Environmental Load Reduction Due to Modal Shift Resulting from Improvements to Railway Freight Stations

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Intermodalism has become one of the most important ways of transporting freight with the development of social economy and industry. In order to correspond to the changing nature of freight transport and to improve railway transport effectively, it is essential to upgrade conventional freight stations to provide sophisticated facilities where loading/unloading services are directly handled on siding tracks for arrival and departure. In this paper, we discuss the improvements of railway freight stations based on advantage analysis by comparing the conventional type with the new one. We then cover the development of a mode-share model using stochastic distribution of freight time value. Next, we estimate the modal shift of freight resulting from improvements to station facilities, and finally we investigate the related environmental effects such as reduction in CO₂ emissions.

Keywords: environmental load reduction, modal shift, freight station, mode-share model

1. Introduction

The excessive dependence of surface freight on all-road transport has generated many serious negative effects in terms of environmental and social burdens, including traffic congestion, air pollution, infrastructure damage, road accidents, *etc.* Additionally within the field of logistics, inefficiencies and labor shortages in all-road transport have also posed significant problems. Since the 1990s, many developed countries (including Japan and Europe) have stipulated and actively promoted relevant legislation, policies and countermeasures known as *modal shift policies* to shift freight transport from the all-road mode to large-volume traffic modes such as railway and ship. However, the completion of road network and flexible truck transport means that modal shift policies have not achieved the desired results. One of the main reasons for this is that the conventional transport method based on existing railway facilities is held back by a lack of competitiveness in the modern transport market. According to freight shippers, one of the most important improvements to railway freight transport is to shorten the lead time of door-to-door transport ¹⁾. In addition, in the future, if railway is unreasonably integrated with road to form an intermodal transport system, it is impracticable that railway competes solely with all-road freight transport.

One of the key elements of an intermodal transport system involves freight terminal stations acting as hubs to connect different modes together. The many obvious disadvantages of conventional railway freight stations, where many premises operations must be handled, mean that they are unsuitable for seamless intermodalism ²⁾. Some innovative attempts to upgrade freight terminal facilities were in fact made during the era of Japan Na-

tional Railway, including the construction of a new type of station where loading and unloading operations are directly handled at arrival and departure tracks. However, rapid changes in the logistics market and JNR management have meant that railway freight now encounters increasingly serious internal and external issues. Although the reconstruction of some freight terminals (approximately 8% of the total) is by now completed, most of the work has been based on other projects such as urban development or Shinkansen construction ³⁾. In addition, analysis of the effectiveness of the new type of station for freight transport is characterized by a lack of objective evaluation.

The new type of railway freight station enables many premises operations to be reduced, and also allows significant reduction in the staying time of containers. This paper reports on efforts to reconstruct station facilities toward the evolution of railway station to act not only as a hub for joining different modes of transport but also as logistics base for seamless combination.

The first part of this paper discusses the fundamental area of an intermodal freight transport system achieved by seamlessly combining railway with road, as well as by making detailed improvements to railway freight station based on advantage analysis through comparison of the conventional type with the new one. We then developed a mode-share model using stochastic distribution of freight time value, and used a case study to estimate the modal shift of freight from all-road to intermodal transport through the improvements of station facilities. Finally, using the LCA method, we investigated the resulting environmental effects such as the reduction of CO₂ emissions in freight transport according to the volume of modal shift freight estimated.

Fig. 1 Arrangement of facilities in a conventional freight station

Fig. 2 Arrangement of facilities and operational procedures of the new type of station

2. Improvements of conventional freight stations

The conventional facility arrangement of freight stations shown in Fig. 1 corresponds to a wagon-handling transport system. The basic facilities of this type of station include the following:

- Main lines, branch lines in some cases, an arrival and departure yard with multiple tracks,

- Loading and unloading tracks with cargo platforms and storage, limited space for truck parking and transshipments between railway and road,

- Soft pavement at station premises, sidings for trains to pass each other and waiting tracks for wagons to be used in certain operations,

- Switching engines for yard operations and forklift cars for freight loading and unloading,

- Warehouses for freight storage, office buildings, electric equipment, etc.

