Geographic Information System Aimed at Understanding the Actual Situation of Freight Transport

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This study describes the development of a geographic information system for freight transport which utilizes existing freight transport data, and which helps users or operators understand real transport conditions with a view to improving freight transport efficiency. This GIS system can be used to examine the state of rail transport along corridors. A simulation using relevant index values, then calculates a comparative evaluation of rail freight compared to road transport. The information thus obtained from the new GIS system can be used to support decision-making to facilitate transport planning for users or operators.

Keywords: freight GIS, container train, road transport, comparative analysis, simulation

1. Introduction

Geographic Information System (GIS), are generally used to provide geographic position as a guide, to manage and process relevant location data (space data), and to display the relevant information visually on a map. This enables decision makers to perform effective analyses and make faster choices [1]. With the progress of information-oriented societies, GIS is used in many fields as a tool to provide useful information to support decision making, and is the subject of active research & development. GIS is also used for car route searching and car allocation planning, etc. [2, 3].

At the same time, rail freight transport which is characterized by its safety, punctuality, large volume and regularity is expected to play a growing role in improving logistics efficiency, and providing practical solutions to societal problems such as global warming, low birthrates and ageing. However, since rail freight is generally invisible to society, its actual state is difficult to comprehend and appropriate evaluation is not easy.

As such, if the actual loaded state of freight trains on the network could be visualized on a map whilst clear and visual comparative analyses were made between rail and road freight, through the processing and analysis of existing data available for freight transport, shippers and operators could obtain relevant information to make more informed decisions. Visualization of rail freight would allow parties to grasp and analyze the actual situation of rail freight transport at a glance, and allow them to make suitable evaluations. In addition, using available information to conduct comparative analyses of transport plans, could lead to proposals for effective measures to improve transport efficiency and add appropriate services.

This study therefore presents a new GIS system for freight transport, which can provide an overview and evaluation of the state of freight transport on each rail corridor, using actual recorded transport data, freight train time tables, and other data relating to the rail network and road transport, etc. With the help of the freight transport GIS, freight train’s loading rate or its container occupancy rate from the departure station to the arrival station can be measured and displayed for each corridor along the container train’s route on a map, quantitatively and visually while comparative evaluative indices are calculated simultaneously to compare rail container and road transport. These results can provide vital and practical information to support decisions for potential rail freight demand thereby to improve the total efficiency of freight transport.

2. Data relating to the geographical information system for freight transport

A basic database compiled with existing data is one of the necessary components of a geographical information system for freight transport.

2.1 Rail freight container data

Rail container transport involves the collection of containers carrying different products and commodities from shippers. And these containers are loaded on a train to the same destination. Therefore, the following related freight data [4, 5, 6] can be used to develop the freight transport GIS.

1) Basic freight data
   ① Type of freight
   ② Container type
   ③ Container transport guidance provided by transport operators
   ④ Shipping charge guidance
2) Information about the freight trains
   ① Freight train timetables and container transport timetables

Freight train timetables include data indicating train paths and departure and arrival time of each train. Con-
container transport timetables include container transport patterns, such as direct transport from container departure station to arrival station, or transfers along the rail route.

2) Freight train operation information on the transport route

This operational information concerns container loading and unloading operation at “Effective & Speedy Container Handling System” (E&S) stations where containers can be loaded and unloaded directly on arrival and departure platforms or at general freight stations, train’s shunting maneuvers and bypassing at the way stations, etc.

3) Transport conditions on rail network

The number of wagons on a freight train is fixed according to a standard, depending on the traction limits on each corridor.

3) Freight transport records

Generally, container transport is organized by rail freight operators and forwarders together. Therefore, container transport records include information about the transport, from reception and container type to departure and arrival station, and train status, etc. The relevant records can be read via the freight transport GIS in the framework format as shown in Table 1.

2.2 Existing data to compile an infrastructure availability database

Freight trains in Japan run on trunk lines which are part of the rail network owned by passenger rail companies. Freight terminal stations and the branch connections to the main network however are owned by freight companies. In order to be effective, data relating to both these parts of the rail infrastructure need to be collected into one infrastructure availability database. In addition, similar geographical information system data for road network for example, and a versatile GIS software, are also needed to develop a freight transport GIS.

1) Rail freight facility data

① Network infrastructure information

Rail freight transport infrastructure information includes data about trunk corridors used by freight, and connections between freight stations and the trunk rail network.

