Construction Logistics System

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Abstract

The importance of a logistics system is not widely recognized in the Japanese construction industry. The distribution of materials used in construction projects, as well as their cost, have therefore, not yet been investigated. Our previous report [1] examines material transportation to and from construction sites and estimates the transportation cost. Estimates show that 5 to 10% of the construction cost is spent on material transportation as a result of hiring vehicles.

Studies on construction logistics are currently underway as one possible solution for a restructured multilayered contract system as well as for improving the productivity of construction projects. A new system of material distribution was designed and tested at one site in order to determine the effects on overall construction cost. The study revealed that the system reduces the workload of everyone involved, such as that for unloading materials from trucks, arranging received materials and checking orders for transportation. The study also revealed that, the more material is controlled, the less time there is for distribution. As a result of the above-mentioned findings, 27 partners, including nine general contractors, have become involved in introducing the new construction logistics system

In this paper, we report the results of an experiment on a joint distribution as a first step of the aforementioned reform.

1. Introduction

The Japanese economy is currently in a serious depression. Given the Japanese economy's relation with Asia's economic crisis, for the sake of the world economy, the Japanese economy must urgently free itself from depression. The inactivity of the Japanese construction industry under a 6.7 trillion yen annual investment, which is almost the same as that for the entire EU or USA, is a major cause of the depression. Due to the low demand for construction, competition has intensified, resulting in a substantial decrease in the price of construction work compared to that during the bubble economy. This decrease can be largely attributed to the construction industry's efforts, such as the streamlining of various fields and the introduction of new technologies. However, in reality, in each level of the multilayered contract structure, construction work is accepted in order to meet the price in the market even though it produces a problem. As a result, in each level of the multilayered contract structure, problems have accumulated. Therefore, construction business based on these systems is no longer viable. Construction firms are afraid of further expansion of their problems, and as a result, they are prudent and passive, bringing about inactivity in the entire construction industry.

It is of great importance to dissolve the costly multilayered contract structure, which was formed during a period of rapid economic growth, and to reform it into a cost-efficient and rational system. In this project, we focused on practical physical distribution of materials, and simplified and rationalized the distribution through multiple steps of many businesses to the construction site, which was the final consumption area. By the simplification and rationalization of the distribution, our final goal is to create a new role for intermediate businesses that are not directly involved in the transaction of materials and to reform the structure of the construction industry as a whole.

In this paper, we report the results of an experiment on a joint distribution as a first step of the aforementioned reform.

2. Joint distribution Experiment

2.1 Materials used in experiment

We used a 1,072 m^2 individual house, which was a reinforced concrete building with two stories above ground and two levels below the ground.

In this report, "joint distribution" is defined as the system in which a transportation schedule of materials to the construction site is arranged in order to transport all materials to the construction at once so that a conveyance vehicle travels to all of the manufacturers to load the various materials in a single trip.

2.2 Outline of experiment

In this experiment, we aimed to determine the efficiency resulting from the introduction of joint distribution and issues in order to construct a system for joint distribution. Furthermore, we analyzed the load factor for the materials and the transportation cost. At the same time, the effects of joint distribution operation on the construction cost and efficiency of construction work was studied.

(1) Duration of experiment

This experiment was performed for approximately one month, from May 26th to June 26th in 1999. In order to determine the effectiveness of joint distribution, the load factor for materials and the transportation cost were measured before and after the joint distribution. Data were obtained for seven days to measure the load factor for the materials and the transportation cost before the actual joint distribution and for six days to measure it after the actual joint distribution.

(2) Transportation arrangement system and joint distribution

The data on transportation schedule arrangement was shared using Microsoft Excel files via the Internet.

The transportation schedule information is collected from cooperating businesses and material manufacturers by phone or facsimile and given to the site manager. Then, the site manager adjusted the transportation schedule. A different file for the transportation arrangement was prepared every day. After the schedule arranged by the site manager was input, the schedule was disclosed on the server, which was installed at the construction site. The server was different from that connected to the Intranet for the firm and information on the schedule was shared with involved businesses. The transportation schedule for the day was given to the driver when departing from a vehicle base.

