Improving the Safety and Efficiency of Materials Transfer at a Construction Site by Using an Elevator

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Abstract: The aim of this study was to compare materials transfer at a construction site, either by carrying manually or by using an elevator. Data were collected at a construction site by using two methods: continuous automatic collection of data on the use of the elevator, and measuring and observing the transportation of some products when different delivery systems were used. Health and safety risks were at their highest when transporting products manually at construction sites. Risks decrease when vertical (an elevator) and horizontal (a wheeled device) transportation tools are used. A similar improvement as in health and safety risks can be seen in efficiency results: The working time needed with the elevator was 41% of the purely manual handling time. When wheeled devices were used, the transportation time was decreased to 16%. The early use of a permanent elevator succeeded well and its capacity was large enough. The effective use of the elevator and wheeled devices require that pathways are in better condition than normally.

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Introduction

Construction Environment and Logistics

Traditionally construction work is divided into three phases: foundation (basement), structural work (framework), and internal work (finishing). While the foundation and framework stages are short and mechanized, the internal work is the most time consuming, and highly labor intensive. The internal work includes the largest number of material types, while the total mass of the materials is significantly smaller than in the framework.

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A large part of the work at construction sites is related to logistic operations such as transporting, storing, moving, and reloading. The handling of construction materials is done both manually and mechanically. Traditionally a large variety of material handling and transportation methods have been used. Fig. 1 exemplifies some of the most common methods.

Based on the above classification, the use of moving, lifting, and transporting tools is most profitable during the internal work. This is also supported by the observed distributions of material weight and type, and the number of packing units. The more packing units and types of materials are needed, the more profitable is the use of mechanical tools such as an elevator and pallet handling devices, for example.

According to previous published research (Lehtinen and Kiviniemi 1995) the construction time use of a permanent elevator is one solution to decrease the use of stairways in the building phase. Early use of permanent elevators (EUPE) is regarded as an additional service by an elevator supplier. It offers the builder the possibility to use a permanent elevator during construction time so that after being used during construction, the condition of the elevator is as good as new.

Traditionally elevators are taken into use when a building is ready. In some countries like Finland, Sweden, and the United Kingdom elevators are being increasingly installed and taken into use earlier during the interior finishing phase. The use of elevators during construction has been a well-defined practice in high-rise buildings with more than 25–30 floors. In high buildings the main objective for elevator use during construction is passenger transportation. The present study is based on a new concept, in which an elevator is used for a significantly longer period for both passenger and goods transport in buildings with only a few floors.

The size and load capacity of the elevator most commonly used in residential buildings are sufficient for the transportation demands in the finishing phase. If the elevator installation begins right after the shaft is ready, the elevator's usage time on the site

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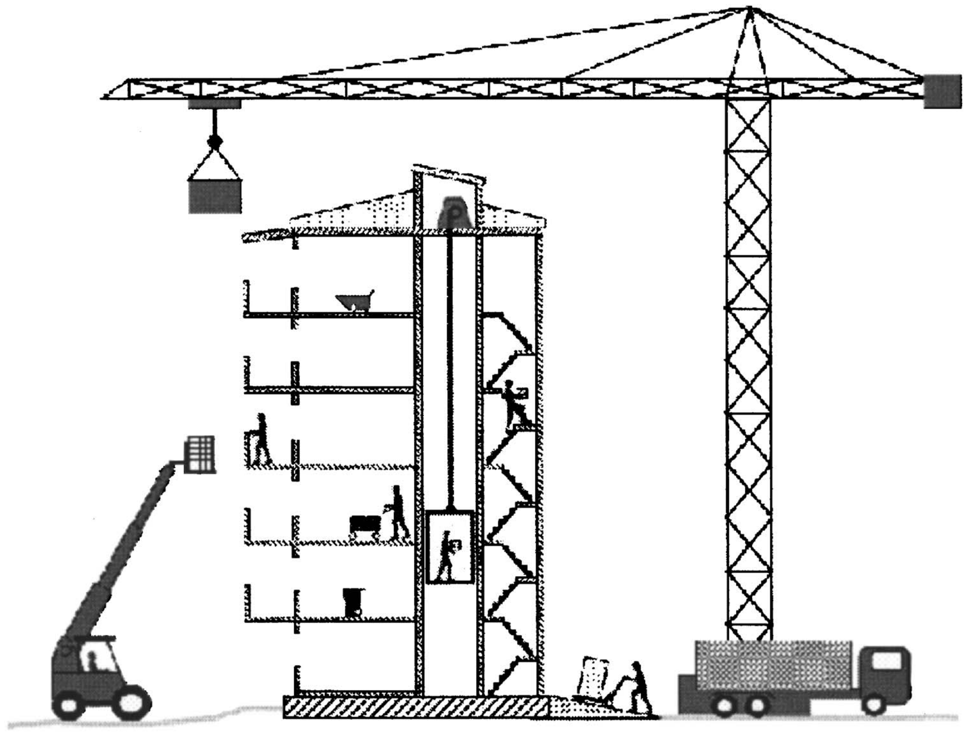

