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# Efficiency Improvement of a Reverse Logistics System

*Kuninori Suzuki and Nobunori Aiura*

## Abstract

This chapter discusses the efficiency of a series of processes from discarded tire recovery to thermal recycling. A simulation model was developed for improving the efficiency of fuel chip transportation in the Kansai region of Japan, and a simulation analysis was carried out based on actual data. Discarded tires from automobiles are recovered through gas stations, tire shops, etc. The discarded tires are crushed into fuel chips at a recycling factory and are used for thermal recycling. Fuel chips are transported to steelworks, paper mills, etc., and are used as a substitute for coal in boilers at those plants. Fuel chips, made from discarded tires, have about the same fuel efficiency, in terms of calorie performance, as coal. However, it has been directly transported from a recycling factory to steelworks by truck, without any consideration for the environment. Therefore, in this research, this study investigated measures to transport fuel chips efficiently and environmentally, by introducing a modal shift, which combines trucks with marine transport, rather than truck alone. As a result of numerical experiments, it was clarified that adequate results can be obtained if the distance of sea transport is sufficiently far apart for the introduction of a modal shift.

**Keywords:** reverse logistics, collection and transport, recycle, intermediate treatment

## 1. Introduction

The present study focuses on discarded tire-derived fuel chips for thermal recycling and examines the effective introduction of modal-shift transportation.

The present study proposes a delivery system using a “milk-run method through a transshipment depot, into which marine transportation is introduced,” instead of using the truck as an effective measure. In the delivery system, discarded tires are treated at an intermediate treatment factory and turned into fuel chips. The fuel chips are then transported and distributed to cement factories and steel and paper mills as valuable materials.

Materials are recycled in such a way that used goods are collected and transported to an intermediate treatment factory, and the used goods are treated to create new products.

Recycled materials used for thermal recycling, such as fuel chips, are not transported and distributed to end users through delivery centers, which handle recycled materials, but in many cases are directly transported and distributed to the warehouses of end users' factories from the warehouses of intermediate treatment factories.

To review the current system of transporting discarded tire-derived fuel chips, the present study examined the logistics and product features of the fuel chips, simulated the arrangement of transportation complexes for the fuel chips in order to optimize the transportation efficiency, and calculated the driving situation of trucks and the transportation cost of the fuel chips.

## **2. Definition of discarded tires and its basic flow**

Concerning the definition of discarded tires, Japan Automobile Tire Manufacturers Association (JATMA) decided to unify the names of used tires into “discarded tires.”

Fuel chips derived from discarded tires recycled after intermediate treatment are valuable; therefore, they are transported rather than collected and transported. This chapter will analyze and consider the flow as reverse logistics, which is a series of steps from the collection of discarded tires to the delivery of recycled fuel chips.

Discarded tires collected and transported by the collection network are recycled into discarded tire-derived thermal recycling fuel chips, which combine licenses for both collection and transportation businesses and intermediate processing businesses. After recycling, the fuel chips stored in the warehouse of the intermediate processing factory are shipped according to the orders received from paper mills, steelworks, cement factories, and the like.

Since fuel chips are transported as valuable material in principle, the licenses for transportation businesses are required, but they are not required for collection and transportation projects. However, the fuel chips are not always valuable. Whether they are valuable or not depends on the market.

The Ministry of the Environment in Japan has issued a notice that “the delivery side will bear the shipping costs, and, if the transportation costs exceed the sale price, it will be considered waste.”

