Inverse Logistics and Recycling Facilities Network Evaluation System

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We have developed the Inverse Logistics and Recycling Facilities Network Evaluation System for evaluating and optimizing a network composed of inverse logistics operations and waste recycling facilities by using actual operational data. An inverse logistics and recycling facilities network is evaluated by virtual engineering using this simulation system before constructing and operating the network and a high performance network can be designed. The system was applied to planning and evaluating a network for collecting and recycling waste plastics in Kawasaki City.

1. Introduction

The advanced socio-economic system of today's affluent society based on mass production, mass consumption, and mass disposal is being reexamined in view of the various problems it has caused, including destruction of the natural environment and ecological system, depletion of mineral resources, and shortage of waste disposal sites. A recycling-oriented society is being promoted for securing sustainable growth by reducing the consumption of natural resources and the burden on the environment.

For defining the basic legal framework, the Basic Law for Establishing a Recycling-oriented Society was enacted in 2000. And since, laws such as the Home Appliance Recycling Law and Containers and Packaging Recycling Law have been successively enacted for promoting systems of social responsibility for suppressing waste generation, and utilizing available resources effectively, in specific fields.

In Japan, around 50 million tons of municipal wastes are discharged annually. Targeting waste containers and packaging, which account for 60% of these wastes by volume, the Containers and Packaging Recycling Law was fully enforced in April 2000. In addition to glass bottles, metallic cans, and PET bottles that had already been designated for recycling, miscellaneous plastic containers and packaging other than PET bottles, and paper containers and packaging, were legally obligated to be recycled. Under the framework of this law, each party involved shares the responsibility for recycling waste containers and packaging: consumers for selectively discarding; municipalities for collecting, sorting, and storing; and businesses for recycling these wastes.

Municipalities play an important role in this social movement. In cooperation with consumers and businesses, municipalities need to prepare plans for dealing with municipal wastes, selectively collect them, construct and operate waste treatment and recycling facilities, and thus establish so-called "inverse logistics systems".

In order to facilitate the system for recycling resources, fundamental measures for suppressing waste generation are essential. It is also indispensable to reduce environmental burdens and recycle resources in view of the social system as a whole including production, consumption, and transportation. It is therefore important to evaluate the entire inverse logistics system including all the material flows, from waste collection and transportation to intermediate treatment and recycling, and to minimize the cost of running the system as a whole. In particular, glass bottles, metallic cans, plastic bottles, and other containers and packaging regulated by the Containers and Packaging Recycling Law have low bulk specific gravity, which lowers the transportation efficiency and increases the collecting and processing costs. In order to promote the recycling of waste containers and packaging across the country, a system that can efficiently collect and process these types of wastes is required.

Issues to be addressed include: to establish a wide-area recycling system that can handle wastes discharged from dispersed locations; to properly allocate waste recycling functions to distributed-treatment and centralized-treatment facilities; to efficiently manage the inverse logistics network by fully using advanced information technology; and to optimize the total system by evaluating all the steps from waste collection to recycling as a whole.

NKK is providing diverse solutions related to the environment and recycling for establishing a recycling-oriented society. In order to assist clients in planning, constructing, and managing inverse logistics systems efficiently, the Company developed the Inverse Logistics and Recycling Facilities Network Evaluation System which combines the GIS (Geographical Information System) with a proprietary inverse logistics simulation technology.

This paper outlines the evaluation system and a case study of its application.

2. Outline of the system and its configuration

2.1 Outline of the system

The inverse logistics system for building a recycling-oriented society has a variety of functions, which include waste collection, transportation, sorting and recovery, incineration and volume reduction, and recycling. It is necessary to construct effective infrastructure as part of the social system and to operate them steadily over a long term while minimizing the cost and environmental burden. It is not sufficient to optimize individual functions; all functions must be evaluated and optimized as an integral system taking into account the existing infrastructure in the area, distribution of population and waste-discharging points, and other local factors. **Fig.1** shows the process flow for optimizing an inverse logistics and recycling facilities network.