Fig. 1. Logistic devices at construction site: For horizontal moving, e.g., wheelbarrows, pallet handling devices, forklifts, and manual carrying are used. For vertical moves, cranes (during first two phases of construction), telescopic handlers, builder's hoists, elevators (installed already in end of framework phase), and manual carrying are used.

will be 2–4 months. Ambient temperature, variations in temperature and humidity, and dust limit earlier installation, in practice.

Safety in Construction Work

The construction industry is considered to be one of the most hazardous industries on the basis of accident frequency (Kumar 1991; Salminen 1995) and injury rate (Zwerling et al. 1996). In Finland 25% of fatal occupational accidents occur in the construction industry (Yrjänheikki and Savolainen 2000). Materials transfer is an essential part of the work at construction sites. Unfortunately, accidents have been an integral part of materials handling (Lortie and Pelletier 1996), which cause more serious accidents than other work activities (Perttula et al. 2003).

Materials handling at a construction site is often done manually inside the building. Manual materials handling increases the risk of overexertion and strains (Perttula et al. 2003). The workload of construction workers can be lightened by using auxiliary handling devices, even though they do not necessarily decrease the muscular load (Sillanpää et al. 1999).

Stairs are one of the most hazardous locations in buildings (Roys 2001). Even in a finished environment people may stumble or trip while descending stairs (Nagata 1995). Stair accidents cause severe injuries, typically bruises, fractured bones, and sprains (Nagata 1991). At construction sites, where numerous materials and objects are handled, transferred, and used, the work environment is seldom tidy. For instance, debris left in the stairway causes a risk of falling. In addition, risks arise because of the unfinished and continually changing work environment.

Objectives of Project

This study is a part of the Safer and more effective operations in construction "SAFETI" project. The main objectives of the project were to:

- Develop an integrated transport system for construction sites;
- Eliminate manual handling of heavy loads, which is a major health hazard for workers;
- Reduce the overall need for manual handling at construction sites;
- Improve occupational safety at construction sites;
- Diminish demanding physical tasks; and
- Increase the efficiency of the construction process by the mechanization of handling tasks.

Objectives of Study

The objective of this study was to show how well the objectives of the project were met by combining two manual methods into one sophisticated method. This paper presents some results from a pilot construction site and relates the effects to health and safety, as well as efficiency, when materials are transferred by manual carrying or in an elevator. The objectives were approached by collecting the data on the use of the elevator and by measuring the efficiency and safety at the pilot construction site.

Although the arguments of this paper may seem self-evident, these aspects still need to be demonstrated in practice. The large number of accidents at construction sites indicates that these safety matters are not yet thoroughly understood.

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Fig. 2. Data were collected and measured at Puteaux République building site in Paris, France

Experimental Methods

Building

The construction site (Fig. 2) was located in Puteaux République, Paris, France. The first phase of the construction started in June 2002 and the construction was completed in March 2004. The data collection and measurements took place at one staircase where the permanent elevator was operating during the finishing phase. The building was a ten-floor residential building with 29 dwellings per staircase, on average four dwellings per floor (two dwellings on the first floor). The floor height was 2.75 m (ground floor 4.49 m). A spiral staircase was used for the manual transportation. The dimensions of the elevator car (Fig. 3) with the installed protections for the construction phase were: car floor (width×depth) 1.05 m×1.35 m, car height 2.05 m, and car door (width×depth) 0.8 m× 2.0 m. The maximum load of the elevator was 630 kg and its nominal speed was 1.0 m/s.

