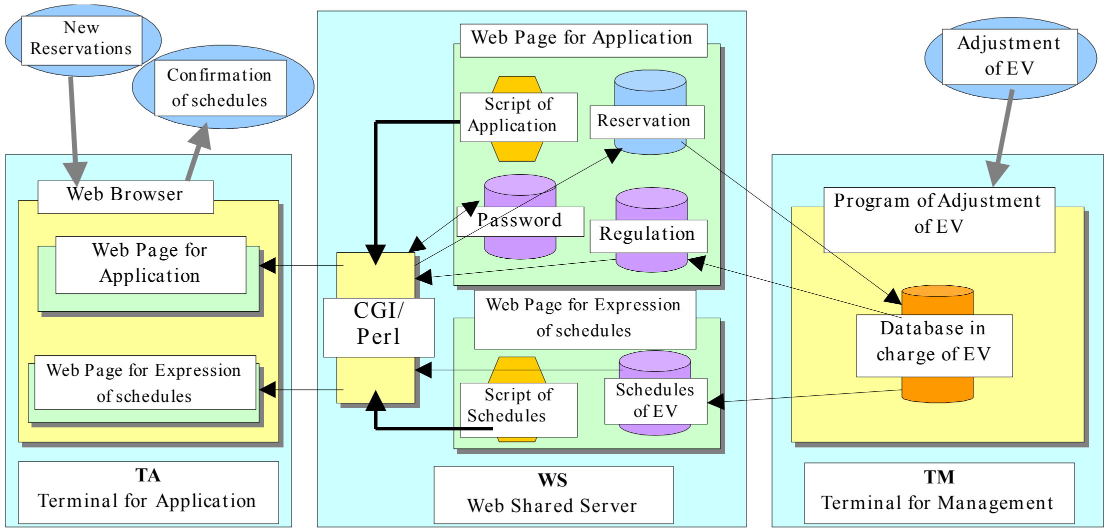

Fig.5 The structure of The Web Delivery Control System

4.2 Management of Transfer Web delivery scheduling system

The EV's manager and subcontractors held a meeting once a week to adjust the EV schedule for the following week. Before the meeting, the EV's manager downloaded the application data and closed the applications. After the EV schedule's adjustment, the administrator uploaded the determined schedule to the WS.

Fig.6 Calendar Indication of WSS

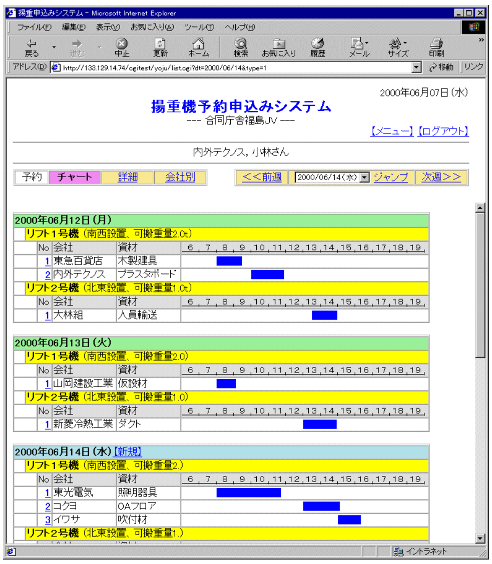

Fig.7 Bar Chart Indication of WSS

5. APPLICATION RESULT

5.1 Automated Equipment

We analyzed the EV's operating rate - Or - described by:

$$Tn = To - Ti$$

$$Or = Tn / To \qquad (1)$$

Where: Tn is net EV operating time, To is EV operating time, and Ti is EV downtime (waiting for materials, workers, etc.).

Fig.8 shows the EV's operating rate transition every day during the operating period. Fig.8 contrasts the Or of this system with that of the conventional system for the same construction scale. Fig.8 indicates that the automated system average was higher than that of the conventional system.

Fig.9 compares the delivery performances of the conventional and automated systems. The conventional system's performance is assumed to be 100. The average weight between the two systems is approximately equivalent, whereas other items of the automated system exceed those of the conventional system. In particular, the automated system shows a delivery manpower saving of nearly 45 %. By comparing the two systems, we confirmed that the delivery capacity per unit time of the automated system was 1.44 times that of the conventional system.