In this evaluation system, information concerning actual operations (e.g., target waste, volume of discharge, discharging points, function of each facility, candidate plans on the recycling network, operating conditions, and constraints) is used as input conditions, and the operations such as collection and transportation are optimized. The resultant simulated output information (e.g., required number of vehicles, zoning of collection areas, allocation of zones, capacities of facilities, and environmental burden) is used in the evaluation.

2.2 System configuration

An example of the material flow in an inverse logistics and recycling facilities network is shown in **Fig.2**. As an inverse logistics system, this network performs a series of functions: collection of wastes discharged in each zone, treatment at a relay facility, transportation from a relay facility to a recycling facility, and treatment at a recycling

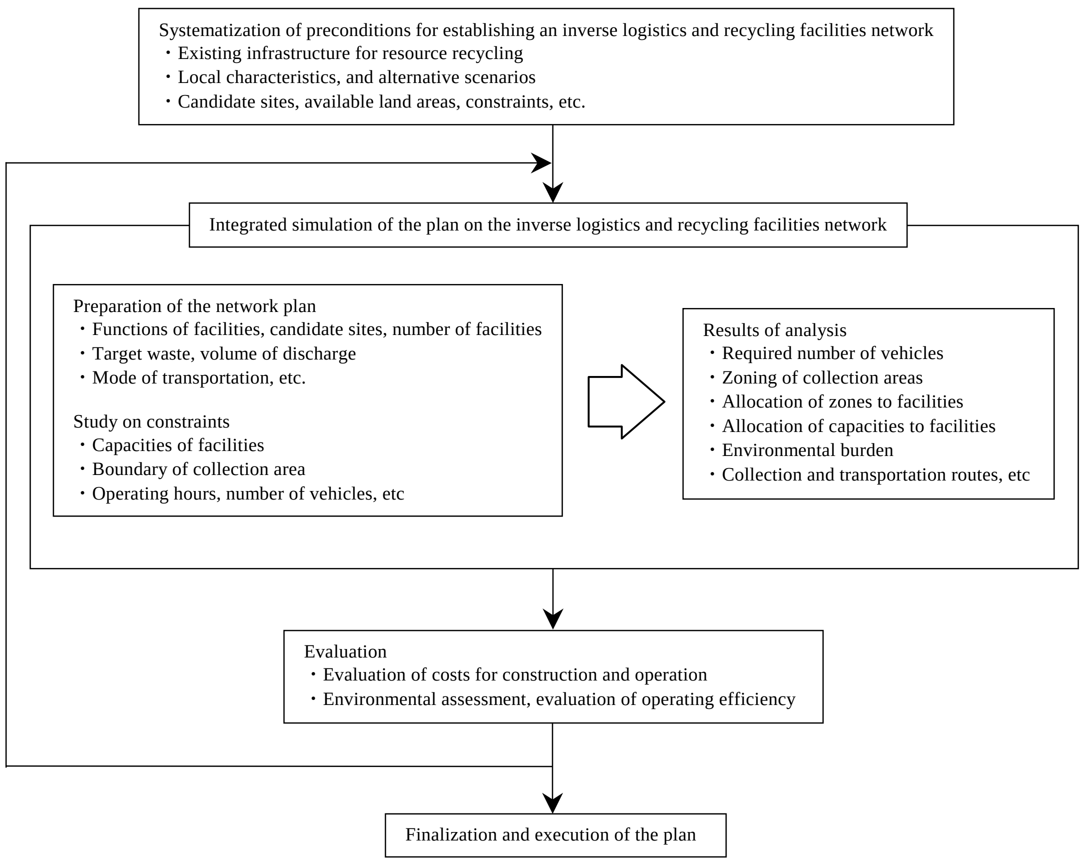

Fig.1 Process flow for optimizing an inverse logistics and recycling facilities network

facility. The system uses databases on recyclable materials, transportation, environmental burdens, and other information required for analysis. An individual municipality or a wide-area waste treatment project that covers two or more municipalities can define the region to be analyzed according to its particular needs such as proposed types of networks and types of wastes to be handled.