Data Collection

The data on the elevator were collected on September 5–October 9, 2003 and January 16–March 2, 2004. This included all trips that the elevator made during that time. The observation data were gathered during 3 days. The data included information on the delivery of three different products and four different delivery processes (traditional manual delivery and three advanced delivery systems using the tools developed and introduced during the SAFETI project). All measurements took place in the staircase, where the elevator was operating.

Two researchers collected the data for the evaluation of the safety, health, and efficiency. The data included the times used for the different tasks (s), manual forces (to push or pull a load in the starting situation, continuous force, and forces on different surfaces N), weights of the loads (kg), asymmetry of lifting (°), and dimensions (lifting heights, horizontal distances while lifting, transportation distances from loading point to unloading point, e.g., length of corridors and staircases, staircase dimensions, etc.). The measurements were documented on the data collection sheets. The delivery processes were also recorded by video and photographs. The measured cases demonstrate the transportation of single products.

Fig. 3. Elevator car with protection for construction phase installed on floor, walls, and ceiling. Some instructions to workers were posted next to door (e.g., maximum material dimensions).

In addition to the manual transport (Fig. 4), two other advanced systems used the elevator. Other components in the advanced systems were a small pallet sized 60 cm×80 cm (called the SAFETI pallet) (see Fig. 5), and a device for horizontal transfers. The SAFETI pallet is half of the size of the European standard pallet: Euro-pallet (120 cm×80 cm). The smaller pallet was needed due to the limitations of the width of the inside corridors. The horizontal mover (Fig. 5) looks like a traditional transpallet, but has big wheels to overcome some smaller obstacles at a construction site. The front wheels can be tipped over to lower the height of the horizontal mover to permit the loading and unloading of pallets. The mover was developed during the project.

A so-called local innovation as a simple and low-cost concept was included in the on-site measurements: a SAFETI pallet was equipped with wheels (Fig. 6). The wheeled pallet was constructed for experimental purposes only, e.g., the structure was not strong enough for extended usage, and the pulling bar was not rigid, causing a safety problem.

The measured products were: (1) ceramic wall tiles packed in cardboard boxes (weight 19 kg, Fig. 5), and plumbing items for bathrooms such as; (2) toilet seats (weight 19 kg, Fig. 6); and (3) water tanks (weight 13 kg, Fig. 4).

Transportation of the products during on-site observations started on the ground floor and ended up five floors higher. The measured handling systems were:

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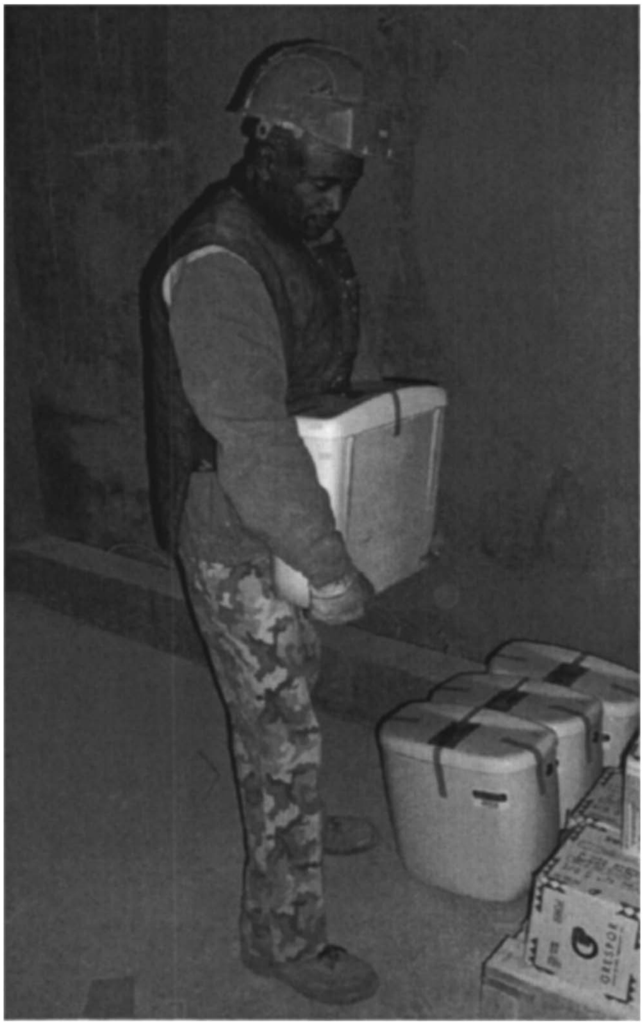