According to the needs of conventional transport system, many operations take place at the premises of freight stations, including the following:

- Train arrival and departure operations, empty wagon storage, cargo disposition and storage, papers' dealing concerning freight bill and invoice etc., transshipment of freight between wagons and storage facilities or trucks, loading and unloading of freight, shunting operations between the arrival / departure yards and loading / unloading tracks, coupling and uncoupling operations of freight trains. Since most of these freight stations correspond to operation with fewer wagons, shorter loading and unloading tracks were often set up, especially at intermediate stations.

However, with the current situation resulting from changes in the logistics market, the amount of wagonload handling freight has rapidly decreased, while container cargo has seen an increasing trend. The functions of

freight stations therefore need to be converted to create joint facilities acting as part of an intermodal transport system. Since containers are generally collected and delivered using trucks as the fundamental mode, major operations in the freight station should be limited to the transshipment of containers between trucks and trains, and other work/operations should be minimized.

To enhance the operational efficiency of freight stations, in 1986, Japan National Railway began to reconstruct conventional stations to create a new type where loading and unloading operations can be handled directly on arrival and departure tracks. Such reconstruction is very important in the development of an intermodal freight transport system featuring organic integration of railway and road. Figure 2 shows the new type of freight station, which offers efficient on-site operations in addition to acting as a logistics base and a hub within the intermodal transport system.

This new type of freight station is a fundamental part of developing an intermodal transport system. Transshipment of containers between trains, or from trains to trucks, or from trucks to trains can be handled using a toplift or forklift car, with trains stopping only for short duration^{2) 3)}. The arrangement of station's facilities is very simple and easy to approach, and the resulting advantages for freight transport can be generally described as shown below.

- 1) Reducing relevant shunting operations and greatly increasing the efficiency of railway transport
- 2) Expanding the number of freight trains at hub stations
- 3) Considerably shortening the staying time of freight trains at stations
- 4) Expanding the acceptance period for cargo at stations and enhancing flexibility for customers
- 5) Increasing the opportunities for freight shippers

to use railway through improved transport services

- 6) Expanding the service of small- or middle-scale intermediate stations along trunk lines (where freight trains do not stop for cargo at conventional stations, meaning that feeder transport from hub stations is required). The development of the new type of station enables freight trains to stop directly on the arrival and departure tracks of intermediate stations to supply cargo transport service.
- 7) Realizing stable and direct freight train transport between base stations due to the reduction of train shunting operations at way stations
- 8) Contribution to reduction in transport cost because fewer staff members can fulfill the needs of cargo handling operation
- 9) Raising the efficiency of land use as the overall operation of the station can be handled within smaller area
- 10) Reducing maintenance cost due to simple facility arrangement
- 11) Reducing the project cost for construction in comparison to other stations with similar handling capability based the above points
- 12) Sharply reducing door-to-door transport time due to the smooth connection between railway and road resulting from trucks being able to approach tracks for direct transshipment of containers
- 13) Providing a range of advantages and points of convenience to shippers and logistics companies through additional services in freight stations such as building logistics centers
- 14) Extending related services in the logistics chain, such as on-site vanning and devanning of freight

A number of examples illustrate the effectiveness of the new type of station in railway transport. After reconstructed Kitakyushu freight terminal opened for operation in 2002, the number of daily freight trains handled in the station increased from 23 to 44 per day. Additionally, at the Kobe railway freight terminal opened in 2003, the number of daily freight trains increased from 10 to 14 per day as a result of renovating the conventional type of station to create the new type ⁴⁾.

According to statistics on railway freight since 1990, the average yearly rate of increase in container volume over the whole railway network is 1.7%, while the figure for the new type of station is about 7%. This result shows that the reconstruction of conventional stations to create the new type has a significant impact on railway transport.