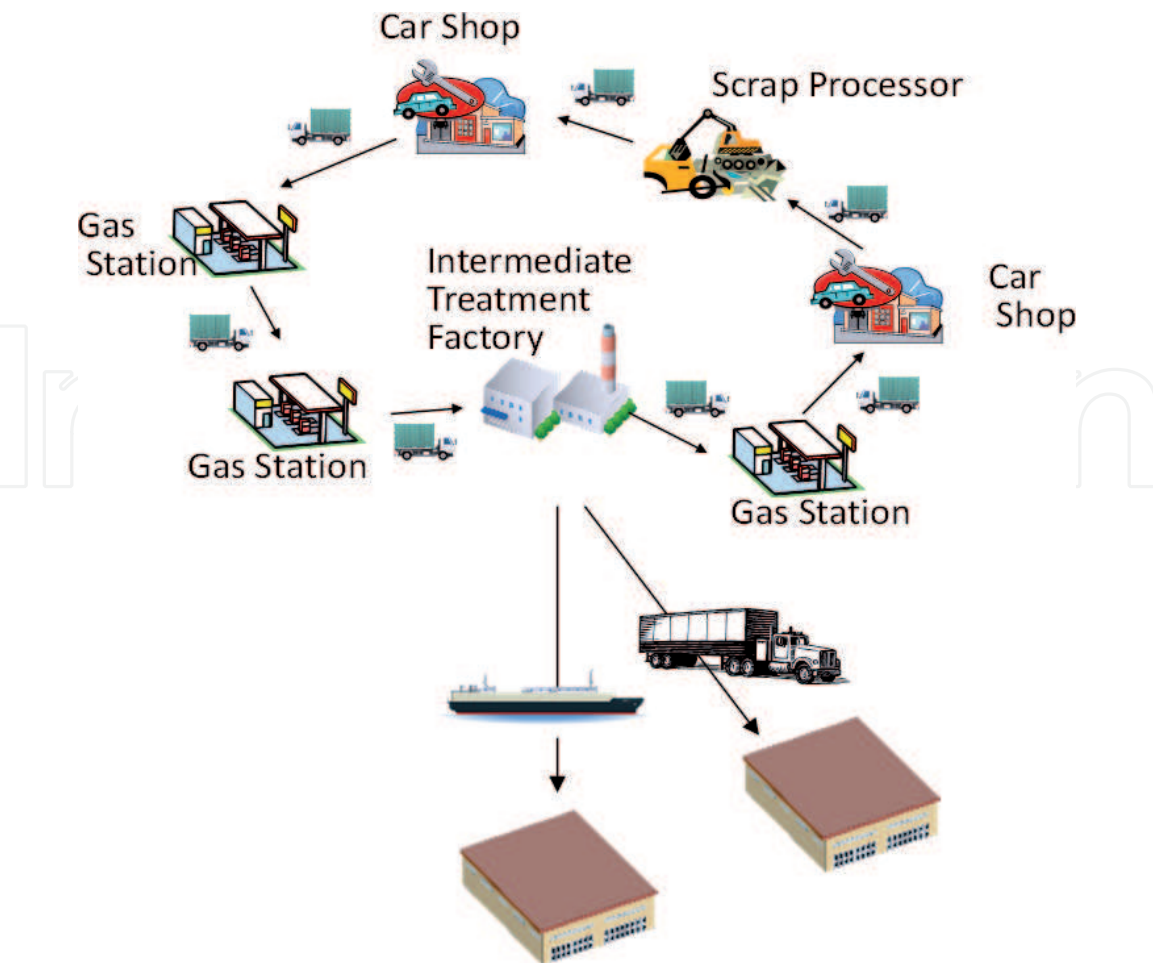
In the case of reverse payment, it will be treated as waste and transported. Therefore, in view of the possibility that it becomes waste due to market demand, it is desirable that a business owner, who has licenses for both collection and transportation businesses, work with the transportation industry to haul the fuel chips.

Also, if industrial waste is discharged from the supplier and it becomes a return shipment, it is possible to reduce transportation and transportation costs. In other words, delivery from discarded tires to intermediate processing and delivery to discarded tire-derived fuel chips that are recycled and produced can correspond to thermal recycling.

Trucks transport fuel chips for short distances, but, for long distances, a modal shift will be introduced combining marine transportation with truck transportation.

In theory, it is possible to combine sea transportation, but currently it is not done. In many cases, fuel chips are delivered by truck from a nearby waste disposer. The risk of illegal dumping increases when the area is broadened as described above and when the processing company is small in scale. It is difficult to develop large lots in many cases.

However, considering the efficiency of reverse logistics for discarded tires, it is necessary to expand the area of fuel chip transportation as well as widen the collection and transportation networks. Although the amount of waste tires generated is larger in metropolitan areas, the location of paper mills, ironworks, cement factories, and the like will be industrial parks in the suburbs of local cities.