It thus follows that the automated delivery system is more efficient than the conventional system. The main reasons are:

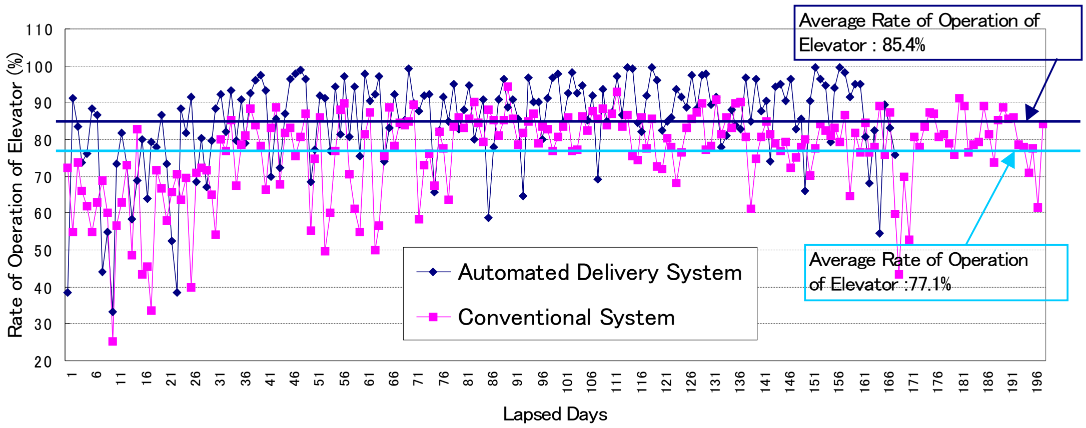

Fig.8 The Transition of EV's Operating Rate

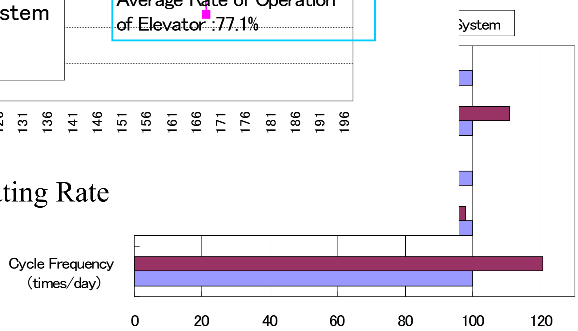

Fig.9 The Comparison of Delivery Performance

1) The application of full-time material transportation workers - these workers can deliver materials stocked on multi-stage racks in the EV's spare time
2) Setting of multi-stage racks - this enabled the EV to deliver materials even when there was a delay of delivery trucks
3) Introduction of two kinds of automated equipment - these enabled a reduction of delivery work and labor saving

5.2 Web delivery scheduling system

We analyzed logs stored in the server of the Web delivery scheduling system for seven months from August 2000 to March 2001. Fig.10 shows the transition of the number of log-ins according to the type of business. This shows that the total number of log-ins was 2700, and the average weekly logins was 84. Furthermore, the number of log-ins decreased gradually with time. The number of log-ins according to the type of business confirms that the percentage for building equipment was 55.4 %, and the percentage for building finishing work was 26.4 %.

Fig.11 shows the percentage of access points to the WSS. As shown, the access points to the WSS were mostly out of the construction office.

Fig.12 shows the number of log-ins according to the time period. As shown, reservations during regular working hours (8 a.m. -5 p.m.) occupied 60 % of the total, whereas those during holidays or from midnight to early morning occupied 40 % of the total.

We carried out a questionnaire survey of about twenty users of the Web delivery scheduling system. The findings of this questionnaire survey include:
1) Although there were many inexperienced users, the average log-in time was short, about ten minutes, and the operability and speed were highly rated.
2) There were many positive comments on the laborsaving ability.