3. Mode-share model

3.1 Time value model

Shippers or logistics companies choosing a mode of transport for freight take into account a number of factors concerning transport conditions. These include transport expenses and lead time from the sending shipper to the receiving shipper, items and price of the cargo in-

involved, lot size, and frequency, safety and certainty of the transport service, *etc.*

Although the logit model theory which can take into account a range of explanatory variables is often used to construct a mode-share model for freight transport, in most cases the relevant factors are not completely independent of each other due to the respective relationships that exist among them. These can be grouped into two representative fundamental types of factor such as transport expenses and transport time; indeed, these two factors generally become the ultimate determinants of shippers in the selection of freight modes. The mode-share model in this study will therefore be derived on the basis of a time value model, which is readily introducible. This model is based on the idea that shippers will choose transport modes with the lowest generalized expense. This figure is the sum of all transport expenses, including any tolls and fares incurred in the transport process as well as the door-to-door time converted into a monetary value. In other words, shippers will choose the transport mode with minimum value of S in formula (1).

$$S = C + \omega T \quad (1)$$

Where S = the generalized expense, including that which the user (i.e. the shipper) pays to the transport operator and loses in the time freight spends in transport (yen/ton),

C = freight charges for transport and relevant handling in all transport procedures (yen/ton),

T = the transport time from door to door (in hours),

ω = the time value per hour (yen/ton/hour).

Figure 3 shows a conceptual illustration of a time value model in which shippers have three alternative modes of transport. In this situation, the generalized expense of each mode is S_i , the time value per hour is ω with a probability density function of $f(\omega)$, and the sharing rate of each transport mode is P_i . Considering every actual transport OD, the mode corresponding to the minimum value of S_i is chosen based on ω . For example, mode 1 in $\omega \leq \omega_{12}$, mode 2 in $\omega_{12} \leq \omega \leq \omega_{23}$, and mode 3 in $\omega \geq \omega_{23}$ will be chosen. In this situation, the sharing rate of mode 1, 2 and 3 is the corresponding accumulative probability of $f(\omega)$, and the values are given as P_1 , P_2 and P_3 based on each mode respectively.

Since there are variations in subjective evaluation by different shippers of time recognition according to the type of freight item and the content involved, ω is often expressed as a probability distribution. If the relevant distribution is experientially assumed to follow log-normal distribution, the probability density function of log-normal distribution $f(\omega)$ with parameters μ , δ will be described as in formula (2):

$$f(\omega) = \frac{1}{\sqrt{2\pi}\delta\omega} \exp(-(\ln\omega - \mu)^2 / 2\delta^2) \quad (2)$$

Where, if the accumulative probability of $f(\omega)$ is P , it can be described as formula (3):

$$P(\Omega \leq \omega) = \int_{-\infty}^{\omega} f(\omega) d\omega \quad (3)$$

Then, if formula (2) is substituted into formula (3) and formula (4) is used, then formula (5) can be derived:

Fig. 3 Concept of time value model

$$e = \frac{\ln \omega - \mu}{\delta} \quad (4)$$

$$P(\Omega \leq \omega) = \int_{-\infty}^{(\ln \omega - \mu)/\delta} \frac{1}{\sqrt{2\pi}\delta\omega} \exp(-e^2/2) \delta\omega de \quad (5)$$

$$= \int_{-\infty}^{(\ln \omega - \mu)/\delta} \frac{1}{\sqrt{2\pi}\delta\omega} \exp(-e^2/2) de = \Phi((\ln \omega - \mu)/\delta)$$

Formula (5) is the standard normal accumulative probability distribution. Therefore, the inverse function of Φ can be shown as formula (6). In this, the alignment relationship between the inverse function of Φ and $\ln \omega$ can be found:

$$\Phi^{-1}P(\Omega \leq \omega) = (\ln \omega - \mu)/\delta = \ln \omega / \delta - \mu / \delta = \alpha \ln \omega - \beta \quad (6)$$

Where $P(\Omega \leq \omega)$ = the standard normal accumulative probability,

$\ln \omega$ = the logarithm value of time value (ω),
 μ, δ = parameters.