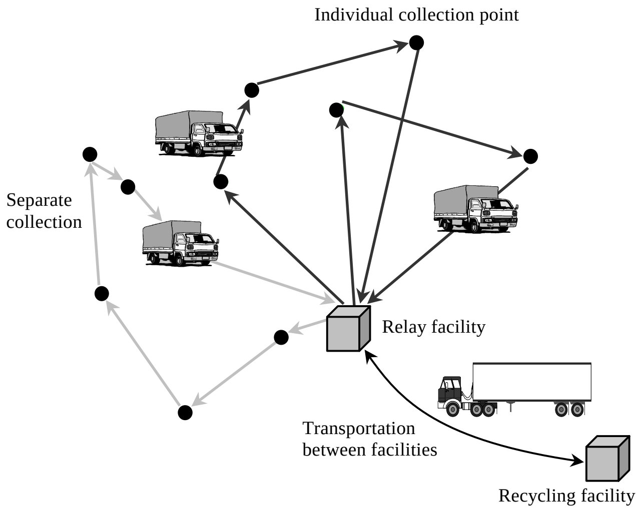

Fig.2 Example of inverse logistics and recycling facilities network

Using the objective functions as parameters that reflect the costs for collection, intermediate treatment at a relay facility, transportation between facilities, etc., the total operations in the network are simulated, evaluated, and optimized.

For example, the objective function for transportation is expressed by the following equation:

$$F(\alpha) = f/w_j + (m + s + V) / L_\alpha \cdot w_j \qquad \cdots\cdots(1)$$

where,

- f : Fuel cost
- m : Vehicle maintenance cost
- s : Labor cost
- V : Vehicle depreciation cost
- L : Transportation distance in operating days
- w_j : Effective load-carrying capacity of a type-j vehicle
- α : Recycling facilities network α

The first term represents the cost of fuel, and the second term that for vehicle maintenance, labor, and vehicle depreciation. By using the objective function $F(\alpha)$ as an evaluation parameter that reflects the transportation distance obtained by simulating the operation in a network, the transportation efficiency is derived.

The constraint inequality for the loading weight of a vehicle used for collection and transportation is expressed by the following equation:

$$\Sigma\, y(i) \leqq Kj \qquad \cdots\cdots(2)$$

where,

- $y(i)$: Weight of wastes to be collected at collection point i
- Kj : Maximum loading weight of a type-j vehicle
- $T^{j,kq}$: Trip No.q by the type-j vehicle No.k

The constraint inequality for the operating hours for optimizing a particular collection and transportation plan is expressed by the following equation:

$$\sum^{q_{jk}} \{\tau(v, \mathrm{head}\,(T^{j,kq})) + \sum \tau(i, i+1) + \tau(v, \mathrm{tail}\,(T^{j,kq})) + \sum \lambda(i) + \theta(T^{j,kq})\} \leqq T_0 \qquad \cdots\cdots(3)$$

where,

- T_o : Operating hours per day
- q_{jk} : Number of trip per day by the type-j vehicle No.k
- λ (i) : Working hours at collection point i
- θ (T) : Working hours at recycling facility v in trip T
- $T^{j,kq}$: Trip No.q by the type-j vehicle No.k
- head(T) : The first collection point in trip T
- tail(T) : The last collection point in trip T
- τ (i, i+1) : Travel hours between collection points i and i+1

Fig.3 shows an example of the computer display for setting the simulation conditions. In this screen, the waste type and transportation mode are selected, and the coefficient of environmental impact is set. The standard data have already been set. However, when actual data have been measured and made available, or when detailed operating conditions can be defined, these conditions may be incorporated into the database for enabling detailed evaluation based on a more realistic simulation.

