



## I. INTRODUCTION

Due to stringent regulations and environmental concerns as well as high energy prices, the problem of cost and emissions in transportation has attracted more considerations. There is an ever increasing concern regarding to the effectiveness and cost of speed reduction on emissions from international shipping[1,2,3].

According to the report of International Maritime Organization [4], the CO<sub>2</sub> emissions from international shipping accounts for 2.7% of global total emissions, whilst speed, as a crucial factor, has direct and remarkable effect on emissions and cost in maritime shipping. Thereby a majority of papers focused on effect of sailing speed optimization on emissions and cost, or to be more exact, the impact of speed reduction on emissions and/or cost. And the sailing speed reduction represents one key operational change for potentially reducing CO<sub>2</sub> emissions and cost from international fast shipping as well as some technology-based approaches [5]. However, limitations of speed reduction have led to new discussions about how and how long the “slow steaming” can hold considering cost and emissions. Partial researchers have intent of transport mode shift and/or split modal aiming to the limitations of speed reduction. [3] indicated that the slower ships may be induced to prefer land-based transport alternatives, but it proposed the road alternative which may increase overall GHG emissions and make worse environment than maritime in terms of GHG emissions per tonne-km. Furthermore[6] had discussed that sea shipping may be a shifting to more environmentally intrusive land-based modes considering the emission reduction, and indicated that electric railway may emit less CO<sub>2</sub>.

With the rapid development of express railway, railway/sea-railway transportation instead of ship individual may be a good choice and it will take less time and contribute to emissions reduction. The objective of this paper is to study emissions and cost consequences regarding railway/sea-railway and maritime shipping on speed optimization. It extends the scope of speed reduction on emissions in maritime shipping to combined optimization of sailing speed and railway speed in sea-railway transport. It attempts to provide new transport mode selection so as to minimize emissions and cost in some special areas. This kind of optimization depends on related technical support, and intelligent transportation system is an effective method in improving transportation systems, and sustained transportation optimization in cost and energy. Therefore it is significant to study cost and emission reduction in transportation based on ITS.



Hence, the work should be done in this field [11]. Intelligent scheduling and optimization will be more crucial to integrate different modes of transportation aiming to cost saving and emission reduction.

## 2.2 THE INFLUENCE OF SAILING PEED REDUCTION ON EMISSION AND COST

Greenhouse emission from shipping, rail, aviation and road accounts for 2.7%, 0.5%, 1.9% 21.3% respectively[4]. Owing to stringent regulations and requirements along with environmental strength for shipping, more and more researchers pay attention to the emissions for shipping from a perspective of speed reduction. The emergency of emissions speed model is in recent years, and [3] had generalized speed models that consider emissions. The emissions speed model contain two taxonomies depending on whether cost is considered, one is single emissions speed model which only considers emissions minimization, the other is double emissions speed model which not only consider emissions but also cost.

Single emissions speed model derive from the relationship of energy consumption and speed. Emissions produced, mainly CO<sub>2</sub>, is proportional to fuel burned (usually energy consumption multiply by emissions coefficients could get emissions), whilst the energy consumption is appropriate cubic power of speed, thereby the emissions speed model could be explained energy consumption-speed model to some extent without considering the difference of fuel type and concrete emissions .

[14] indicated that speeds have been reduced and realized emission reduction in the past years and proposed the utility of oversupply of ships to reduce emission. Meanwhile it explained how to reduce the emissions under slow steaming, that is possible speed reduction should be determined in the first instance considering the related factors such as the supply of ships, the maximum capacity utilization of vessels, the demand of transport, the character and type of engine, and then determined the emission under previous speed reduction. It turned out that it is feasible to reduce emission under slow steaming by utilizing oversupply ships.[13] formulated a non-linear continuous model of speed optimization in order to minimize fuel consumption and emissions on shipping routes, and the model was transformed into a shortest path problem on a directed acyclic graph by discretizing the arrival times in further. It certified that the proposed method is more applicable and much faster than non-linear programming solver. [14] examined whether slow steaming, which have been implemented widely, can be a sustainable means of



to land which (mainly road) has the potential to produce more emissions on land than those saved at sea, nevertheless, it presented an attempt for coping with some emissions regulation. [17] investigated the effect of speed reductions on the direct emissions and cost in maritime shipping, and developed model to calculate emission and cost for individual ship classed as a function of speed. During which different types of ship including ro-ro vessels, container vessels, bulk vessels were selected to experiment on the impact, and these experiments were represented the world fleet. The results show that it is a potential operational measure for reducing emissions by speed reduction optimization.