While the value of $\ln \omega$ and $P(\Omega \leq \omega)$ can be obtained from actual statistics, parameters μ, δ can be derived by the least-squares method.

In concrete terms, the actual modal sharing rate of mode i in each OD $_j$ is used as the mode-choosing probability P_i . The threshold value (ω_{j12}) of a two-mode choice on the time axis can be computed from the differences between the transport expenses of the two modes and the differences between the lead time of the two modes. Then, using all P_i and ω_{j12} values based on the ODs, a time value distribution can be estimated statistically.

3.2 Estimation of the mode-share model

1) Case-study background

This study focuses on surface freight transport. Freight Station X situated in Prefecture W of Japan's northeastern region is used as a case study to estimate a mode-share model that uses all-road and intermodal transport including railway. In addition, all-surface freight including all-road and container freight that can

be shifted to railway is seen as a potential area of demand for intermodal transport.

Prefecture W has about 98 million tons per year of departure freight, and approximately 105 million tons per year of arrival freight. The sharing rate of each mode for departure freight is 92% with all-road, 2% with railway and 6% with coastal shipping. The corresponding values for arrival freight are 84% with all-road, 0.8% with railway and 15.2% with coastal shipping. Moreover, if only inter-region freight is considered, excluding freight within regions, departure freight from Prefecture W is approximately 27 million tons per year, while the arrival total is 34 million tons per year. In this case, the relevant sharing rate of each mode for departure freight is 71% with road, 6% with railway and 23% with coastal shipping. In the same way, the values for arrival freight are 50.8% with road, 2.5% with railway and 46.7% with coastal shipping. Furthermore, if only surface freight transport is considered, the sharing rates of road and railway for departure freight are 92% and 8%, while those for arrival freight are 95% and 5%, respectively⁵⁾. Of course, the low sharing rate of current railway freight is caused by many complex interior and exterior factors related to railway, one of those is the aging infrastructure and facilities of conventional freight stations.

Freight Station X is visible as a railway freight base-terminal in Prefecture W, and was established in 1961 as part of a wagon-handling system. The loading and unloading tracks are comparatively short. Although corresponding improvements of the station facilities have gradually been introduced with the trend from the conversion of wagon handling to container freight, inefficient operation at the station is conspicuous. As the station represents an important freight base of Japan's northeastern region, relevant reconstruction is conceivable to contribute to reduction in lead time and expansion in the amount of arrival and departure freight.

2) Comparison of freight expenses and lead time between all-road and railway transport

According to the methodology of building the mode-share model, the expenses and door-to-door lead time of transport are important factors to be taken into account. In this study, door-to-door transport from the government office building of Prefecture W to that of all other prefectures is considered. To reflect the actual transport expenses when comparing freight charges, the lower-limit fare of the legal tariff is used for all-road transport. For railway container transport based on conventional railway facilities, the overall transport expenses are computed considering railway container fares and the pick-up/delivery freight charges of terminals, which can be discounted to a certain extent. Moreover, OD lead time for door-to-door transport is calculated in consideration of the staying time, the transport time required and the operation time of each. The results thus calculated can be used to compare the transport expenses and lead time of each OD between all-road and railway transport.

The results of comparison for each freight transport OD between Prefecture W and adjacent prefectures show a predominance of all-road transport in terms of transport expenses and lead time. However, comparison between Prefecture W and non-adjacent prefectures shows that railway transport becomes predominant in terms of transport expenses for distances of over about 300 km. Moreover, the results of comparing the lead time indicate that all the ODs of all-road transport are in predominance.

