A Geographical Model of Green Transportation with Different Modes

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Abstract: Reducing CO₂ emissions is a very important mission in green transportation. In Japan about 20% of total CO₂ emissions are from transportation department. Modal shift from truck to railway or ship transportation is a good alternative because it may bring a lower environmental impact. In this paper, a geographical simulation model is constructed in where the advantageous areas of railway can be shown, comparing with truck transportation when the departure point is given. Three evaluating factors of transportation cost, delivery lead time and CO₂ emissions are combined into the geographical framework to clarify the advantageous areas totally by the modal shift. Simulation experiments are designed and executed based on the real data of Japanese companies, to show the performance and utility of the model.

Key Words: Modal Shift, Modeling, Green Transportation, Transportation Cost, CO₂ Emission, Delivery Lead Time

1. Introduction
Transportation is a major contributor in global climate change. It accounts for almost 23% of the world’s total CO₂ emissions from fossil fuel combustion. Of these total CO₂ emissions, road transport accounts for 75% and this share is increasing every day. Around 95% of all road transportation depends on oil, this corresponds to 60% of world’s total oil consumption [1]. All this puts lot of pressure on the enterprises and the governments to devise policies to reduce greenhouse gas emissions as well as oil demands. Transportation is the prime target for reducing air pollution and obtaining sustainable environment. This leads to Green Transportation, which means any kind of transportation practice or vehicle that is eco-friendly and does not have any negative impact on the immediate environment. One important objective of green transportation is to integrate different modes of transportation while addressing climate and environmental concerns such as decreasing private car and truck use and congestion and increasing public transportsations. Here mode means different transportation forms like as train, ship, car, bus, bicycle, walking and so on.

Sometimes changing different modes also be called modal shift. Modal shift can reduce CO₂ emissions had been reported in several cases. For example, changing transportation mode from automobile or air to ship or railway in waste transportation [2], using bus instead of private cars in urban traffic congestion [3] and school transportation [4]. Also modal shift is not only influencing CO₂ emissions but also other objectives like as safety, healthy and outdoor activities related human life [5][6][7]. Several special researches focused on modal shift from trucks to railway or marine transportation had been reported. The concept of modal shift is first defined by Ministry of Land, Infrastructure and Transport of Japan in 2001. They introduced a modal shift rate to show a state of modal shift, then presented the procedure of estimating the modal shift rate, the result of estimate of each area and the trends of modal shift in years [8]. Japanese government also established a subsidy system to assist enterprises to promote their modal shift from truck to railway or ship in 2002 [9]. After then several articles show the effect of modal shift policies on the reduction of CO₂ emissions in local region [9][10][11], under different conditions of transportation modes. However, because changing transportation modes is a very important strategy for enterprises, only reduction of CO₂ emissions is not enough let top managers change their transportation policies. Several other management indexes such as transportation cost and delivery lead time also should be considered simultaneously to judge the benefits from the modal shift.

In this paper, we discuss a special case in where the effect of reducing truck transportation is quantitatively analyzed by using an alternative of railway transportation, under a combinational multi-objective of transportation cost, delivery lead time (LT) and reduction of CO₂ emissions. A geographical simulation model is constructed to compare the different modes of railway and truck transportation. By executing the model, we can find the destination points of changing the mode from truck to railway when the departure point is determined. Then the advantageous geographical areas of railway transportation can be simulated under different conditions of transportation cost, delivery lead time and CO₂ emissions. Several experiments based on real data of Japanese companies are designed and executed to show the performance and utility of the model and some useful insights of constructing transportation modes are clarified by analyzing the experiment results.

This paper is organized as follows. Section 2 describes the geographical transportation model. Also a simple example is presented to illustrates the model. Section 3 executes the simulation model based on the real data from Japanese companies. The advantageous areas of railway are shown geographically. Also several different delivery methods are discussed to improve the performance of the modal shift. Finally, conclusion

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remarks and future works are presented in section 4.