② Information about freight terminal stations

These include freight handling stations, non-stop stations, stations with sidings to allow bypasses, signal stations, shunting stations where the train operation is performed, etc.

Among freight handling stations, there are hub freight stations for making up freight trains, Effective & Speedy Container Handling System (E&S) Stations, and Off-rail stations (ORS) where trucks are used instead of freight trains to cover the distance from the ORS to the nearest container handling stations.

③ Information about the transport conditions of rail lines

There are restrictive conditions on each rail corridor such as the standard number of wagons composing a freight train on the existing network.

2) Network availability data for the rail and road network

Usually, rail and road infrastructure data is provided by national organizations, such as the Geospatial Information Authority of Japan (GSI). This availability data can be used to build the freight transport GIS.

3) Basic data from the geographical information system (GIS)

Generic software applications can be used for the basic GIS data, such as Super Map Objects NET 6R, etc.

2.3 Database for freight transport simulation

Surface freight transport is composed basically of rail freight and road freight. To simulate freight transport, the following fundamental data are used:

1) Related data for the calculation of rail and road transport fares and charges

2) Distance data corresponding to the transport route

3) Related data for calculating the transport time

4) Laws and regulations related data concerning freight transport

5) Access and egress conditions for freight facilities such as terminal stations and expressway interchanges

6) Relevant attribute data, etc.

3. Basic functions of freight transport GIS

The main functions of the freight transport GIS are to provide the freight train’s loading state on the corridors of the rail network, and simulate comparisons between rail and road transport.

3.1 Function concerning the loading state of freight trains

One of the freight transport GIS main functions, as de-
scribed above, is to grasp the train’s loading state based on existing data about rail freight transport. These data are first employed to compile the network availability database. Freight data is then matched with train data. Freight loading state or container occupancy for each corridor is displayed on a map.

Figure 1 illustrates the fundamental structure of the rail freight geographic information system to display the train’s loading state. It contains the following contents: input and process of data, measurement and statistical analysis of train loading states for each corridor, and graphics and visualizations on a map, etc.

This system allows the users including shippers and forwarders or operators to select the corridor to be analyzed on a map, and provides a choice of suitable transport routes for freight trains and operation stations.

At the same time, the transport situation for each type of train can be visualized, by inputting data such as the train’s running plan, type of freight and container type being carried.

1) Network availability data handling for rail freight transport

Figure 2 shows the network availability data for rail freight transport obtained by integrating the infrastructure data of the rail network owned by passenger rail companies, the data concerning freight terminal stations and relevant facilities, GIS basic data, etc.

Using the network availability data, the target corridor on the network, running trains, and freight stations to be analyzed can be chosen freely. Users or operators are also able to zoom in and out on the map, as required.

2) Processing function for freight record data

There are many types of rail freight transport data, including type of freight train, type of freight and container, transport routes, etc.

The GIS can synthetically manage and process the data as shown in Fig.1. Freight related information is matched to train data, according to the day on which the freight train is running.

3) Measurement and statistical analysis function relating to the actual train transport situation

A freight train undergoes many operations along a passing corridor between departure and arrival, such as the loading and unloading operation of containers, shunting operation for breaking up or composing trains, etc. Therefore, even on one route, the type of freight train can vary. The loading situation of through trains which do not stop between the departure and arrival stations, can be analyzed statistically on the basis of loading or transfer data from local trains at the departure station. For other trains, loading status should be measured statistically in the light of other information from stops and operations along the corridor. Figure 3 describes the freight transport situation for these trains, depending on the geographic position of the corridors used.

4) Display of actual freight train status using geographic position

The freight train’s actual state is visualized through the geographic position of the corridor it is using, on a map, using its loading situation or container occupancy.

5) Other additional functions

This system includes analytical functions, such as search and selection of a freight train and its relevant running route, visualization of the actual transport situation on a map, system maintenance, etc.