Fig. 4. Toilet water tanks manually handled: walking and carrying using stairs

Fig. 5. Ceramic wall tiles packed in cardboard boxes on SAFETI pallet are transferred using horizontal mover to elevator

1. Manual: totally manual; products are carried manually using the stairs;
2. Manual+elevator: manual handling combined with the use of the elevator; products are carried manually to the elevator floor and then again to the installation site; and
3. SAFETI pallet+horizontal mover+elevator: products are loaded onto the pallet, which is transferred with the aid of the horizontal mover to the elevator, lifted to the required floor, and transferred again to the installation site.

Elevator Data

The automatic data collection system consisted of a computer linked to the network of the elevator. Since the motion control system of a modern elevator is based on digitized discrete commands, it was possible to plug an extra recording computer into the network and extract the desired data and the time signal. The software used for data logging was modified for recording the extra functions of a site elevator. The analysis is based mainly on the elevator's trip data: one trip was defined to start when the elevator is called (call button pushed) and to end when the elevator's doors were closed on the destination floor. Waiting time was defined to begin when the elevator was called and to end when the elevator's doors started to open at the call level. The trip data included the following values recorded from each trip of the elevator:

- Date of the trip;
- User identification (card ID);
- Weight of load in elevator (at the beginning of the trip);
- Waiting and loading/unloading time;
- Time and floor level of departure and arrival; and
- Total time of trip.

The two main traffic observations were elevator trips and elevator calls. The trip data included information on starts and destinations of the elevator, while call data describes the actual need for an elevator.

Analysis of Efficiency

Efficiency was determined by MatSim in order to reach the objectives. MatSim is a simulation method which is based on Factory Flow static simulation software. The Factory Flow runs on top of AutoCAD. The MatSim method has been used earlier in

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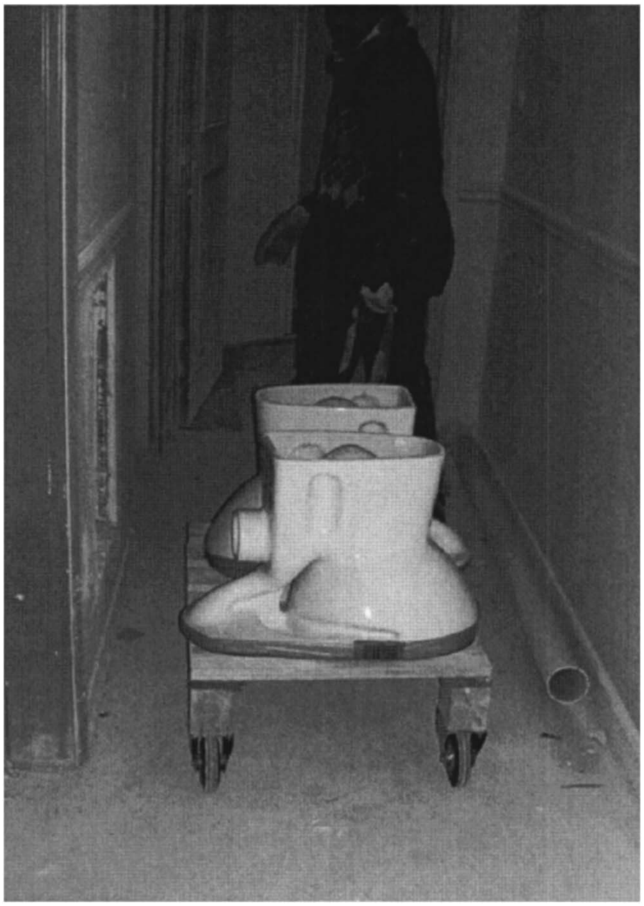

Fig. 6. Toilet seats on SAFETI pallet with wheels are being pulled from elevator car to installation site

various cases for analyzing safety, effectiveness, and economics of transportation. The MatSim method is a tool for experienced users.