2. Description of Geographical Transportation Models

In this paper, a geographical model is constructed to compare the different modes of railway and truck transportation, to find the destination points of changing modes given the cargoes departure point. The railway transportation is considered as a more environment friendly mode than truck, however it is not customer friendly because cargoes cannot be sent to customers directly. There are also truck transportation be between departures/destinations points and railway stations. Fig. 1 shows the different transportation modes of trucks and railway. In the case of railway (real lines in Fig.1), cargoes are first sent to departure railway station from departure point by trucks. Then they are transported by railway to the destination railway stations. Finally, they are sent to destination point by trucks.

On the other hand, cargoes are transported by trucks directly to destination points, is shown the case of truck transportation (point lines in Fig.1). Given the departure point of cargoes, the geographic areas of different modes can be calculated by several criteria. Comparing those geographical areas the destination points of changing modes can be obtained to achieve the performances of modal shift.

There are a lot of criteria can be used to evaluate the transportation efficiency. In this paper we consider three criteria while costs is used to evaluate the transportation efficiency, delivery lead time is used to evaluate the service level and reduction of CO₂ emissions is used to evaluate the environmental consideration of transportation modes.

The cost of railway transportation is calculated based on the official data table of Japan Railways Freight Charge [12] and cargo handling charge. The costs of truck transportation are calculated by using the charter carfare by distance. These costs consist of standard fare and 20% range fares. Therefore, in this model we use the standard cost as a criterion.

Delivery lead time of railway transportation includes not only transportation time but also handling and staying time at railway station. The transportation time is calculated by the velocity of 90 km/h. The handling and staying times at the station are also calculated as a fixed time of 1 hour handing and 2 hours staying time. The transportation time of truck transportation is calculated by using an average velocity assumed be 30 [km/h] in general road and 80 [km/h] on highway. Also, rest time of driver is considered. We assume it is 30 minutes per 4 hours in truck transportation. Cargo handling at the departure and destination point are necessary in both cases. Here cargo handling time and cost are considered at the departure and destination railway station only.

CO₂ emissions are calculated as an environmental measure while railway exhausts CO₂ emissions by transportation activities and cargo handling operational activities and truck exhausts CO₂ emissions by transportation activities. The CO₂ emissions of truck transportation is calculated by ‘Improved ton-km method [13] which is determined by the cargo volume, truck size and the load rate. This method is able to reflect the load rate of trucks, but this is not applied to the calculation for CO₂ emissions of railway and ships. In Improved ton-km method, CO₂ emissions are calculated as below formula:

\[ CO₂ \text{ emissions} = \text{cargo volume} \times \text{mileage} \times \text{improved specific CO₂ emission coefficient of fuel species} \]

where, CO₂ emission coefficient is predetermined. For example, Diesel coefficient is 2.62 (g – CO₂/t·km). For calculating the CO₂ emission of railway transportation, ‘Ton-km method’ [14] is used.

\[ CO₂ \text{ emissions} = \text{cargo volume} \times \text{mileage} \times \text{specific emissions of fuel species} \]

where, CO₂ emission coefficient of past ton-km method is predetermined. It is 173 (g – CO₂/t·km) by truck and 22 (g – CO₂/t·km) by railway.

Given a cargoes departure point, the advantageous area of railway mode can be found by calculating these criteria respectively. The destination points of changing modes can be determined by following formula (see Fig.1).

\[ C_{d,0} \geq C_{d,1} + C_{d,2} + C_{d,r} + 2CL \]  
\[ T_{d,0} + T_{1} \geq T_{d,1} + T_{d,2} + T_{d,r} + T_{L} + T_{W} + T_{I} \]  
\[ E_{d,0} \geq E_{d,1} + E_{d,2} + E_{d,r} + E_{L} \]

where

\( C \) represents cost (Japanese Yen),
\( T \): delivery lead time (hour),
\( E \): CO₂ emission (kg – CO₂),
\( d \): represents the distance(km),
\( i \): interval (i=0,1,2),
\( r \): railway,
\( L \): cargo handling,
\( W \): staying time (hour),
\( I \): rest time (hour)