The transportation cycle usually proceeded as follows.

i. When departing from a vehicle base, the driver is given the collection schedule for the day. Then, the driver delivers materials to the construction site, which were loaded the previous day and remained on the carrier bed overnight.
ii. After confirming the collection schedule, the driver leaves the vehicle base and travels to the intended business sites.
iii. The delivery schedule depends on the collection sites and the types of materials to be collected. (If the place where materials are to be collected is located near the construction site, materials are collected and delivered to the construction site on the same day, and then, the truck departs to collect materials again.)
iv. The truck usually returns to the vehicle base loaded with materials.

(3) Materials

We selected businesses to participate in the experiment on the basis of hearings held prior to the experiment; next, we decided to use various materials from the selected businesses. Table 1 lists the materials used in the experiment.

Table 1 Subject materials in joint distribution.

Work	Example(s)
Elevator	Panels, rails, doors, elevator system, wires
Equipment	Air conditioning system, pipe, valve, feed water pump, water supply pipe/ fixtures
Glazing	Glass plate
Interior finish	Glass wool board, gypsum board, light gauge steel (LGS)
Joiner's	Aluminum sash, steel sash / door, shutter
Plaster	Cement, sand
Reinforcement	Reinforcing bar
Structural	Deck plate
Temporary	Scaffolding, temporary materials
Waterproofing	Waterproof material, asphalt waterproofing
Curtain wall	Aluminum curtain wall

(4) Measurement items

In order to determine the efficiency of joint distribution, measurement was made from the viewpoints of "vehicle load factor" and "cost related to material transportation."

- **Vehicle load factor**

There are two types of vehicle load factors, the volume load factor and the weight load factor. The calculation equation of each load factor is shown below. In the experiment, a digital camera recorded the type of packing, and the volume load factor was determined by visual approximation. The weight load factor was calculated by the material weights recorded on delivery statements.

Volume load factor = cargo volume/maximum load volume of truck (1)

Here:

Truck's maximum load volume = carrier bed area x carrier bed height

Cargo volume = area (percentage) of cargo occupancy of the carrier bed area x height (percentage) of cargo

<<Note>> Height: maximum value: 100%, Gate height was defined as 30%. However, the gate height was set at 50% in the truck used for the joint distribution.

Occupancy area: maximum value: 100%, (cargo which is bigger than the carrier bed area is considered 100%).

Table 2 shows standard values of volume obtained from actual measurements.

Weight load factor = cargo weight/maximum load weight of truck (2)

Table 2 Standard value of volume.

Type	Truck mounted crane	Width (m)	Length (m)	Height (m)	Width x Length (m^2)	Truck's maximum load volume (m^3)	Truck's maximum load weight (ton)
4tu	Mounted	2.1	5.5	1.5	11.6	17.3	2.75
3t	Non	1.9	3.5	1.4	6.7	9.3	3.00
2t	Non	1.9	4.4	1.4	8.4	11.7	2.00

- **Cost for material transportation operation**

On the basis of the activity-based cost (ABC) method, we measured the cost and analyzed the efficiency of operations related to material transportation before joint distribution was implemented. Using the results of this analysis, the expected effectiveness of joint distribution was calculated. The ABC method is used to determine the actual cost by identifying the cost, which is dependent on each activity (operation activity).

Material transportation is classified into the following six processes according to the transportation procedure: 1) waiting time after the truck arrival, 2) signing of delivery slips, 3) preparation for unloading, 4) unloading, 5) transfer of materials to the storage place, and 6) cleaning after unloading.

3. Results

During the experimental period, we measured the vehicle load factor and the transportation cost of conveyance vehicles of 40 trucks for conventional transportation and four trucks for joint distribution.

3.1 Vehicle load factor

The photographs shown in Figures 1 and 2 present how materials transported to the construction site are loaded. Tables 2 and 3 list the vehicle load factors obtained by measurement.

Fig. 1 Situation of material transportation (curtain wall).

Fig. 2 Situation of material transportation (joint distribution: a reinforcing rod, a plywood board and a curbstone).