[2] developed a general profit maximization model for a shipping company to probe into the effectiveness of speed limit versus bunker-levy to total profit and amount of CO<sub>2</sub> emitted from container shipping. And this paper argued that the measures of the speed limit from European Commission could not automatically reduce the amount of CO<sub>2</sub> emitted on a global scale. [18] determined the optimal operational speeds (laden and ballast) of a tanker as a function of fuel price, freight rate and other parameters, and estimated the emissions based on the output of optimal speed. The study of this paper focused on, but did not limit, Very Large Crude Carriers (VLCCs).

[19] investigate the difference in speed with SECA and outside SECA subject to sulphur emission limitation set by Annex VI of Marpol, and proposes a cost model for a shipping company operating a liner service that includes a SECA. This model determines the combination of cost-minimizing speeds and the corresponding quantity of CO<sub>2</sub> emitted, among which the cost includes fuel consumption (main engine and auxiliary engine) and vessel fixed operational costs. This objective function of model addressed cost primarily, and seeks for the optimal combination of speed so as to minimize total cost. Meanwhile the corresponding to CO<sub>2</sub> emission got depending on energy consumption multiplying by emission coefficients.

It is to be considered that [6] studied the implications of various maritime emissions reductions policies for maritime logistics in depth. In addition to speed reduction on cost and emissions, it explored the effect on modal split and proposed that shipping may be a shifting to more environmentally intrusive land-based modes in some certain region.

### 2.3 THE INFLUENCE OF TRAIN SPEED ON EMISSIONS AND COST

[20] discussed whether high-speed trains could reduce energy consumption. The author stated that the increasing speed while a train can run on downward slopes lead to a reduction in travel



emission as well as cost. This paper will give a comparative analysis on CO2 emission and cost for freight train and shipping considering speed.

### III. EMISSIONS AND COST MODEL BASED ON ITS

#### 3.1 DATA FUSION AND ITS

With the advent of modern communication and computational devices and inexpensive sensors it is possible to collect and process data from a number of sources. Data collection is convenient and economic. Data fusion (DF) is collection of techniques by which information from multiple sources are combined in order to reach a better inference [24], and DF is an inevitable and effective tool for decision making in ITS.

Sea-railway transportation system combines shipping and railway transport, which focuses on transport optimization. DF techniques can be used to combine network control, traffic forecast, accurate position and energy consumption estimation in railway and shipping transportation. Thereby the decision making model can be established based on data fusion in sea-railway transportation system. In this paper, mode selection of transportation network regarding to cost and emission saving is discussed based on ITS.

Figure 1 shows the configure of shipping and railway intelligent transportation, it is evident that phase 1 and phase 2 focus on data collection and analysis, phase 3 provides analytical model and phase 4 determine the optimal programming, and it is possible to exchange data across all modes of transportation. In next section, we assumed that phase 1 and phase 2 have been done, and phase 3 and phase 4 will be discussed. And then the comparison of cost and emission between different modes of transportation will be analyzed.

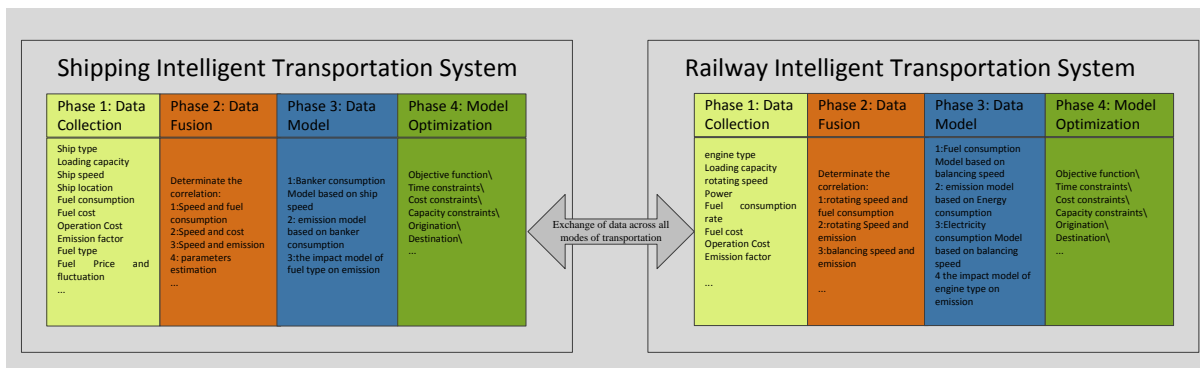


Figure 1 The configure of intelligent transportation system within shipping and railway





forward direction allowing for the latest delivery date.  $T_f$  is real sailing time for forward;  $T_d$  is sailing time for return trip, and  $T_c$  is charter period time.