During the SAFETI project the MatSim was modified to be used as a tool for construction sites, e.g., the aspect in the development of the usability of MatSim was to take into account both horizontal and vertical movement on the site in the same simulation model. In this project only the current layout of the stores and routes was analyzed.

The program generated charts of: total distance, production volume, total time, total moves, average move distance, average time of moving a ton, total moves per vehicle, and distance intensity. This part of the method is used to find out which products spend most of the resources, and to prioritize the possible alternatives of changes in the transfers.

Analysis of Ergonomics and Safety

The analysis of ergonomics and safety was performed by using SAFERtool. SAFERtool is an analysis method for assessing safety and ergonomic features of transportation systems at a construction site. It is based on the Ergotool method of the project participative simulation environment for integral manufacturing enterprise renewal (Van Rhijn et al. 2002) and on European standards (EN 1005 series: Safety of machinery. Human physical performance). The evaluation requires expert assessment, and therefore the user must be familiar with construction work, as well as safety and health aspects.

SAFERtool was constructed in the form of Excel worksheets for easy adaptability to different solutions. The modules of SAFERtool for assessing physical load are: lifting, carrying, pulling and pushing. The Safety module evaluates safety and environmental factors. The analysis is done by assessing the risk levels of separate work phases. The most stressful situations should be picked out during the observations. In order to get the total physical loading in the task, the combined risk factor is calculated as the cubic average value

$$\text{combined risk index} = [(\Sigma t_i * \mathrm{R}F_i * \mathrm{R}F_i * \mathrm{R}F_i)/\Sigma t_i]^{1/3}$$

where $\mathrm{R}F_i$=assessed risk index in the work phase i; t_i=time of work phase i; and the sum Σ is calculated over all work phases $i=1,\ldots,n$ during the task.

Results

Usage of Elevator

As illustrated in Fig. 7 the daily elevator call distribution gives an indication of the distribution of transport need. For example, the call peaks during the early hours give an indication of the workers coming to work with their tools and materials, while the lower intensity of usage during the afternoon indicates a lower need for transportation. The daily distribution of elevator calls can also be used to estimate the need for both material and labor on a specific floor, provided that the number of passengers, calls per floor, and the transported mass can be determined.

Fig. 8 describes the variation of daily use during a specific period of construction. The intensity of use of the elevator varied from 10 to 30% between working days. Intensity of use can be seen in relation to both transported mass and personnel traffic.

The usefulness and applicability of the elevator varies by lot in relation to the building process and user. This phenomenon is best described by comparing the elevator's actual intensity of use. It can be seen that the elevators are seldom used at their full capacity, but that certain peak times and zones exist. For efficient use of elevators, the average waiting time must also be considered because calls in the case of multiple users always overlap.

Both the gaps and bottlenecks in transportation are easily found by charting whether floor-specific elevator start counts, distributions of usage intensity, and average waiting times are simultaneously monitored (Fig. 9). The average waiting time is 21.8 s and median waiting time 15 s.

Occupational Health and Safety

The highest risk indexes were found in manual carrying in the stairs, and in pushing and pulling the loaded horizontal mover over obstacles and to start the movement. Their magnitude was two times more than what is allowed. High values were also found in lifting situations (lifting objects from the pallet onto the floor).

The combined risk indexes for each transportation system and product are shown in Table 1. The combined risk indexes are calculated for the task time, which differs in the different transportation systems.