Formula (1) presents the destination points where the cost of truck transportation is larger than the total cost of railway transportation, including the cost of truck transportation between departure point to railway station and railway station to delivery point; cost of railway and cost of cargo handing at railway stations. Similarly, formula (2) presents the destination points where the delivery lead time of truck transportation is larger than the total delivery lead time of railway transportation. Note the rest time of left side is not equal to that of right side in the formula, because the rest time of left side shows the rest time in all trip however that of right side just shows the trips between departure point to railway station and railway station to delivery point. Formula (3) presents the destination points where the CO₂ emission of truck transportation is larger than the total CO₂ emission of railway transportation.

Fig.2 shows an example of the advantageous geographical areas and the destination points of railway transportation under the calculation of costs, delivery lead time and CO₂ emissions respectively. Simply in this case, we assume 5 ton cargo; 5 ton...
truck and 12ft container are used. The distance from the departure point to railway station is 20 km, the distance between the railway stations is 400km, the handling time at the railway station is 0.5 hour and staying time is 0 hour.

If there is a destination point within these areas, railway transportation is a good way than truck only. In other words, parts of overlapping of three areas, the railway transportation has become advantage in all criteria. And this case is parts of surrounded by the delivery lead time line. We can find the railway advantageous area becomes wide in terms of cost and CO\textsubscript{2}, but becomes narrowed in terms of lead time. This result shows the lead time is an important issue of railway modal shift.

3. Results and discussion of the simulation models

The basic data used in the simulation model are from real world of Japan. Table 1 shows the cases of conventional and after changing modes. They all show the transportation route from left side to right side. Where Kanuma, Numazu and Fukuoka are warehouses of a Japanese company, Utsunomiya, Numazu, Shizuoka and Fukuoka are railway stations. The transportation distance and transportation mode are also shown in Table 1.

3.1 The advantageous areas

The comparison simulations of advantageous areas of modal shift are executed by given a departure point. Figure 3 shows the transportation routes by truck and railway, and departure location of Numazu warehouse and Numazu railway station, to destination location of Fukuoka railway station and Fukuoka warehouse. This transportation route is over 1500km while railway mileage is about 1400km.

First, the simulation has been executed in a case of departure point to destination point, where transport cargo weight is 10 tons, the handling time at the station is 1 hour and staying time is 2 hours. Table 2 shows the simulation result on the criteria of cost, CO\textsubscript{2} emissions and delivery lead time (LT), respectively.

In Table 2, “Before” means a mode of just trucks, “After” means a mode of truck and railway combination. Reduction and reduction rate means the difference and percentage of the modal shift. From Table 2 it can be observed that through modal shift not only CO\textsubscript{2} emissions but also cost and lead time can be reduced significantly, in the case of transporting 10 tons cargo from Numazu to Fukuoka. That means changing transportation modes may be a possible alternative to reconsider company’s transportation strategy. Then how to determine the point of changing transportation mode is important to guarantee a successful modal shift. Here we show by using our geographical simulation approach the changing points can be obtained critically.

Second, several simulations to show the advantageous area of railway transportation have be executed by given several different destination points, under different criterion. Fig. 4 shows the results in where destination points are within these advantageous areas enclosed by three lines represented CO\textsubscript{2} emissions (green line), cost (red line) and lead time (blue line) respectively.

From Fig.4 it can be observed that there are a clear changing points (line) to show the advantageous area of railway transportation. However because the areas of lead time is smallest and included in the areas of CO\textsubscript{2} emissions and cost, lead time is a critical criterion in the modal shift.