The average vehicle load factor is 43% for the volume load factor and 55% for the weight load factor. The frequency distribution of volume load factors is shown in Fig. 3.

Figure 3 shows that the distribution of the vehicle load factors exhibits two peaks, in accordance with the material characteristics. Materials with low load factors are mainly mechanical-system materials which are not mix-loaded with other materials in most cases because 1) they are specially used only at the construction site and 2) the mechanical components of materials are manufactured by different manufacturers. One truck is prepared to transport each of the material components. Therefore, the volume load factor and the weight load factor vary greatly depending on the materials transported, most of the materials transported have low load factors. Materials with high load factors are mainly raw-material-type materials. Raw-material-type materials have almost full load factors because 1) the number of materials is large, and 2) they are commonly used materials and are therefore used at multiple construction sites.

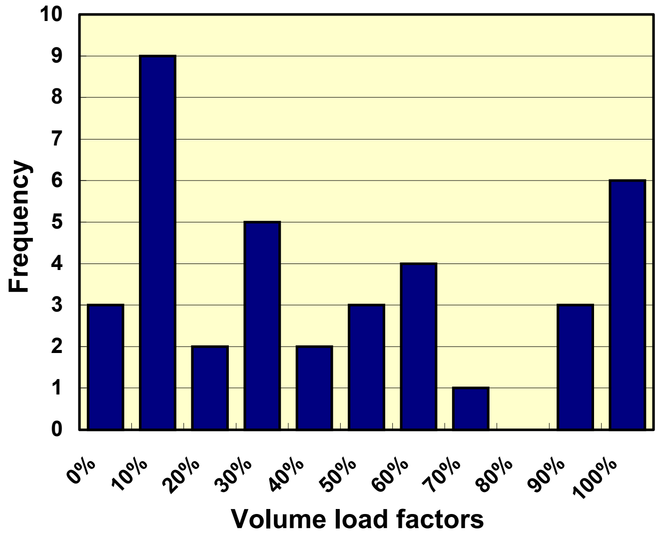

Fig. 3 Distribution of volume load factor.

3.2 Cost for material transportation operation

The transportation cost is calculated as follows: the transportation operation is classified on the basis of the operation unit, cost for each operation is obtained by multiplying the unit cost, time and frequency of each operation, then the cost of all operations are summed. The data for calculating cost are based on the unit cost information published from the Economic Research Association [2]. The truck driver's unit cost, for example, is ¥37/min and worker's unit cost is ¥39/min.

The transportation cost of measured materials ranges from ¥114 to ¥15,115 with an average cost of ¥2,809. Figure 4 shows the frequency distribution of the transportation cost.

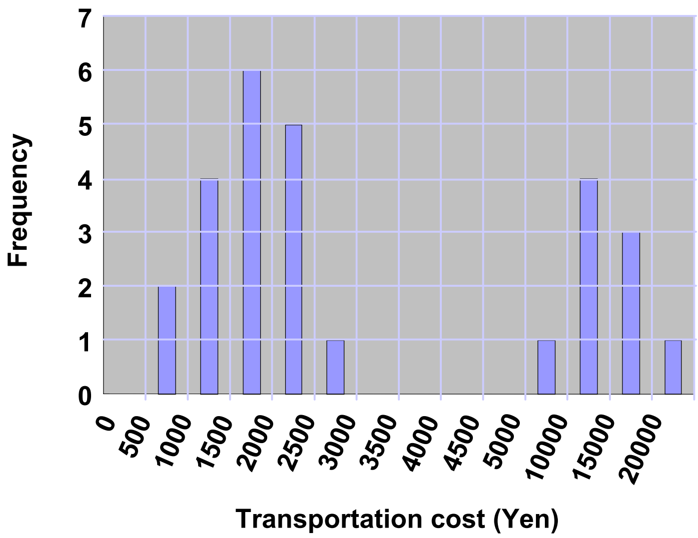

Fig. 4 Frequency distribution of transportation cost.