Health and safety risks are at their highest when transporting materials manually at construction sites. The risks decrease when vertical (an elevator) and horizontal (a wheeled device)

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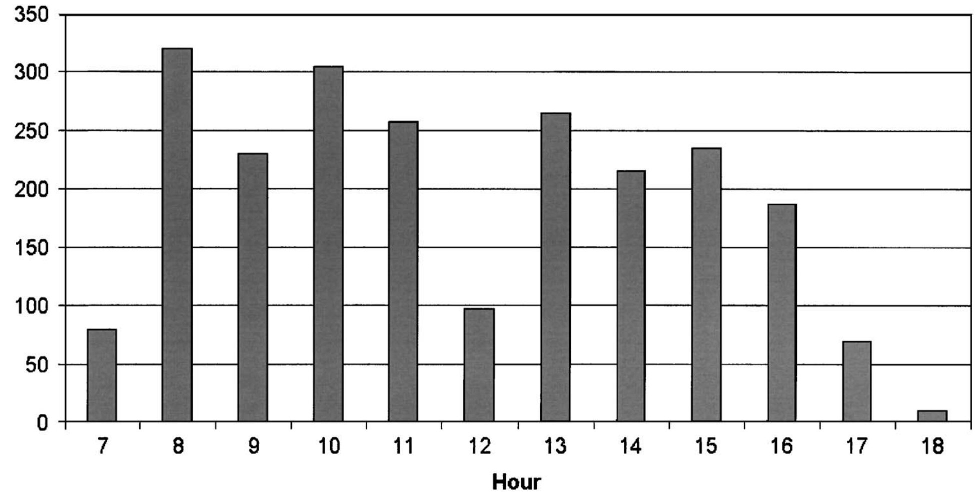

Fig. 7. Elevator departures per hour. Average number of elevator departures per hour during period January 16–March 2, 2004.

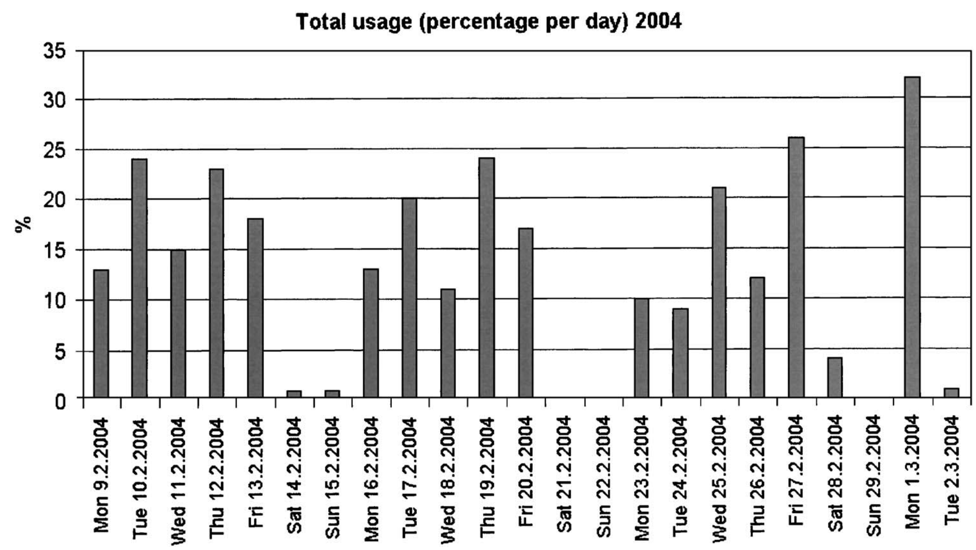

Fig. 8. Total elevator use time (%) of theoretical maximum (12 h/day) during period February 9–March 2, 2004