By applying this evaluation system, various potential problems in actual operation are identified, and so an efficient recycling facilities network can be designed. It also enables an efficient recycling facilities network to be proposed to the communities and related administrative agencies at the policy planning stage for evaluation, thus promoting early consensus building.

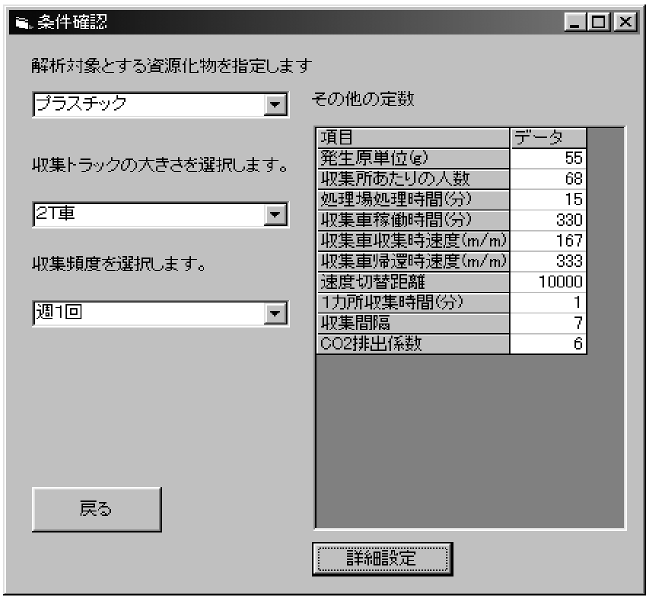

Fig.3 Example of simulation model screen

3. Case study

This evaluation system was used to evaluate an actual recycling project in Kawasaki City[1].

Kawasaki City is conducting various activities toward establishing a recycling-oriented society that ultimately discharges no waste. These activities include the Eco Town Concept that covers the coastal industrial area of the city, wide-area collaboration with other municipalities along the Bay of Tokyo, and the siting of environmental protection industries in the city. As the city area is stretched out from northwest to southeast, the four waste incinerating facilities are spread out across the city, and so the city constructed one relay facility for efficient collection and treatment of combustible waste discharged in the entire city[2].

The city is also encouraging separate collection and recycling of waste containers and packaging. One day a week is designated as Recycling Day, when glass bottles, metallic cans, and some PET bottles as well as miscellaneous waste metals (small metal products) are collected separately and recycled. The city achieved a recycling ratio of 15.4% in 1999, and aims to raise this to 22% by expanding the collection area of PET bottles to the entire city and also collecting miscellaneous waste plastic containers and packaging.

The city spent a total of 22.5 billion yen on waste collection and treatment in fiscal 1998 alone, of which 58% was for collection and the remaining 42% for treatment and disposal. The city is concerned that increased collection of light but bulky waste PET bottles and plastics will further push up the collection cost due to their poor transportation efficiency. Therefore, the city is trying to make the recycling network more efficient by evaluating the waste collection and recycling operations as a whole[1),2)].

3.1 Evaluation of recycling facilities network

Candidate locations for new recycling facilities are shown in **Fig.4**.

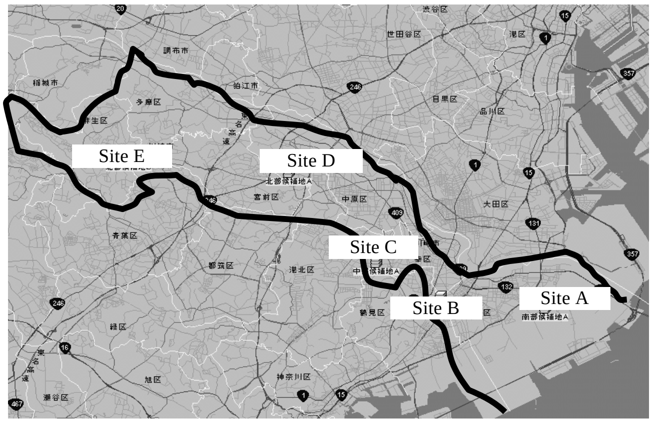

Fig.4 Candidate locations of new recycling facilities

It was assumed that waste plastic sorting and recovery facilities will be located adjacent to incinerating facilities to fully utilize the existing infrastructure, and that at these sorting and recovery facilities, collected waste plastics will be compressed, packaged, and temporarily stored before being moved out. Three simulated cases are summarized in **Table 1**.