Figure 4 shows that the frequency distribution of the transportation cost exhibit two peaks. Materials from ¥1,000 to ¥1,500, which exhibit the first peak, are light gauge steel (LGS), sashes, heat-insulating materials and boards. Materials from ¥5,000 to ¥10,000, which exhibit the second peak, are elevators (ELVs), shutters, LGS and boards.

Materials with low transportation costs have characteristics such as 1) they are generally used parts, 2) they have a low load factor, and 3) they have low specific gravity. Meanwhile, materials with high transportation costs have characteristics such as 1) they must be treated carefully, and 2) the load factor is high even though they are generally used parts.

Figure 5 shows a process flow consisting of six procedures, which is based on the transportation procedure.

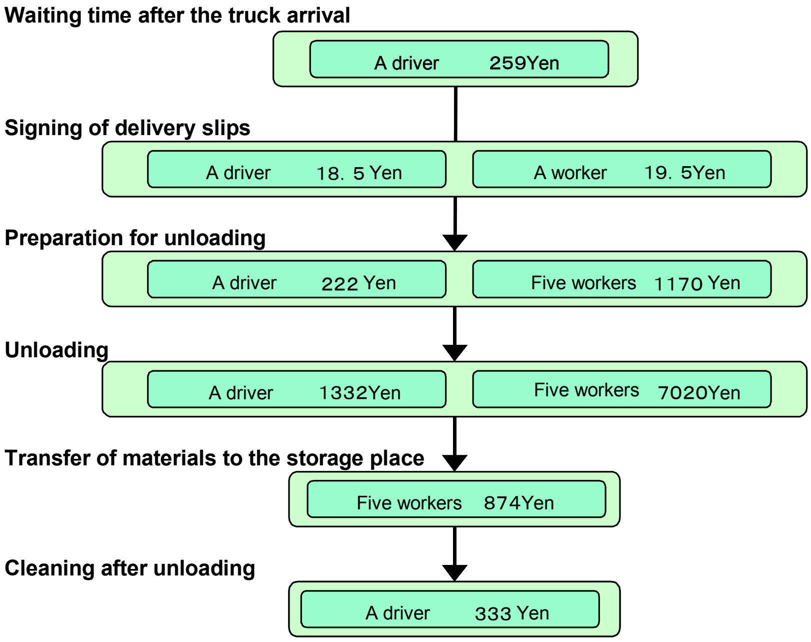

Fig. 5 Example of study results on material transportation (curtain wall).

For the materials shown in Fig. 5, approximately 87% of the total cost is related to receiving and unloading materials and approximately 8% of the total cost is used to transfer materials to the storage place. Similarly, we calculated the cost of each activity for materials, which were measurement targets in this experiment. Our calculation revealed that waiting for transportation required ¥14,946, receiving and preparing for unloading required ¥11,072, unloading required ¥32,500, transfer to the storage place required ¥48,992 and cleaning after unloading ¥4,845.

Even though the cost for each activity differs depending on the materials, approximately 39% of the total cost is related to receiving and unloading materials, and approximately 44% of the total cost is related to the transfer of materials to the storage place.

4. Discussion

In this report, we calculated the effect (load factor and transportation cost) of joint distribution in which materials are mix-loaded on the basis of results obtained by the measurement of volume and weight load factors. The conceptual development required to perform joint distribution and implement a system of it will be discussed.

4.1 Load factors

Table 3 presents one example of a combination of materials in this study, which was subjected to joint distribution as well as the load factor of the combination of materials. The combined materials are an air-conditioning system and boards transported on June 9th. The photograph in Figure 6 shows the transportation situation of each material. These materials were transported on the same day; however, they were transported in different vehicles. The air-conditioning system represents 40% of the volume load factor and 25% of the weight load factor, while boards present 15% of the volume load factor and 5% of the weight load factor. If these materials were transported by one four-ton truck, the volume and weight load factors would be 38% and 32%, respectively, thus enabling these materials to be conveyed by one vehicle with space still remaining.

Table 3 Example of combined material joint distribution.