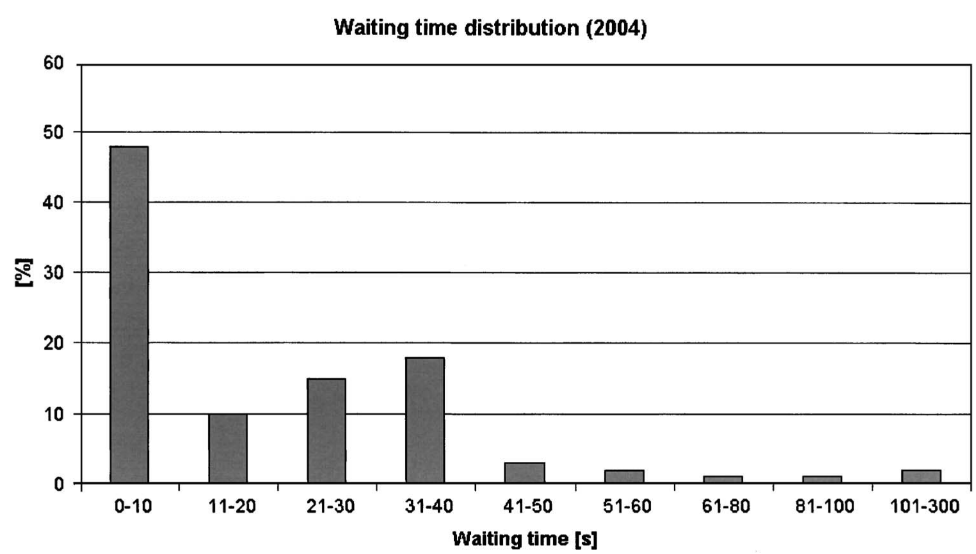

Fig. 9. Waiting time distribution (total 100%) during period January 16–March 2, 2004

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Table 1. Combined Risk Indexes Calculated as Cubic Average Values of SAFERtool

Combined risk indexes	Products		
Transfer systems	Ceramic tiles	Toilet seats	Water tanks
Manual	1.57	1.58	1.08
Manual+elevator	0.95	0.87	0.68
SAFETI pallet+horizontal mover+elevator	0.74	0.79	0.49

Table 2. Delivery System Efficiency for Ceramic Tiles: Unit Times, Times to Deliver All Products for One Level (Measured Times from Ground Floor to Installation Floor), and Relational Efficiency (Manual=100)

	Relational efficiency	
Ceramics delivery	Unit time	(%)
Manual	3 min 27 s	100
Manual+elevator	1 min 25 s	41
SAFETI pallet+horizontal mover+elevator	32 s	16

transportation aids are used (see Fig. 10). Risks are at their lowest when transportation is performed in an integrated way with minimal manual handling.

Efficiency

Here efficiency describes the efficiency of three different products. Thus it does not include the efficiency of the entire construction site. A similar improvement such as in health and safety risks can be seen in efficiency results (Table 2): The working time needed after introducing the elevator was 41% of the purely manual handling time, and after introducing the horizontal mover it was only 16%. The complementary effect is the direct saving of time as compared to walking in the stairs.

Introduction of the elevator led to a significant improvement of the health and safety level and of efficiency. Introduction of the combined use of the horizontal mover+elevator led to further considerable improvement of the health and safety level and of efficiency (Fig. 10).

Discussion

Health and Safety

Materials transfer is an essential part of the work at construction sites. When a job requires focusing attention also on the simultaneous performance of other secondary tasks, such as materials handling, the possibility for errors in the performance of the primary task is present (Cohen et al. 1985). Particularly when transferring fragile materials, one may pay more attention to the material being handled instead of the work environment.

The results of the study can be evaluated in relation to both improvement of logistics and assuring safer and healthier working conditions in construction work through the elimination of the manual handling of construction materials. In addition, the data on elevator traffic can be used to determine the need for work-related personnel traffic in the building.

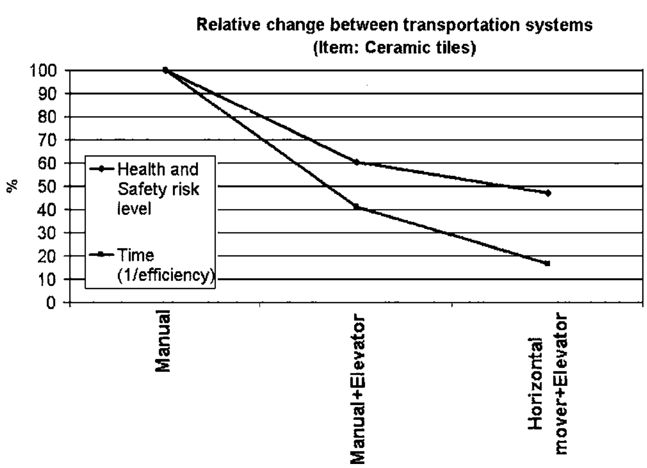

Fig. 10. Relative change in health and safety level and efficiency. Item being delivered is ceramic tiles. Health and safety risk index in manual delivery=100, and time needed in manual work=100.