$$T_f + T_c = \frac{s^{sail}}{24v_f} + \frac{s^{sail}}{24v_d} = \frac{s^{sail}}{24} \times \frac{(v_f + v_d)}{v_f \times v_d} \leq T_c \quad (7)$$

$$T_f \leq T_l \quad (8)$$

Although the charter bear bunker fuel cost, loading and unloading expense, port charges, this paper considered bunker cost and charter hire. Assumed charter rate is (\$/day), and the rent is.

$$TC_r = R \times T_c \quad (9)$$

And total CO2 emission and total cost of round trip is equal to

$$TCO_{2e} = 3.17 \times (0.0043 \times v_f^{3.358} \times T_f + 0.0043 \times v_d^{3.358} \times T_d) \quad (10)$$

$$TC = TC_b + TC_r = P \times (0.0043 \times v_f^{3.358} \times T_f + 0.0043 \times v_d^{3.358} \times T_d) + R \times T_c \quad (11)$$

The model of emission and cost can be formulated as following.

Minimize:

$$\{3.17 \times (0.0043 \times v_f^{3.358} \times T_f + 0.0043 \times v_d^{3.358} \times T_d); P \times (0.0043 \times v_f^{3.358} \times T_f + 0.0043 \times v_d^{3.358} \times T_d) + R \times T_c\} \quad (12)$$

Subject to

$$\frac{s^{sail}}{24} \times \frac{(v_f + v_d)}{v_f \times v_d} \leq T_c \quad (13)$$

$$T_f \leq T_l \quad (14)$$

$$24 \times T_f = s^{sail} / v_f \quad (15)$$

$$24 \times T_d = s^{sail} / v_d \quad (16)$$

$$v_l \leq v_f, v_d \leq v_u \quad (17)$$

Wherein (13) and (14) are time constraints for sailing. eq (15) and (16) are the relationship function of time, distance and speed for sailing; (17) are speed constraints for  $v_f$  and  $v_d$ , and  $v_l, v_u$  represent the maximum and minimum sailing speed respectively depending on technical and weather conditions.

Table 1 sailing speed and bunker consumption

Average speed(knots)	Bunker(ton/day)	Average speed(knots)	Bunker(ton/day)
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We discretized eq(18) corresponding to five speed scenarios on the different rotating speeds and transform it as following:

$$\prod_{j=1}^3 \varphi_j(v_i)/1000 \quad i=1,..5 \quad (20)$$

The CO2 emission factor of diesel fuel is 22.23 lb CO2/gal [26], and is equivalent to 2.73kg/litre, namely approximate 3.25kg CO2 emitted for combustion of per kilogram diesel fuel.

The quantity of CO2 emission is equal to:

$$TCO_{2e}^d = E \times e_c = 3.25E = \prod_{j=1}^3 \varphi_j(v_i)/1000 \times 3.25 \quad i=1,..5 \quad (21)$$

The unit price of diesel is  $p_d$ , and the total cost of diesel is equal to:

$$TC_d = E * p_d = \prod_{j=1}^3 \varphi_j(v_i)/1000 \times p_d \quad i=1,..5 \quad (22)$$

Objective function

$$\min\{\prod_{j=1}^3 \varphi_j(v_i)/1000 \times e_c; \prod_{j=1}^3 \varphi_j(v_i)/1000 \times p_d, i=1...5\} \quad (23)$$

### 3.3.2 EMISSIONS AND COST OF ELECTRICAL LOCOMOTIVE

Freight trains for electrical locomotive, [27] presented the amount of energy consumption.

$$EC_{jm} = \frac{2.725M_{jm} + 2.724 \times 10^{-3} R_{jm} d_m}{\eta_{jm}} \quad (24)$$

Where  $M_{jm}$  is a train of weight operating along the segment  $d_m$ ;  $R_{jm}$  is the train's resistance along  $d_m$ ;  $\eta_{jm}$  is efficiency of the electric locomotive. For simplicity, [23] employed the transformation formula (25) instead of (24) according to the estimation of energy consumption of a freight train of a gross weight of  $M_{jm}$  along  $d_m$  [28].

$$EC_{jm} = 0.315 * M_{jm}^{0.6} * d_m (kWh) \quad (25)$$

The corresponding emissions of greenhouse gases in terms of CO2 can be estimated as

$TCO_{2e}^e = EC_{jm} \times e_{jm}$ . Where  $e_{jm}$  is the emission rate (kgCO2/kW.h), and the value  $e_{jm}$  of is 0.46kg CO2/kW h of electricity produced [29]. Therefore the emission is equal to:

$$\begin{aligned} TCO_{2e}^e &= EC_{jm} * e_{jm} \\ &= 0.315 * M_{jm}^{0.6} * d_m (kWh) * 0.46 \\ &= 0.145 * M_{jm}^{0.6} * d_m (kWh) \end{aligned} \quad (26)$$



- Scenario II for electrical locomotive Average haulage weight is 5000 tons, and it needs 12 trains. The value of  $p_e$  is assumed 0.15USD/kWh considering the price variance of different regions and different time.