3) Probability distribution of time value

Since there are two types of train (non-stop and relay) used in all ODs according to differences in the importance of time, and also there are differences in the item composition of arrival and departure freight, based on the available statistics and using formula (6), the probability distributions of the time value of arrival and departure freight for non-stop and relay trains are estimated separately.

Table 1 shows the results of the estimations. Although the estimated results can not be considered with sufficient accuracy, from the relevant correlation coefficient and t-value of each parameter, confidence can be determined to a certain extent. The time value distribution estimated can therefore be taken as a reasonable approximation.

4. Modal shift effectiveness analysis based on the new type of freight station

The significance to change conventional railway container transport to an intermodal freight transport system with the development of logistics is described in details above. This is followed by an discussion to the influence of improvements to conventional stations on railway freight transport. Distributions of time value are then approximated on the basis of conventional railway container transport. Here, we assume that the improvements of freight stations are for intermodal transport. Using the results obtained, we can derive the possibility of shifting all-road freight to intermodal transport when the conventional Freight Station X is upgraded to the new type.

With the new type of freight station, many useless and needless operations for containers on station premises are greatly deleted, meaning that the staying time of freight at stations can be drastically reduced. As freight stations are improved according to the existing conditions, the transport time advantages obtained in terms of staying time reduction are at least approximately 2 hours and 30 minutes for departure freight and approximately 2 hours and 10 minutes for arrival freight³⁾. Using the mode-share model estimated, the shift of freight volume from all-road transport to intermodal transport between Prefecture W and others can be calculated when the lead time involved is reduced.

The procedure for calculating freight modal shift from all-road to intermodal transport with the new type of station can be discussed as shown in Fig. 4. The diverging point of the time value between railway and all-road transport in surface freight transport OD_j between Prefecture W in the northeastern region of Japan and other regions prior to the reconstruction of Station X is given as ω_{12} , and the sharing rate of railway is given as $P_{1(j)}$. After the reconstruction of Station X to create the new type, the relevant diverging point of the time value and sharing rate of intermodal transport change from ω_{12} to ω'_{12} and from $P_{1(j)}$ to $P'_{1(j)}$ respectively, because the generalized expense S_l is changed to S'_l due to the reduction in transport lead time with railway ΔT_l . Therefore, if the total freight volume in OD_j is assumed as Q_j , freight volume Δq_j that shifts from all-road to intermodal transport in OD_j under the newly reconstructed Station X is $(P'_{1(j)} - P_{1(j)}) Q_j$.

According to the discussion above, the total volume

Table 1 Estimation of time value probability distribution

	Type of transport	Coefficients of formula (6)			Parameters of model	
		α (t-value)	β (t-value)	Correlation	μ	δ
Arrival	Non-stop train	0.948 (5.363)	7.045 (-6.269)	0.82	7.431	1.055
	Relay train	0.861 (4.623)	5.642 (-5.016)	0.825	6.553	1.161
Departure	Non-stop train	1.103 (3.757)	7.365 (-3.834)	0.799	6.680	0.907
	Relay train	0.758 (5.531)	5.059 (-6.754)	0.793	6.674	1.319

Fig. 4 Modal shift of freight from all-road to intermodal transport with the new type of station

of freight shifted from all-road to intermodal transport in line with the reconstruction of Station X can therefore be calculated with the following formula (7):

$$\Delta q = \sum_{k=1}^4 \sum_{j=1}^{n_k} \Delta q_{k,j} = \sum_{k=1}^4 \sum_{j=1}^{n_k} (P'_{1(k,j)} - P_{1(k,j)}) Q_{k,j} \quad (7)$$

Where Δq = the total shift volume (in tons) of freight from all-road to intermodal transport for all ODs between Prefecture W and others as a result of the reconstruction of Station X,

$\Delta q_{k,j}$ = the shift volume of freight from all-road to intermodal transport in OD_j between Prefecture W and other regions,

k = the freight train pattern in OD_j, in that $k=1$ represents non-stop train departures from Station X in Prefecture W, $k=2$ is the departure freight from Station X needing to be transshipped at a station in OD_j transport, $k=3$ represents non-stop trains arriving at Station X from other regions, and $k=4$ is the arrival freight at Station X needing to be transshipped at a station in OD_j transport.