Early Use of Permanent Elevator

The use of elevators at a construction site makes material handling more efficient during the construction process. The productivity of work, flexibility of production, and working conditions can be improved with an efficient vertical materials handling system. For logistic efficiency, several factors related to the material flow should be considered: First, to reach optimal logistic conditions the bottlenecks of transportation should be detected. In the construction of multistored buildings, the transportation of personnel and goods may face a bottleneck on a certain floor at a certain hour of the day, meaning that the workers must devote part of their work efforts for carrying the material and tools instead of performing actual construction work such as assembly, installation, finishing, etc. The primary objective of the present analysis of elevator traffic data was to locate and identify the logistic bottlenecks. Second, elevator traffic data can be used to evaluate the amounts of work needed to perform logistic phases such as transportation, handling, and storage, in general. Figs. 7–9 give examples of elevator traffic data illustrating the above-mentioned construction site logistics in the finishing phase. For the sake of comparison, it is known from general elevator practice that ordinary goods elevators seldom exceed 30% of their theoretical usage intensity.

The experiment of using a local innovation called a wheeled pallet as an aid tool showed us that it is essential to have a wheeled aid at a construction site. The aid need not necessarily be sophisticated. The advantages of a sophisticated aid come up only when the routes are clean and easy to use.

The following question may be posed regarding the use of a permanent elevator in the building phase: who will pay for its use? We attempted to clarify this by introducing user identification cards. At a construction site several types of elevator users can be distinguished depending on the progress of the construction work. For user identification, a personal identity badge and a reader connected to the elevator command and traffic control system was used. This system enabled defining the number of calls and use of the elevator per worker. In this study it proved to be complicated to gather the elevator user information at the construction site. Thus we did not get reliable personified information that would have served as the basis for the distribution of the costs.

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The elevator is an essential part of an effective and safe chain of materials transfer. If the early use of an elevator is hoped for, all the other parts of the chain must be considered carefully. This includes, e.g., appropriate packaging of the materials, training of the employees, correct use of the devices, and just-on-time deliveries. The use of site elevators makes the materials handling more efficient during the construction process, and the elevator is also in good condition after the construction period.

Obviously it involves some extra costs to install the permanent elevator already in the construction phase (e.g., protecting the elevator from dust and damage). The operating cost of the elevator is determined by the maintenance contract cost, protection of the car and landings, and possibly the cost of an increased need for spare parts.

Because the period of using an elevator is not limited to the building process, the cost efficiency is determined by the frequency of use (vertical transportation intensity). Transportation intensity increases in terms of the number of subcontractors and in the variety of materials and amount of deliveries to the site. The efficiency of an elevator therefore increases significantly toward the end of the construction project. The more labor intensive the work, the more profitable is the use of a construction elevator.

We also know that using an elevator instead of the stairs diminishes the risk of accidents when carrying materials at a construction site. In a short study it was not possible to estimate the monetary value of the improved working conditions.

Relevancy of Methods

The data gathered about the use of the elevator gave us an overall picture of the entire construction site during the finishing phase. By using SAFERtool and MatSim methods we gathered data on the transfer of three different products that were part of the site logistics. Thus the measurements describe only the materials transfer of these particular products. However, these products represent well the materials transfer at a construction site, e.g., shape and weight of the products. Thus we strongly believe that the results obtained from transferring these products can be generalized to overall site logistics.

Conclusions

The use of a vertical transportation system diminishes physical loading as well as accident risk when compared to manual material handling. The use of a permanent elevator already in the construction phase is a suitable solution for this purpose. The car dimensions and capacity are sufficient. Horizontal transportation can be improved with wheeled devices, but then the environment at the construction site must be in better order to decrease physical loading. Some manual handling is always present in transportation because delivery batches are not equal to the amounts needed at the installation sites.

Acknowledgments

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