Figure 2 Shortest Shipping Route

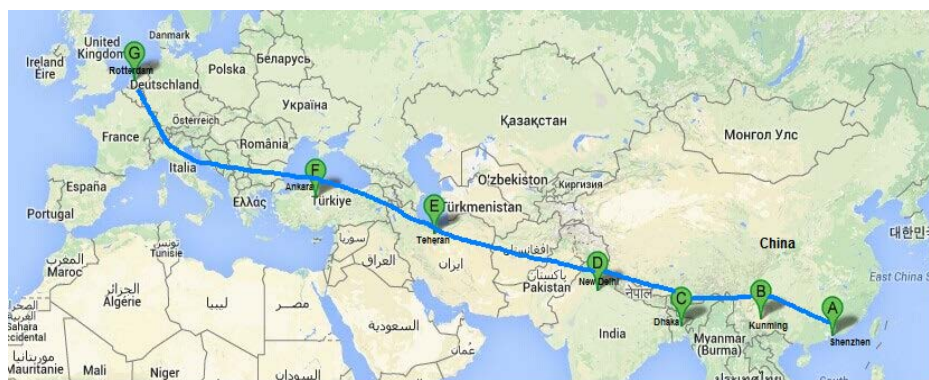


Figure 3 Eurasia Land Bridge  
(Complied according to the third Eurasia land bridge)

## 4.2 RESULTS ANALYSIS

### 4.2.1 RESULTS OF SAILING

To assess the effects of sea- rail substitution, using the given data of shipping and freight rail service, the impact of shipping on emissions and cost are given. The outcome for the mode includes: Carbon dioxide  $5.7605e+003$  tons; Sailing Speed of forward and return  $v_f = 14.9, v_d = 13$ ; Total cost of round trip is  $2.2505e+006$  USD. If extended to 30, or reduced to 25, 22 days respectively and other parameter kept constant, the results will be.

(1)  $T_l = 22$  Carbon dioxide:  $7.5011e+003$  tons,  $v_f = 18.9, v_d = 10.9$ , total cost  $2.7446e+006$  USD

(2)  $T_l = 25$  Carbon dioxide:  $6.3176e+003$  tons,  $v_f = 16.7, v_d = 11.9$ , total cost  $2.4086e+006$  USD



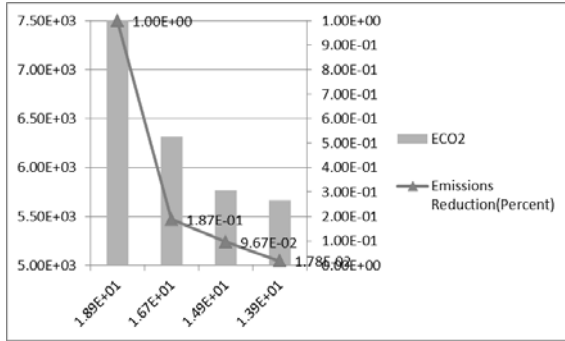


Figure 6 ECO2 Reduction Varying with  $v_f$

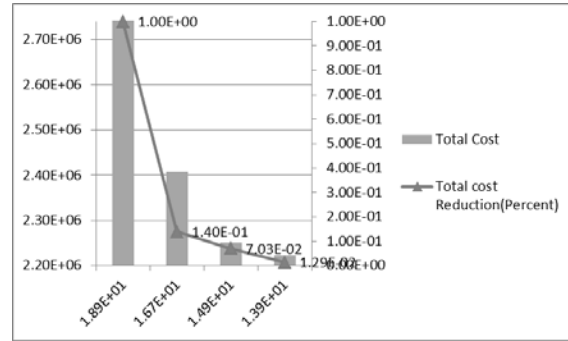


Figure 7 Total Cost Reduction Varying with  $v_f$

We extended  $T_c$  to 90 days further, and relaxed the constraints of  $T_l$  without speed limitation. We could attain a set of new solutions in Table 4.