Usually, railway station has been selected as the nearest to these warehouse. However, in the case that cargo could not be shifted entirely to railway transportation by departure time, then the selection for appropriate train in the lead time should be made by expanding the alternative railway stations. For example, transporting the cargo to Shizuoka station from the Numazu warehouse, instead to Numazu station. The truck distance of Numazu Station to Numazu warehouse is 8.5km and the distance of Shizuoka Station to Numazu warehouse is 43.6km. Also the railway transportation distance could be shorten 51.2km in the case of the transported from Numazu Station to Shizuoka Station. Such alternative transportation policy may influence the behaviors of modal shift. Then by changing the alternatives of different departure and destination railway stations, the advantageous areas of shifting from truck to railway can be calculated clearly. Here we assume the departure point and railway station is fixed. Several alternative destina-
Table 1: Data of modal shift simulation

| Departure point | Transportation Mode | Distance (km) | Destination Point       |
|-----------------|---------------------|---------------|-------------------------|
| Kanuma Warehouse| Truck               | 1211          | Fukuoka Warehouse       |
| Numazu Warehouse| Truck               | 967           | Fukuoka Warehouse       |

| Departure point | Transportation Mode | Distance (km) | Departure station | Transportation Mode | Distance (km) | Destination station | Transportation Mode | Distance (km) | Destination Point |
|-----------------|---------------------|---------------|------------------|---------------------|---------------|---------------------|---------------------|---------------|------------------|
| Kanuma Warehouse| Truck | 15.4 | Utsunomiya station | Railway | 1283.2 | Fukuoka | Truck | 7.9 | Fukuoka Warehouse |
| Numazu Warehouse| Truck | 8.5 | Numazu station | Railway | 1061.1 | Fukuoka station | Truck | 7.9 | Fukuoka Warehouse |

Table 3: Distance from Numazu station to destination station

| Destination Station | Distance (km) | Destination Station | Distance (km) |
|---------------------|---------------|---------------------|---------------|
| Fukuoka             | 1061.1        | Kobe                | 463.8         |
| Kitakyushu          | 993.1         | Kyoto               | 389.2         |
| Shinnanyo           | 877.7         | Gifu                | 274.5         |
| Hiroshima           | 761.8         | Nagoya              | 243.7         |
| Nishiohkayama       | 604.8         | Nishihamamatsu      | 132.9         |
| Himeji              | 507.1         | Shizuoka            | 51.2          |

Fig. 5: Cost influence of changing the railway distance

Fig. 6: Influence of CO₂ emissions of changing the railway distance

Fig. 7: Lead time influence of changing the railway distance

Station stations exist in the route from Numazu station to Fukuoka station. The alternative stations and distance between railway stations are shown in Table 3. Fig.5 shows the advantageous areas of changing the railway distance under the condition of cost. Different lines and circles represent different distances (destination stations). Note circles show the advantageous areas are only around the railway stations. From Fig.5 it can be observed that the advantageous areas are becoming narrow when the destination railway station changes to be near by the departure station. There is a limit of the advantageous area of railway, in this case it is 463.8km (Kobe Station). When the distance is smaller then it changing mode from truck to railway can not achieve any benefit in terms of cost.

Fig. 6 shows the advantageous areas of changing the railway distance under the condition of CO₂ emissions reduction. Different lines represent different distances (destination stations). From Fig.6 it can be observed that the advantageous areas are becoming narrow when the destination railway station changes to be near by the departure station. However, the advantageous areas are enough wide to cover the land. For example, the advantage areas of railway cover the next railway station of Shizuoka Station. That means changing mode from truck to railway has a high superiority on the CO₂ aspect.

Fig. 7 shows the advantageous areas of changing the railway distance under the condition of delivery lead time. Different lines and circles represent different distances (destination stations). Also circles show the advantageous areas are only around the railway stations. From Fig.7 it can be observed that the advantageous areas are becoming very narrow when the destination railway station changes to be near by the departure station. And there is also a limit of the distance from departure point. For this example it is 761.8km (Hiroshima Station). That means changing mode from truck to railway can not achieve any benefit in the areas of smaller than 761.8km in term of delivery lead time.

Overlap the three figures (Fig.5-7) to find the the advantageous areas of shifting from truck to railway, it can be observed that the superiority of the modal shift for cost and CO₂ emissions but be limited by delivery lead time. Generally, the modal shift to railway is effective over more than 500km distance transportation. Especially when only cost and CO₂ emissions are considered, railway distance may is less than 500km. Moreover, the advantageous areas of modal shift may be im-
proved largely if the delivery lead time of destination points could be shorten by several management approaches.