	Volume load factor				Weight load factor				
Materials	Area of cargo occupancy of the carrier bed area (%)	Height of cargo (%)	Volume load factor (VLF) (%)	Volume load factor reduce to a four-ton truck basis (4VLF) (%)	Type of truck	Maximum load weight (MLW) (Kg)	Load weight (kg)	Weight load factor (WLF) (%)	Weight load factor reduce to a four-ton truck basis (4WLF) (%)
Air conditioning system	80	50	40	23	3t	3000	738	25	27
Gypsum boards	15	100	15	15	3t	2750	140	5	5
Sum			55	38				30	32

Fig. 6. Joint distribution situation on 1999/6/9.

Table 4 Example of joint distribution
(all materials in the experiment during the entire experimental period).

Date	Materials	MLW (ton)	VLF (%)	4VLF (%)	VLF by joint distribution (%)	WLF (%)	4WLF (%)	WLF by joint distribution (%)
‘99/5/26	ELV 1	3	4	4	60			
‘99/5/26	ELV 2	3	56	56				
‘99/5/28	Pomp system	2	60	60	87			
‘99/5/28	Air conditioning system	2	27	27				
‘99/5/31	Shutter 1	4	30	30	40			
‘99/5/31	Shutter 2	4	10	10				
‘99/6/1	Sash	2	5	4	22			
‘99/6/1	LGS	2	25	18				
‘99/6/2	Aluminum sash	2	10	7	48			
‘99/6/2	Gypsum board	2	56	40				
‘99/6/2	Gypsum board	3	85	49	99	45	52	93
‘99/6/2	Gypsum board	3	85	49		37	41	
‘99/6/4	Air conditioning system	2	100	72	95			
‘99/6/4	Air conditioning system	3	40	23				
‘99/6/4	Deck plates	5.5	8	8	8	5	11	
‘99/6/4	Glass wool	2	0	0				
‘99/6/9	Gypsum board	3	40	23	38	25	27	33
‘99/6/9	Air conditioning system	3	15	16		5	5	

Similarly, Table 4 lists the load factors of materials, which were transported on the same day in cases of joint distribution. As summarized in Table 4, a total of nine vehicles (approximately 23% of the total fleet) could be reduced during the measurement period. Materials, which can be subjected to joint distribution, are mainly mechanical-system materials with low load factors.

The total number of trucks used for transportation of materials to the construction site, which has an approximately one-year operation period and a total floor area of 3,000 m^2, is approximately 1,200. Therefore, approximately 270 vehicles would be reduced if joint distribution was implemented throughout the entire construction stage, and approximately ¥10 million (¥37,000/4-ton truck crane) would be saved.

4.2 Transportation cost

Since the construction site vehicle entrance is narrow and temporarily made space for materials is very limited in small and medium construction sites, only one vehicle at a time is allowed to enter the construction site or occupy space for unloading. When multiple materials must be transported simultaneously under these conditions, vehicles other than transport vehicles, which are involved in the loading operation, must wait outside the construction site. Having other vehicles wait extends material transportation time and deteriorates the peripheral environment of the construction site. Figure 7 shows the transportation time schedules of three types of materials by different vehicles and by the joint distribution system.