In addition, the increase in the number of freight ton-kilometers of intermodal transport by modal shift can be described as shown in formula (8):

$$v = \sum_{k=1}^4 \sum_{j=1}^{n_k} \Delta v_{k,j} = \sum_{k=1}^4 \sum_{j=1}^{n_k} (P'_{1(k,j)} - P_{1(k,j)}) Q_{k,j} d_{k,j} \quad (8)$$

Table 2 Modal shift of freight from all-road to intermodal transport based on station improvement

	Shift freight volume (tons)	Increase rate (%)	Increase in ton-kilometers (millions)
Departure freight	89,267	13	58.1
Non-stop train (11 regions)	80,509	14	49.2
Relay train (22 regions)	8,758	7	8.9
Arrival freight	57,525	9	39.5
Non-stop train (20 regions)	49,038	9	30.4
Relay train (14 regions)	8,487	8	9.1
Total	146,792	11	97.6

Where Δv = the total increase in the number of freight ton-kilometers of intermodal transport for Prefecture W including arrival and departure freight (ton-km),

Δv_{kj} = the increase in the number of freight ton-kilometers of OD_j intermodal transport for Prefecture W including arrival and departure freight,

d_{kj} = the transport distance of the railway in OD_j (km).

Table 2 shows the results of calculating freight modal shift for Prefecture W based on the new-type Station X. It is possible that the shifted volume of freight is approximately 90,000 tons/year for departure freight from Prefecture W, and approximately 60,000 tons/year for arrival freight in the prefecture. The increase rate of intermodal transport freight is approximately 13% for departure freight and about 9% for arrival freight. Moreover, the increase in the number of freight ton-kilometers with intermodal transport is approximately 60 million ton-km for departure freight and about 40 million ton-km for arrival freight. In other words, based on the reconstruction of Station X, the total increase in the number of freight ton-kilometers of intermodal transport will reach approximately 100 million ton-km for Prefecture W.

The above results represent quantitative clarification of the effectiveness of modal shift through the improvements of conventional freight stations.

5. Environmental load reduction from the improvements of freight stations

The previous section of this report discusses the shifted volume of freight from all-road to intermodal transport stemming from improvements to conventional freight stations. It is possible to investigate the resulting environmental load reduction of CO₂ emissions by calculation according to the shifted volume of freight from all-road to intermodal transport in OD_j as outlined below.

1) CO₂ emissions with all-road transport of shifted freight

When the shifted freight volume in OD_j is transported from door to door by truck, the relevant CO₂ emissions can be calculated from the number of transport ton-kilometers of the shifted freight volume multiplied by the basic unit of CO₂ emissions for truck transport.

2) CO₂ emissions from the intermodal transport of shifted freight

When the shifted freight volume in OD_j is moved using an intermodal transport system, the CO₂ emissions can be divided into the two parts of railway on trunk lines and trucks on both sides of the arrival and departure sta-

tion for freight delivery and pick-up. Railway-related CO₂ emissions can be calculated from the number of ton-kilometers of the shifted freight volume on the railway multiplied by the basic unit of CO₂ emissions for railway transport. In addition, truck-related CO₂ emissions can be calculated from the number of ton-kilometers of the shifted freight volume of trucks on both sides of the arrival and departure station multiplied by the basic unit of CO₂ emissions for truck transport. In this paper, a distance of 10 km is estimated for truck transport on both sides of the arrival and departure station for freight delivery and pick-up.

The Ministry of Land, Infrastructure and Transport's figures for the basic unit of CO₂ emissions for each mode are as follows:

Railway freight: 21 g-CO₂/t/km, coastal shipping: 38 g-CO₂/t/km, commercial truck: 174 g-CO₂/t/km, private truck: 388 g-CO₂/t/km⁶⁾.