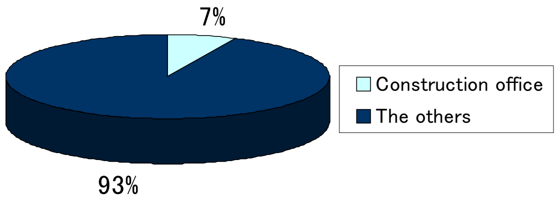

Fig.11 The percentage of access points to the WSS

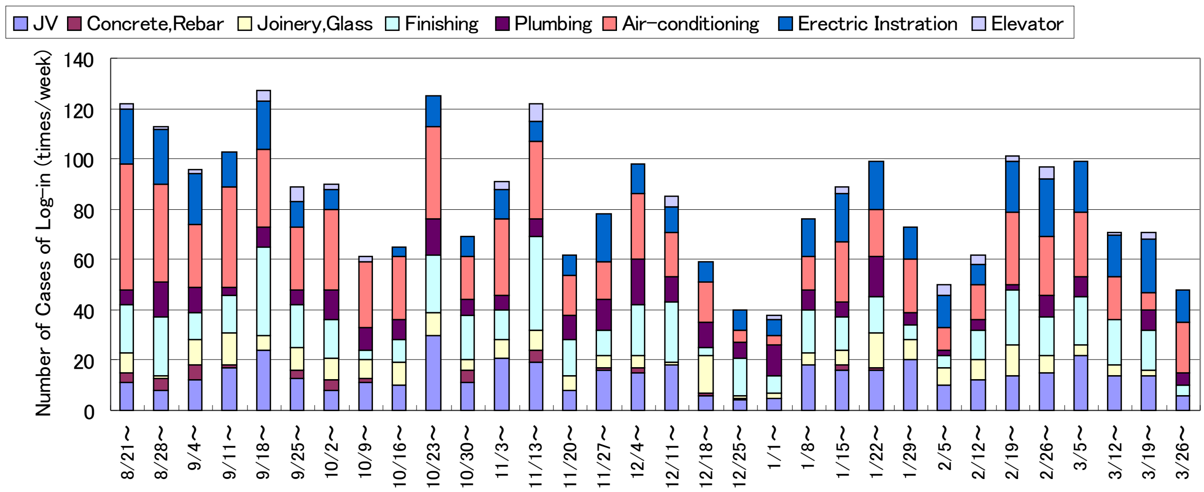

Fig.10 The Transition of The Number of Log-ins

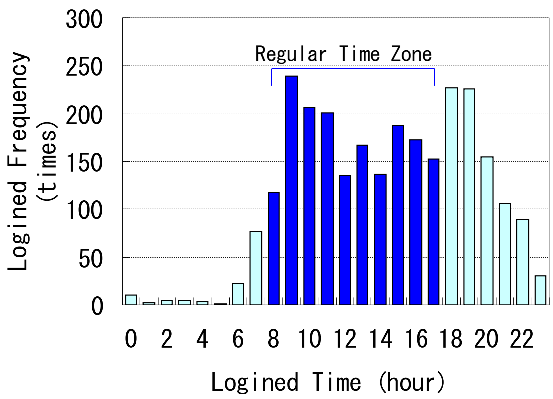

Fig.12 The Number of log-ins According to The Time Period

3) The assignment, such as data input and adjustment, of the EV's manager was reduced by 20%.

In view of the results so far achieved, we concluded that it is very effective to use the Internet for EV management, because the EV can be reserved any time and from any place.

6. CONCLUSION

An automated delivery system has been developed for reducing delivery costs and improving delivery efficiency. Results show that the delivery capacity per unit time of the automated system is 1.44 times that of the conventional system, and it achieves a 45% delivery labor saving. In addition, using the Web delivery scheduling system reduced the manager's assignment of the EV. We covered development costs of automated equipment for one project. Results show that total delivery costs can be as little as initial costs because of the reduced number of installed EVs.

We believe that delivery costs can be reduced even further by expanding the application range of the automated delivery system. Moreover it is hoped that the automated delivery system will develop into construction logistics by improving the management method in a storage facility and expanding the WSS's functions.

References

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