**Figure 1.**  
*Material flow of discarded tires.*

However, such a local waste tire recovery network alone will not generate the necessary supply of fuel chips. Also, in large metropolitan areas, the number of discarded tires is large, but the number of factories using them is small.

Therefore, if the delivery areas are limited, the destinations for fuel chips that have been recycled will be insufficient. Thus, by increasing the destinations for fuel chips widely, it is possible to effectively supply surplus fuel chips in large cities to regional cities.

However, in order to efficiently supply discarded tires generated in metropolitan areas to rural areas, it will be necessary to construct a system that establishes new transportation depots at local bases to circulate and optimize the route.

As shown in **Figure 1** rather than directly transporting large quantities of trucks from the intermediate processing plant in a metropolitan area to a local paper mill, etc., the introduction of a modal shift can carry large lots to local sea ports.

Regarding depots, a system should be established in which a plurality of factories in the area is visited by the *milk run system*. The newly established depot will have the function of storing exports and acts as a base for temporarily storing fuel chips transported over a long distance from metropolitan areas and the like.

### 3. Fuel delivery system: case study

The fuel chips are packed and transferred to the specific warehouse, where they are stored until shipment by truck [1]. However, Company A can ship big lots, such

as 1000 t, by sea transportation to its specialized customers, which include large paper factories and steel mills that are located further away.

Recycled fuel chips are purchased by companies such as steel mills. Therefore, the supply system needs of those types of companies are different from needs of companies that collect and transport waste tires. For companies such as steel mills, general cargo carriers typically deal with the shipment of materials.

How the waste is determined depends on the market price. In the case of fuel chip recycling, some of the waste materials produced will be assigned a market price that is not valuable. Additionally, potential waste treatment affects the values even if the transportation cost is changed.

Therefore, the treatment or handling of these products is slightly different from the treatment and handling of genuine products, which is why the transportation of the fuel chip is often included in the framework of reverse logistics. Recycled fuel chips are produced by a simple process that cuts the size stipulated by the tire circle cutting machine.

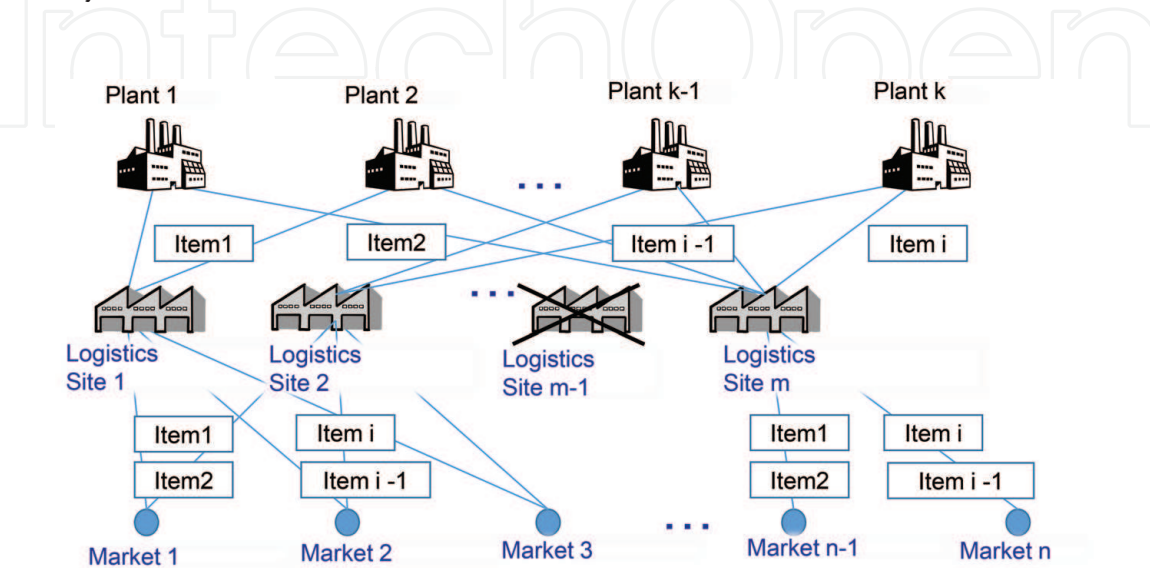
4. Building a simulation model

This issue can be explained as a simple multi-stage location model, which consists of production facilities and Transfer Centers, markets.