3.2 Consider different delivery methods

As mentioned at the end of last section, the above simulation experiments are executed under a set of fixed conditions (especially on delivery method), in order to evaluate the advantageous areas of modal shift by different criteria. Suppose that different delivery methods may achieve different performances by modal shift, here two scenarios are considered to show the effects of modal shift. One is a round-trip transportation in where cargo are delivered to destination point and then the empty cargo are returned to departure point. The other is a case of joint delivery in where two companies use a joint delivery method, both have warehouses at departure and destination points, to reduce their truck empty rate.

Fig. 8 shows the transportation routes by truck and railway of two companies (A co. and B co.), departure points of Utsunomiya warehouse, Utsunomiya railway station, and destination points of Osaka railway station and Osaka warehouse. 10 tons cargoes are transported. The transportation distance and transportation mode are shown in Table 5. We assume that A co. only use railway and B co. only use truck for their own transportation. Also a special case of joint delivery to coordinate their transportation is shown in Table 5. In this case, railway transportation is advantageous in the areas of destination point exists within a 30km radius from the destination railway station.

CO₂ emissions, and round trip and return empty cargo. The result of delivery lead time is committed because it is same to the result of Fig.9. From Fig.10 it can be observed that the advantageous area of railway transportation is larger than Fig.9 in terms of CO₂. That shows empty truck transportation exhaust more CO₂ emissions than empty railway container transportation. Therefore, improvement of empty transportation in a round trip can lead a good performance of cost and CO₂ emissions. We define a load rate (equals to (1- empty rate)) to evaluate the performance of the modal shift. Fig.11 shows the simulation results of the cost and CO₂ when the load rate is changed, where horizontal axis shows the load rate and vertical axis shows cost and CO₂ emissions.

It can be observed from Fig. 11 that the load rate is possible to be more than 60% will lead superiority on truck transportation in a round trip. However, it is difficult to secure so many loads to up the load rate by only one company. Cooperating delivery may be considered as an alternative transportation policy. Here we consider a very simple case where two companies (A co. and B co.) share their expense for empty return cargoes. Table 5 shows three simulation cases based on real data of Japan transportation. These are (i) halves with the two companies, (ii) B Co. pays the all, and (iii) A Co. pays the all. Because the round trip of A co. only used railway and B co. only used truck, when they are cooperating their deliveries the empty cargoes of both companies can be transported by only railway, even there may be some additional fee for transportation between the two companies. The calculation results shown in Table 5 represent that the benefits of not only cost but also CO₂ emissions can be obtained for both companies in the three cases when they are sharing the return cargoes expenses. (see the third row of Table 5 which shows case (iii)). Moreover, the advantage of railway will be different in the different cases.
## Table 4  Transport routes and transport distances