Table 1 Simulated cases for recycling facilities network

Case No.	Waste to be collected	Candidate site of recycling facilities
1	Miscellaneous plastics	A
2	Miscellaneous plastics	B, D, E
3	Miscellaneous plastics	A, B, C, D, E

It was also assumed that miscellaneous waste plastics other than PET bottles will be separately collected one day a week to be designated as Waste Plastics Recycling Day, and the operating conditions were determined with reference to existing operating data for combustible wastes. The amount of miscellaneous waste plastics discharged by one person per day was set as 38 grams based on the mid-term forecast and possible variation in future, hence the amount of waste plastics collected per week is 330 tons. The bulk specific gravity at the time of collection was set as 0.08 ton/m^3.

Table 2 shows the simulation results for this recycling facilities network. It was found that the collection efficiency of Case 2 (with three facilities) is 1.7 times higher than that of Case 1 (with only one facility in the coastal zone). The travel distance for collection in Case 2 is one-fifth that in Case 1, thus markedly reducing the environmental burden. Compared with Case 2, Case 3 (with five facilities) showed little improvement in terms of collection efficiency.

With the network composed of three facilities, it was found most effective to provide each facility with the following capacities to minimize the collection cost, which is a significant financial burden on the municipality: Site B (in the southern zone) 5400 tons/year (30% of the total), Site D (in the central zone) 7900 tons/year (44%), and Site E (in the northern zone) 4700 tons/year (26%).

Table 2 Result of simulation of recycling facilities network

	Number of facilities	Candidate site	Weight (t)	Weight (%)	Distance (km)	Number of vehicles	CO_2 (kg/d)
Case 1	One facility	Site A	330.9	100	26499	366	2034
Case 2	Three facilities	Site B	99.3	30	1302	59	136
		Site D	146.4	44.3	2004	99	210
		Site E	85.2	25.7	1517	60	147
		Total	330.9	100	4822	218	493
Case 3	Five facilities	Site A	15.4	4.6	199	9	22
		Site B	54.6	16.5	496	30	53
		Site C	47.3	14.3	529	31	57
		Site D	128.4	38.8	1656	83	174
		Site E	85.2	25.7	1517	60	147
		Total	330.9	100	4396	213	453

4. Conclusions

A recycling-oriented society is being built in order to ensure sustainable growth by recycling resources and minimizing the environmental burden. The Basic Law for Establishing a Recycling-oriented Society of 2000, and successive laws such as the Home Appliance Recycling Law and Containers and Packaging Recycling Law were enacted in order to suppress waste generation and promote efficient use of available resources.

In promoting resource recycling, an integrated, inverse logistics system that encompasses all activities from waste collection to treatment and recycling must be evaluated and optimized, as well as improving the forward flow that starts with resource extraction and finishes with final consumption[3].

NKK is providing diverse solutions related to the environment and recycling for establishing a recycling-oriented society. To help clients in planning, constructing, and managing inverse logistics networks efficiently, the Company developed an evaluation system that can optimize such networks by combining the GIS (Geographical Information System) with a proprietary inverse logistics simulation technology.

This paper outlined the Inverse Logistics and Recycling Facilities Network Evaluation System and a case study of application of this system. NKK will continue to contribute to the establishment of a recycling-oriented society through providing such services.

The study to verify the effectiveness of the evaluation system reported here was carried out in 2001 in cooperation with Kawasaki City. We thank Messrs. Ishiwata, Ohsawa, and Kamiyama of the Environment Department of Kawasaki City for their valuable assistance.

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