In **Figure 2**, the locations of the Transfer Centers and handling products at each Transfer Center are determined to minimize the total cost. This multi-stage location model is comprised of basic operating cost and transportation cost. The site integration is also included in the determination of the location of the Transfer Centers.

In **Figure 2**, as for the item (1 through i), which are produced in Plant (1 through k), the item (1) and item (2) in the Logistics Site (1), and the item (i-1) and item (i) in the Logistics Site (2) are treated; these items are distributed from both Logistics Sites to Market (1 through 3). All items handled in the Logistics Site m are being supplied to the market (n-1) and market (n). Furthermore, Logistics Site (m-1) is not located because no handling of the items is required.

**Figure 2** shows an example of the supply to the market in which delivery is being made only through the Logistics Sites. However, in this study, it is also possible that items could be sent directly to the customer from the intermediate treatment factory.



**Figure 2.**  
*Example of multi-stage location [2].*



The similar model has been used for a forward logistics system, but as for the reverse logistics network simulation, this simple multi-stage location model has not been regarded as the effective one.

5. Data for simulation

To simulate the arrangement of transportation complexes for discarded tire-derived fuel chips, the present study used the actual data of Company A, a waste-disposal operator located in Chigasaki-shi, Kanagawa Prefecture.

Company A collects discarded tires from gas stations, auto repair shops, and tire dealers. In the company’s intermediate treatment factory, a recycling process is performed for the collected discarded tires to be turned into fuel chips used in the boilers of cement factories and steel and paper mills.

The fuel chips are then regularly delivered to customers’ factories. Before performing the simulation, actual data and estimated values were obtained from factories of the company’s present and potential customers by conducting an in-person interview survey. The latitude and longitude of a factory to which fuel chips were assumed to be delivered in the simulation were derived from the address of the factory.

The site for a transshipment depot was set in each delivery area, and an area for transportation and distribution was also set based on the results obtained by performing a hearing survey for the company. **Table 1** shows the conditions examined for the simulation of the delivery system based on the actual data.

Regarding potential customers, fuel chips are assumed to be used in many production facilities, which possess boilers, such as food-processing plants, in addition to cement factories and steel and paper mills.

Since the number of discarded tires collected in a local area is limited, it is important to transport and distribute discarded tire-derived fuel chips from the metropolitan area in which a large number of discarded tires can be collected to Tohoku, West Japan, and Kyushu areas in order to satisfy the supply-demand balance.

In the future, a system may be constructed in which discarded tires are imported from foreign countries, including China, and a recycling process is performed to turn the imported discarded tires into fuel chips at intermediate treatment factories in Japan. The fuel chips would then be delivered to each area in Japan.

Item	Contents
Delivery point	West Japan:15 factories(customers)
Candidate Sea Port	West Japan: Mizushima, Hiroshima, Kobe, Osaka North
Delivery lot	5–55 t/week
Frequency	1–2 times/week
Transport mode	20 t-truck, 1000 t-ship
Vehicle	Nonlimited
Standard working hour	8 hour/day
Period	4 weeks

**Table 1.**  
*Delivery system conditions.*

Company A is a typical collection and transport company, which can enlarge its collection area. Therefore, the data can be used as in a general and typical case for reverse logistics simulation.

To calculate the total transportation cost of discarded tire-derived fuel chips, direct delivery to customers' factories by truck and a combination of marine and land transportations using ship and truck were examined. The location of the port in which a transshipment depot was to be set was examined.

Each candidate sea port can be accepted a 1000 t-bulker-ship, 1–2 times a week, which is dealt with a crane material handling.

## **6. Increase in transportation efficiency**

Fuel chips are primarily delivered from company A (the head office and intermediate treatment factory are located in Chigasaki-shi, Kanagawa Prefecture) to factories in each area by truck.