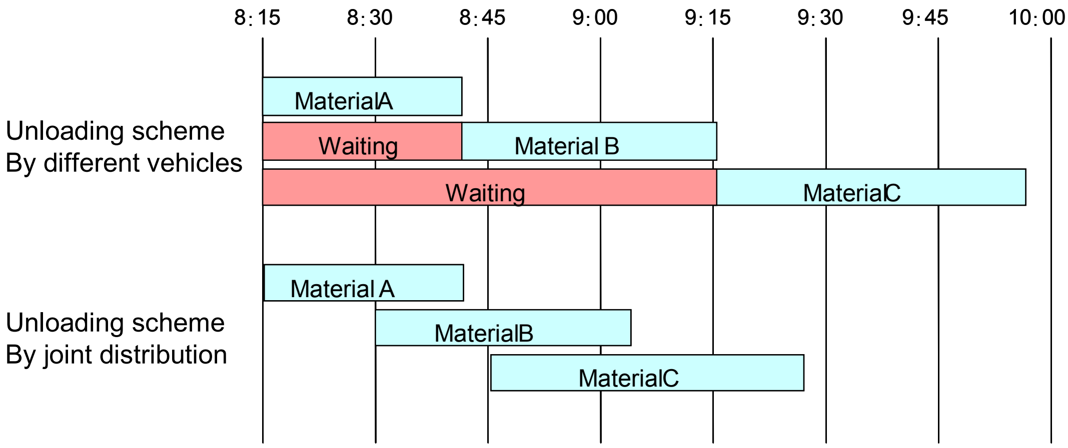

Fig. 7 Transportation time schedule.

Joint distribution eliminates wait time, leading to a reduction in personnel cost for workers and truck drivers involved in transportation waiting. The cost for wait time accounts for approximately 13% of the total transportation cost, with approximately ¥365/transportation. During the experimental period, nine trucks could be reduced by joint distribution and reducing the cost of transportation waiting could save ¥3,285. If joint distribution were introduced throughout the entire construction stage, 270 trucks and ¥98,550 of the transportation cost would be reduced.

4.3 Introduction of loading and unloading agents

We have discussed joint distribution's effect on the reduction of transportation vehicles and the cost for wait time due to the improvement of the load factor. In this section, we will discuss the effect on transportation in the case of using loading and unloading agents in the material transportation operation.

In joint distribution, the lesser the frequency of material transportation, more the transportation time for each operation. The greater the amount of materials transferred at one time and the higher the load factor is, higher the ratio of original transportation operation (unloading and transfer to the storage place) to the total transportation time becomes. However, the transportation operation remains the same even after the introduction of joint distribution, and the burden on workers remains the same. In general, the per hour unit cost of workers for loading and unloading materials is less than that of workers involved in the construction work. Therefore, it is possible to reduce the personnel cost by leaving only the transportation operation up to other businesses' workers. Actually, it is common to prepare a loading and unloading agent for the transportation of boards or LGS. With the introduction of loading and unloading workers, we expect that construction workers can spend time, which they previously used for the transportation operation for their original and specialized construction operation, thereby leading to an improvement in productivity. On the basis of the aforementioned reasons, the cost for unloading when construction workers are replaced by loading and unloading workers is estimated.

The cost of workers represents approximately 64% (¥72,380) of the total cost (¥112,355). If loading and unloading workers replaced workers who are specialized in the construction operation, the personnel unloading cost would be reduced by ¥12,991 to be ¥59,389. A cost decrease of 11.6% of the entire cost could be expected. If loading and unloading workers were used throughout the entire construction period, a cost decrease of ¥389,730 could be expected.

5. Conclusions

To identify the effect of joint distribution and to determine the subjects for the construction of the system, we analyzed the load factor of materials and the transportation cost. Then, the influence of joint distribution on cost and efficiency were studied.

The average load factors of transported materials were as follows: the volume load factor was 43% and the weight load factor was 55%. Our study revealed that mechanical- and machine part-system materials have low load factors since they were transported on a component basis, whereas raw-material-type materials presented high load factors since they have a single shape and can be voluminous.

The average transportation cost was ¥2,809. The price range can be almost entirely separated into two categories. The characteristics of materials in the first price range from ¥1,000 to ¥1,500 are generally used materials with a low load factor and low specific gravity. The characteristics of materials in the second price range from ¥5,000 to ¥10,000 require careful treatment and have a high load factor. Among the total transportation cost, 39% is related to the receiving and unloading of materials, while 44% is related to their transfer to the storage place.

Our study revealed that approximately 23% of the vehicles used in the experiment could be reduced, resulting in a cost decrease of approximately ¥10 million if joint distribution was implemented throughout the entire construction period. Accompanying the decrease in the vehicles, approximately ¥100,000 of the transportation cost could be saved. Furthermore, introducing workers who are specialized in loading and unloading could save approximately ¥390,000 saved throughout the entire construction period.