3.2 Freight transport simulation function

A simulation to compare different means of transport can be made of the transport route from sending shipper to
Fig. 2  Network availability data for rail freight transport

- Fundamental data of GIS
- Rail network data released by GIA of Japan
- Facilities’ data concerning freight transport

The Space data of rail freight transport

Fig. 3  Calculation of train’s transport situation along corridor

Passing corridor of a train’s running route

Station : Departure S  Operation S1  S2  ⋯  Si  ⋯  Arrival S

Corridor : Corridor 1  analyzing the target corridor  ⋯  Corridor i  ⋯  Corridor n

Train type :
1. Direct train (non train or freight operation on the running way)
   Case : station A ➡️ station B
   Transport situation of train in passing corridors:
   Corridor 1 = analyzing the target corridor = ⋯ = Corridor i = ⋯ = Corridor n
   Numbers of measuring and statistical analyzing corridors: 1

2. Train with the operation on the way
   Case : Station A ➡️ Station 1 ➡️ station 2 ➡️ ⋯ ➡️ station i ➡️ ⋯ ➡️ station B
   Transport situation of train in passing corridors:
   Corridor 1 ≠ analyzing the target corridor ≠ ⋯ ≠ Corridor i ≠ ⋯ ≠ Corridor n
   Numbers of measuring and statistical analyzing corridors: n
The system can conduct a comparative analysis with shipping schedules, as follows:
- Input shipping time and lot size of dispatching shipper
- Select the truck type for road transport corresponding to the shipment
- Set the road transport route including expressway and interchanges from place of dispatch of the shipment to place of reception, on a map
- Search the possible freight handling stations near the sending and recipient shippers
- Select the available freight trains based on the transport route and shipping conditions

The comparative analysis can then be performed automatically providing multiple results, such as the door-to-door transport costs, lead time of logistics, CO₂ emissions and energy consumption of the freight transport. It can also indicate access conditions to terminals or interchanges. These results help shippers in their choosing their transport plan, by providing a comparative evaluation of both types of transport.

4. Case study for the evaluation of container trains

This freight transport GIS is used to provide practical information to users or operators, by giving them insight into the actual loading situation of freight trains, allowing them to adjust or improve their choice of transport plan.

Figure 4 shows an application case of the GIS. A freight train departs from a freight station in region KS, and arrives at a freight station in the region KT, using the rail route indicated on the map. Using transport record data for a certain period, the statistical distribution of the actual loading situation of the freight train can then be analyzed for each corridor along its route, and simultaneously displayed at the corresponding geographic position on the map.

As a result, the loading rate of the freight train and its relevant occurrence rate can be grasped, clearly and visually. This process can identify when "the loading rate of the freight train when passing the target corridor was not very high, indicating that there was space for further utilization."

In the meantime, comparisons between container door-

![The routes of container train and road transport](image)

**Fig. 4 Loading situation of the container train on the rail network**
Table 2 Comparisons between rail container and road transport

|                              | Rail container transport | Road transport |
|------------------------------|--------------------------|----------------|
| Transport cost (yen)         | Actual cost of rail      | 88,064         | 100,095        |
|                              | container transport      | Tariff fare of container transport | 115,840        | Road fare in distance maximum | 151,620 |
|                              | Actual cost of road      |                      maximum | 151,620        |
|                              | transport               | minimum            | 104,520        |
| Transport duration (hour)    | 15                       | 7                 |
| CO₂ emissions (g-CO₂)        | 170,935                  | 680,012          |
| Energy Consumption (kcal)    | 876,271                  | 2,865,439        |
| Access & egress situations (km) | distance from shipping site to departure station | 16 | Distance from shipping site to the interchange of expressway | 1 |
|                              | Distance from arrival station to destination | 23 | Distance from the expressway interchange to destination | 10 |

to-door transport by rail and road can be simulated, from the sending shipper’s site to the receiving shipper’s site, as shown in Table 2. The comparative analysis clarifies issues currently affecting rail freight transport, such as access conditions to stations, length of transport time, and slightly higher transport costs, etc. On the other hand, the merits of transport by rail, for example, lower CO₂ emissions and low energy consumption, are calculated. All these results are taken into consideration during the decision-making process by transport users or operators.

5. Conclusions

In order to cope with emerging socio-economic problems which are also becoming more serious, such as global warming, low birthrates and ageing, it is necessary to increase the use of mass transportation which has the potential to improve freight transport efficiency and logistics, which also means more than just a modal shift.

This study describes the development of a freight transport GIS to visualize the loading situation of train on a map, and relevant simulations can be performed to compare transport means or plans. Through comparative simulation, the merits and drawbacks of rail freight transport can be clarified. For shippers or carriers, results obtained from this GIS system can be a practical tool to facilitate the analyses and evaluations required when deciding which transport means or plan to use.

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