This is because a reverse logistics network for fuel chips was not constructed on the assumption that the delivery area would be expanded; it was constructed from the perspective that even if fuel chips were delivered by truck, no problem would arise when the transport volume was small.

However, when the reverse logistics network is expanded, fuel chips treated in the company A's intermediate treatment factory in Kanagawa Prefecture are delivered to factories in the Kanto area and to all parts of Japan.

Previously, fuel chips produced from discarded tires in an intermediate treatment factory were mainly delivered to cement factories and steel and paper mills in each area. If fuel chips are delivered from the Kanto area, in which a large number of tires are discarded, fuel chips can be consistently supplied.

However, if large amounts of fuel chips are transported by truck as one lot, various problems, such as traffic congestion, noise problems, and environmental deterioration, will arise in prefectures through which the truck passes.

Therefore, a combination of trucking and shipping is a useful option because the truck is suitable for door-to-door delivery of small amounts of fuel chips and the ship is suitable for transporting and distributing large amounts of fuel chips.

Moreover, the environmental load of a ship is small. In other words, fuel chips are transported from the company A's intermediate treatment factory in Kanagawa Prefecture to the Port of Kawasaki by truck, and then large amounts of fuel chips are transported as one lot from the Port of Kawasaki to each area by ship.

A transshipment depot is set in the main port of each area, and fuel chips are delivered from the transshipment depot to destinations one after another by truck (the milk-run method).

## **7. Delivery to the Kansai area in Japan**

At present, direct delivery of fuel chips by truck as one lot from the company A's intermediate treatment factory in Chigasaki-shi, Kanagawa Prefecture to West Japan (Shiga, Kyoto, Osaka, Hyogo, Okayama, Hiroshima, Tottori, and Yamaguchi Prefectures) is not performed. However, there are many potential customers in that area.

Large amounts of fuel chips are transported as one lot from the Port of Kawasaki to West Japan by ship. In the present study, Company A established its own transshipment depot in West Japan and delivers fuel chips from the depot to 15 paper mills one after another (the milk-run method). It was assumed to establish its

own transshipment depots in Osaka North Port, the Port of Kobe, the Port of Mizushima, and Hiroshima Port.

Regarding the weekly cost for direct delivery of fuel chips by truck from the company A's intermediate treatment factory to West Japan, the simulation results revealed that the variable cost, including the fuel cost, was 275,194 yen; the labor cost for truck drivers was 359,000 yen; and the fixed cost, including the insurance cost and vehicle expenses, was 1,400,000 yen, that is, the total transportation cost per week was 2,034,194 yen. The travel distance was 13,209.68 km. The transit time was 165.12 h. The loading was 225 t. The number of trucks used for the transportation was 14.

In the case where Hiroshima Port as in **Figure 3** was used for the transshipment depot, the variable cost was 133,752 yen, the labor cost for truck drivers was 115,200 yen, and the fixed cost was 459,000 yen, that is, the total transportation cost per week was 707,952 yen. The travel distance was 6420.28 km. The transit time was 80.25 h. The loading was 225 t.

The number of trucks used for the transportation was nine. The total cost of transporting fuel chips was 10,643,328 yen. Thus, the total transportation cost per week was much lower when Hiroshima Port was used for the transshipment depot than when fuel chips were directly delivered from company A's intermediate treatment factory to West Japan. However, after setting the transshipment depot, the running costs for the depot were required.

Consequently, the total cost of transporting fuel chips was higher in the case, where Hiroshima Port was used for the transshipment depot than in the case, where fuel chips were directly delivered.

The variable, labor, and fixed costs were revealed to be significantly lower in the case, where the Port of Mizushima was used than in the case where Hiroshima Port was used for the transshipment depot. The total transportation cost per week was 707,952 yen when using Hiroshima Port and that was 402,354 yen when using the Port of Mizushima.

Loading at Hiroshima Port as in **Figure 4** was the same as at the Port of Mizushima (225 t). The travel distance was 6420 km when using Hiroshima Port and 4001 km when using the Port of Mizushima. The transit time was 80 h when using Hiroshima Port and 50 h when using the Port of Mizushima.