6. Future Tasks

Since this experiment was performed on a single construction site only, trucks were not effectively used, and were to unable to manage the joint distribution well. Joint distribution functions effectively with multiple businesses and construction sites. We aim to optimize efficiencies by having all businesses involved in the construction work. Therefore, the participation of multiple construction sites is essential to achieve joint distribution in its true sense.

One of the issues clarified in this study is the difference in transportation form depending on material characteristics. The difference between mechanical- and machine part-system materials, and raw-material-type materials is particularly evident. As mentioned above, to transport mechanical- and machine part-system materials, one vehicle is prepared for each material, regardless of the size and quantity of materials. Therefore, the load factor is low in most cases. In contrast, raw-material-type materials usually have a single shape and are voluminous to a certain extent; as a result, their load factor is often high. Since the difference in material characteristics greatly influences the mechanism of joint distribution, we believe that it is necessary to determine the relationship between material characteristics (specific characteristics) and the appropriate transportation system. In addition, it is necessary to examine what types of material characteristics are suitable for joint distribution.

To perform joint distribution, construction sites, involved businesses, material manufacturers and forwarding agents must cooperate, disclose information and strive to optimize the entire system. In this experiment, the site manager alone arranged the transportation schedule input into the file, which is important to run joint distribution input. Therefore, it is desirable that all who participate in this system voluntarily input the schedule into the file and in this way; the joint distribution system can run independently. An input interface and database urgently need to be constructed to promote voluntarily input by those involved.

At the same time, it is necessary to enhance carriers' understanding of information technology (IT), which inevitably becomes a significant element in joint distribution. A system with a simple user interface, which can be used by people with low understanding of IT, must be developed.

The data on transportation cost needs to be disclosed in joint distribution. This requires the clarification of the relationship between material characteristics and the load factor, and between the actual rate of hired vehicles and the transportation cost. In addition, the cost for materials, processing and labor must be determined separately. Accordingly, to promote joint distribution, it is essential that all information regarding material characteristics be disclosed, and that such information should be reflected in the cost.

Table 8 summarizes the results of the calculated effect of joint distribution and information sharing on an experimental basis, based on the results of this experiment and previously published reports.[1)]

Table 8 Effectiveness of cost reduction for participants in the construction work as a result of joint distribution and information sharing.

Reduced number of trucks for transportation as a result of joint distribution.	40%
Reduced driver waiting time due to joint distribution.	18%
Reduced transportation operation of construction workers as a result of the introduction of workers to handle the unloading operation.	18%
Reduced visiting frequency of business agent to the construction site as a result of information sharing. [1]	30%
Reduced construction management business as a result of joint distribution and information sharing. [1]	3.2%

It is an urgent task to dissolve the costly multilayered contract structure, which was formed during a period of rapid economic growth, and reform it into a system, which operates efficiently and rationally. In this project, we focused on practical physical distribution of materials. Then, we aimed to simplify and rationalize the distribution through multiple steps of various businesses to the final consumption area, which were construction sites. By utilizing the advantages obtained from the simplification of the transportation system, it is essential to create a new role for intermediate businesses, which are not directly involved in the transaction of materials, and to reform the industrial structure of construction production as a whole.

This structural reform requires drastic changes in the conventional way of working and flow of work. In order to carry out this drastic reform of business practice in a stable manner, it is essential to construct and operate a basic information system as an infrastructure of a business system. In this project, with the promotion of the drastic reform in the flow of business practice, a basic information system for businesses, termed the "physical distribution EDI system with a supply chain in the construction industry," was developed. A practical system to operate this information system was established after successful operation tests.

The reform of the construction industry as a whole must be performed comprehensively through the participation of all companies in the construction industry. Therefore, it is impossible to realize this reform with a small number of companies and research institutions. Therefore, 27 leading firms, including nine major construction firms, are having meetings at the Asia Pacific Research Center in Waseda University. At present, they are involved in the development of a system and are conducting operation system experiments in order to introduce the physical distribution EDI and popularize it. In the future, practical reform is scheduled to be promoted by the participation of owner companies which order the construction work, material supply manufacturers, companies to produce construction facilities and distribution companies.

References

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