| Transportation method | Departure point | Transport | Distance km | Departure railway station | Transport | Distance km | Destination railway station | Transport | Distance km | Destination point |
|-----------------------|-----------------|-----------|-------------|---------------------------|-----------|-------------|-----------------------------|-----------|-------------|------------------|
| A Co: Railway         | Utsunomiya      | truck     | 25          | Railway                   | truck     | 3           | Utsunomiya                  |           |             | A Co Osaka       |
|                       |                 | truck     | 640         | Utsunomiya station        | truck     | 650         | Osaka station               |           |             | A Co Utsunomiya  |
| B Co: Truck           | Osaka           | truck     | 25          | Railway                   | truck     | 3           | Osaka station               |           |             | B Co Utsunomiya  |
|                       |                 | truck     | 30          | Railway                   | truck     | 30          | Osaka                      |           |             | B Co Osaka       |
| B Co: Utsunomiya      | truck           |           |             |                           |           |             |                             |           |             |                  |
| Modal shift by coordinated transportation | Utsunomiya | truck | 10          | Osaka station             | Railway   | 650         | Utsunomiya station         | truck     | 3           | A Co Osaka       |
|                       | Osaka           | truck     |             |                           |           |             |                             |           |             |                  |
|                       |                 |           |             |                           |           |             |                             |           |             |                  |
| B Co: Utsunomiya      | truck           |           |             |                           |           |             |                             |           |             |                  |
|                       | Utsunomiya      | truck     |             |                           |           |             |                             |           |             |                  |
| Pattern | State | Company | Modes | Distance (km) | Cargo | Cost (Japanese yen) | CO₂ Emissions (kg-CO₂) |
|---------|-------|---------|-------|---------------|-------|-----------------|-----------------------|
|         |       |         | Truck | Rail way | Truck | Interval | Sum | A-Co. Sum | A-Co. Benefit | B-Co. Sum | B-Co. Benefit | Interval | Sum | A-Co. Benefit | B-Co. Benefit | Reduction |
| A-Co. Railway |       |         |       |          |       |          |     |           |             |           |               |           |     |               |               |          |
| Outward | A-Co. | Railway | 0     | 10       | 0     | 132,672  | 62,887 | 392,051 | 195,560 | 196,491 | 186.7 | 78.5 | 1450.2 | 265.2 | 1185 |
| Return  | B-Co. | Truck   | 640   | 10       | 0     | 130,994  | 65,497 | 580     |           |           |           | 604.9    | 372.8 | 225    | 62.1    |          |
| (i) Pay halves of A and B-Co. |       |         |       |          |       |          |     |           |             |           |               |           |     |               |               |          |
| Outward | A-Co. | Railway | 0     | 10       | 0     | 132,672  | 27,537 | 158,200 | 162,620 | 33,871 | 186.7 | 24.5 | 428.1 | 203.1 | 225    |
| Return  | B-Co. | Railway | 30    | 10       | 0     | 137,092  | 23,519 | 24.5    |           |           |           | 208.6    | 8.2     |          |          |          |
| (ii) Pay all by A-Co. |       |         |       |          |       |          |     |           |             |           |               |           |     |               |               |          |
| Outward | A-Co. | Railway | 0     | 10       | 0     | 132,672  | 27,537 | 158,200 | 162,620 | 33,871 | 186.7 | 24.5 | 428.1 | 203.1 | 225    |
| Return  | B-Co. | Railway | 30    | 10       | 0     | 137,092  | 23,519 | 8.2     |           |           |           | 208.6    | 8.2     |          |          |          |
| (iii) Pay all by A-Co. |       |         |       |          |       |          |     |           |             |           |               |           |     |               |               |          |
| Outward | A-Co. | Railway | 0     | 10       | 0     | 132,672  | 27,537 | 158,200 | 162,620 | 33,871 | 186.7 | 24.5 | 428.1 | 203.1 | 225    |
| Return  | B-Co. | Railway | 30    | 10       | 0     | 137,092  | 23,519 | 8.2     |           |           |           | 208.6    | 8.2     |          |          |          |
For example shown in Table 5, the advantage of railway in case (i) can be achieved even the distance of railway is less than 500km, however that in case (iii) should be over 550km.

4. Conclusions

This paper discussed a special modal shift case of from track to railway transportation. The contributions are remarked as belows. First a geographical model is constructed to evaluate the effect of reducing truck transportation by comparing an alternative of railway transportation. Second, multi-objectives of transportation cost, delivery lead time and reduction of CO₂ emissions are considered. Third, the three criteria are combined in a geographical framework then lie on the top of other to show the advantageous areas. And fourth, several management factors were discussed based on the simulation results. The customer factor of delivery lead time is a bottleneck in the modal shift model. Improvement of the lead time performance can achieve better advantageous areas of modal shift. Also reducing empty return cargoes and cooperating deliveries are useful for achieving modal shift successfully.

Future works are lot. A mathematical modal should be considered to represent the control variables like as numbers of trucks, length of train, time table of truck and train and so on, so that the problem of modal shift is able to operate in an optimization category. Also several case studies should be made and the simulation results should be proved statistically.

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