**Figure 3.**  
 Use of Hiroshima Sea Port. Delivery point: Shiga, Kyoto, Osaka, Hyogo, Okayama, Tottori, Hiroshima, Yamaguchi.





**Figure 4.**  
Use of Mizushima Sea Port. Delivery point: Shiga, Kyoto, Osaka, Hyogo, Okayama, Tottori, Hiroshima, Yamaguchi.



**Figure 5.**  
Use of Osaka North Sea Port. Delivery point: Shiga, Kyoto, Osaka, Hyogo, Okayama, Tottori, Hiroshima, Yamaguchi.

The number of trucks used for the transportation was nine when using Hiroshima Port and five when using the Port of Mizushima. Thus, the Port of Mizushima was superior to Hiroshima Port in terms of the transportation and distribution of fuel chips. However, the total cost of transporting fuel chips per month was slightly higher when the Port of Mizushima was used for the transshipment depot than when fuel chips were directly delivered.

When Osaka North Port as in **Figure 5** was used for the transshipment depot, the variable cost was 59,582 yen, the labor cost for truck drivers was 51,200 yen, and the fixed cost was 204,000 yen, that is, the total transportation cost per week was 314,782 yen. The loading was assumed to be 225 t. The travel distance was 2860 km.

The transit time was 35 h. The number of trucks used for the transportation was four. Therefore, the total transportation cost per week, the travel distance, the





**Figure 6.**  
Use of Kobe Sea Port. Delivery point: Shiga, Kyoto, Osaka, Hyogo, Okayama, Tottori, Hiroshima, Yamaguchi.

site	distance(km)	distance(km)	shipping lot (t)	number of trucks	total cost (yen)
truck direct delivery	13209.68	165.12	225	14	8136776
Hiroshima	6420.28	80.25	225	9	8519472
Mizushima	4001	50	225	5	8213874
Osaka North	2860	35	225	4	8837224
Kobe	2860	35	225	4	8140552

**Table 2.**  
Numerical result.

transit time, and the number of trucks were lower when using Osaka North Port than the Port of Mizushima.

However, the running costs for the transshipment depot were 7,578,096 yen, and the total cost of transporting fuel chips was 8,837,224 yen when using Osaka North Port, which was higher than using the Port of Mizushima (8,565,312 yen).

Although Osaka North Port was superior to the Port of Mizushima in terms of the total transportation cost per week, the travel distance, the transit time, and the number of trucks, the total cost of transporting fuel chips was higher when using Osaka North Port than for the Port of Mizushima because the land rent for the transshipment depot was higher in Osaka North Port than in the Port of Mizushima.

Consequently, the total cost of transporting fuel chips was higher when Osaka North Port was used for the transshipment depot than when fuel chips were directly delivered by truck from Chigasaki-shi, Kanagawa prefecture.

As shown in **Figure 6** and **Table 2**, the total transportation cost per week, the travel distance, the transit time, and the number of trucks when using the Port of Kobe were the same as those when using Osaka North Port, that is, the total transportation cost per week was 314,782 yen. The travel distance was 2860 km. The transit time was 35 h.

The number of trucks used for the transportation was four. However, the running costs for the transshipment depot were lower when using the Port of Kobe.

Consequently, the total cost of transporting fuel chips was lower when the Port of Kobe was used for the transshipment depot than when the Port of

Mizushima was used for the transshipment depot (8,565,312 yen) and when fuel chips were directly delivered by truck from Chigasaki-shi, Kanagawa prefecture (8,136,776 yen).

The results obtained by performing the simulation can be summarized as follows:

1. The total transportation cost per week, the travel distance, the transit time, and the number of trucks when using the Port of Kobe were the same as those when using Osaka North Port.
2. The Port of Kobe and Osaka North Port were superior to the Port of Mizushima and Hiroshima Port in terms of the total transportation cost per week, the travel distance, the transit time, and the number of trucks.
3. When the running costs for the transshipment depot were taken into account, the total cost of transporting fuel chips was higher when using Osaka North Port than when using the Port of Mizushima because the land rent for the transshipment depot was higher.
4. The total cost of transporting fuel chips was lower when using the Port of Kobe than when using the Port of Mizushima because the land rent for the transshipment depot was lower.
5. The total cost of transporting fuel chips was lower when a transshipment depot was set in the Port of Kobe than when fuel chips were directly delivered by truck from the intermediate treatment factory in Kanagawa prefecture.