3) CO₂ emissions' reduction through the modal shift of freight from all-road to intermodal transport

As stated above, under the conditions of freight shift from all-road to intermodal transport for all ODs between Prefecture W and other regions, the total volume of CO₂ emissions' reduction can be calculated with the following equation:

$$TER(CO_2) = \sum_j ET(CO_2)_j - \sum_j EI(CO_2)_j \quad (9)$$

Where $TER(CO_2)$ = the total volume of CO₂ emissions' reduction due to the modal shift of freight,

$ET(CO_2)_j$ = the CO₂ emissions' volume for trucks when the shifted freight of OD_j is with all-road transport,

$EI(CO_2)_j$: the CO₂ emissions' volume of intermodalism when the shifted freight of OD_j is with intermodal transport.

Table 3 shows the results of calculating the total CO₂ emissions' reduction under the modal shift of freight from all-road to intermodal transport. It shows that the reconstruction of Station X in Prefecture W to create the new type of station can bring about reduction of approximately 8,889 t-CO₂/year in the emissions of departure freight transport and approximately 6,072 t-CO₂/year in the emissions of arrival freight transport. This gives a total reduction of approximately 15,000 t-CO₂ / year.

4) CO₂ emissions' volume of construction work to improve conventional stations

As construction work to improve conventional stations also involves CO₂ emissions, the overall CO₂ emissions' reduction in the transport field as a result of introducing the new type of station is the CO₂ emissions' reduction

Table 3 Reduction of CO₂ emissions based on modal shift of freight

CO ₂ emissions (t-CO ₂ /year)	All-road trucks	Intermodalism	Reduction by modal shift of freight
Departure freight	7,102	1,030	6,072
Arrival freight	10,420	1,531	8,889
Total	17,522	2,561	14,961

due to the modal shift of freight minus the CO₂ emissions involved in the construction process. CO₂ emissions incurred in construction depend on the scale of the construction work undertaken. Generally, the overall CO₂ emissions of construction are computed by the total cost of construction project multiplied by the basic unit of CO₂ emissions for construction.

According to statistical analysis of construction, the basic unit of CO₂ emissions for construction is empirically 4.41 t-CO₂/million yen⁷⁾. Moreover, using some cases of conventional railway station improvement as reference, the relevant construction cost was between approximately 3 and 6 billion Japanese yen⁸⁾. When Station X in Prefecture W is reconstructed to create the new type of station, the CO₂ emissions related to construction will be between approximately 13,230 and 26,260 t-CO₂. Since the useful life span of freight station is around 60 years, the average yearly CO₂ emissions can be derived from around 220.5 to 441 t-CO₂/year.

The environmental effectiveness from CO₂ emissions' reduction in freight transport based on the reconstruction of Station X will therefore be about 14,520~14,741t-CO₂/year.

6. Conclusions

This paper mainly describes the improvements of conventional railway freight stations based on Japan's current railway situation, and the effectiveness of such improvements in promoting a modal shift of freight from all-road to intermodal transport. According to this logistics change, the hub between the different modes is generally visible not only as one of the most important parts of the intermodal transport system, but also as the logistics base where many related services are provided. Through the improvements of conventional stations, many useless operations on station premises can be discontinued, and the staying time of containers at stations can be reduced considerably. A more important point is that the connection between road and railway is smoothly implemented. Based on these advantages, the competitiveness

of intermodal freight transport using railway is improved.

In this paper, the modal shift of freight from all-road to intermodal transport is estimated according to a mode-share model developed under the conditions of reconstructing conventional railway stations to create a new type. Moreover, based on the estimated volume of modal shift freight, environmental effects such as the reduction of CO₂ emissions in freight transport have been investigated using the LCA method. The results clarify that the effectiveness from introducing the new type of station is satisfactory.

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