## **8. Future tasks and direction**

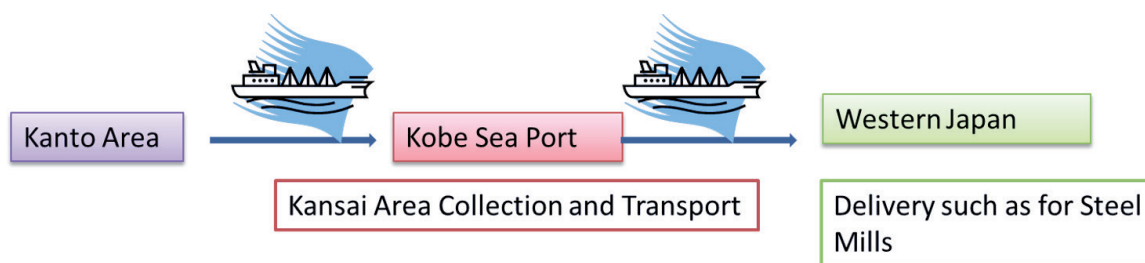
The results obtained by performing the simulation revealed that the transportation efficiency of fuel chips from the Port of Kawasaki to the Kansai area using the milk-run method was higher when a transshipment depot was set in Kobe Port than when a transshipment depot was set in the Port of Mizushima, Hiroshima Port, or Osaka North Port.

The model used in the present study was considered to be useful for examining modal-shift transportation. However, the total cost of transporting fuel chips was not significantly lower when a depot was set in a port than when fuel chips were directly delivered by truck. Therefore, the delivery system using the milk-run method proposed in the present study must be amended.

There is a reform measure, in which discarded tires are collected from a wide area in Kansai and transported together with those collected in Kanto to reduce the transportation cost. This is a business model in which an industrial park adjacent to the Port of Kobe is utilized.

All discarded tires collected in the Kansai area are treated and turned into fuel chips in an intermediate treatment factory adjacent to a berth in the Port of Kobe, and large amounts of the fuel chips are transported from the berth as one lot by ship.

A collection complex for discarded tires, an intermediate treatment factory to produce fuel chips, and a facility for modal-shift transportation of fuel chips are built in the Port of Kobe. Fuel chips produced at the intermediate treatment factory in the Port of Kobe are transported with those produced in the Kanto and Kansai areas to increase the transportation efficiency as in **Figure 7**.



**Figure 7.**  
*Image of further improvement.*

Furthermore, to improve collection efficiency, wood chips and waste plastics should be collected along with discarded tires. By establishing multiple collection complexes for different types of waste in the Port of Kobe, which has excellent access to Kobe and Osaka cities, marine transportation can happen smoothly.

When the characteristics of the Kansai area are taken into consideration, that is, since the Osaka and Kobe Cities are geographically close, the establishment of multiple collection complexes for different types of waste in the Port of Kobe can be an effective remedy.

In this study, however, the collection and transport network and the delivery system of thermal products recycled from tires are systematically covered, viewing the total solution. Finally, this study suggests a direction for the effective improvement for the reverse logistics system for discarded tires.

In the future, the delivery system for fuel chips should also be analyzed to determine the possible reduction in environmental load, and should include a number of factors including collection complexes in overseas regions such as China and South Korea in addition to Japan, and consumption areas for the recycled goods.

Moreover, road development and improved living standards in recent years in Asian markets are remarkable. There is also a high possibility of expanding the deployment of discarded tire collection and thermal recycling by fuel chips derived from it to Southeast Asia. Therefore, further studies will consider what types of reverse logistics schemes can be organized when starting from Japan or the final destination.

In addition, a cooperative reverse logistics network will require the establishment of a new scheme while utilizing accumulated knowledge in forward logistics.

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