Table 4 Emission and Total Cost after Relaxing Time Constraints of  $T_l$  and  $T_c$

$T_l$ (Day)	Emission(tons)		Total cost(USD)		$v_f$ (knot)	$v_d$ (knot)
	$T_c = 90$	$T_c = 60$	$T_c = 90$	$T_c = 60$	$T_c = 90$	
22	6.2913e+003	7.5011e+003	2.4012e+006	2.7446e+006	18.9792	6.1403
25	4.8071e+003	6.3176e+003	1.9798e+006	2.4086e+006	16.7017	6.4237
28	3.8409e+003	5.7605e+003	1.7055e+006	2.2505e+006	14.9122	6.7345
30	3.3820e+003	5.6600e+003	1.5752e+006	2.2219e+006	13.9181	6.9590
35	2.6453e+003	/	1.3660e+006	/	11.9298	7.5917
40	2.2846e+003	/	1.2636e+006	/	10.4385	8.3508
45	2.1757e+003	/	1.2327e+006	/	9.2787	9.2787

By comparison, we knew that there is a sharp decline in CO2 emission and total cost due to relaxations and extension of time. It seems valuable that the relaxation of time constraints presented the possibility of reduction in sailing speed, but it is unrealistic for an unusually low sailing speed on account of technical requirements and delivery date.

As for the practicality, we determined one feasible solution of 5.6600e+003 tons CO2 emission and 2.2219e+006 total cost at average sailing speed of 13.9knts when  $T_c = 60$  and  $T_l$ ; another feasible solution of 2.1757e+003 tons CO2 emission and total cost of 1.2327e+006 dollars at sailing speed of 9.3 knots when  $T_c = 90$  and  $T_l = 45$ .

#### 4.2.2 RESULTS OF FREIGHT TRAIN

Freight train include Scenario I (diesel locomotive haulage) and Scenario II (electrical locomotive haulage). The emission and cost of Scenario I is related to discrete speed as well as fuel consumption rate and power on the condition of different rotating speed. Therefore we calculated the five results corresponding to  $\varphi_j(v_i)$  ( $i = 1 \dots 5$ ) and attained the final results in Table





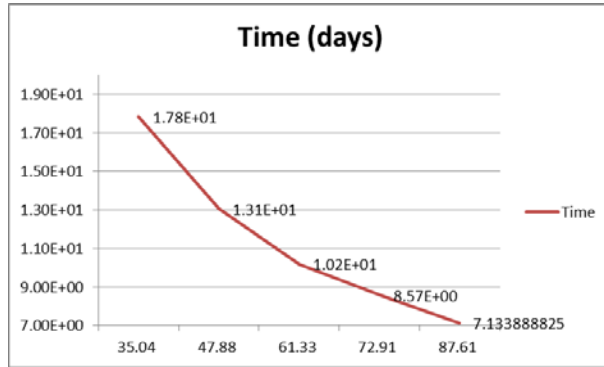


Figure 8 Running Time and v(i)

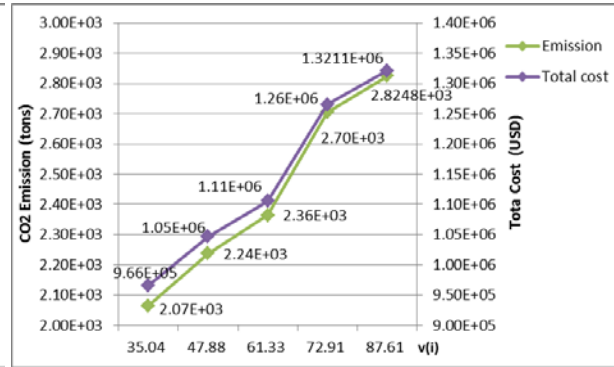


Figure 9 CO2 Emission and Total Cost for v(i)

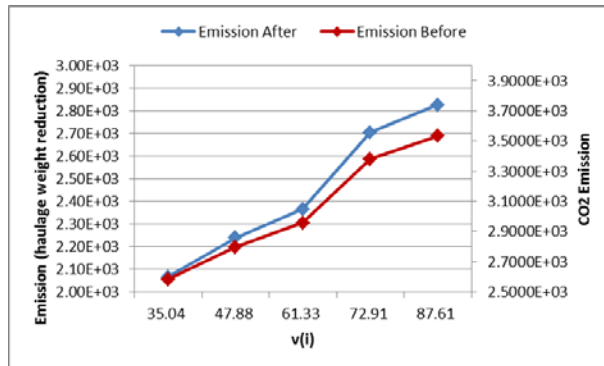


Figure 10 CO2 Emission Change

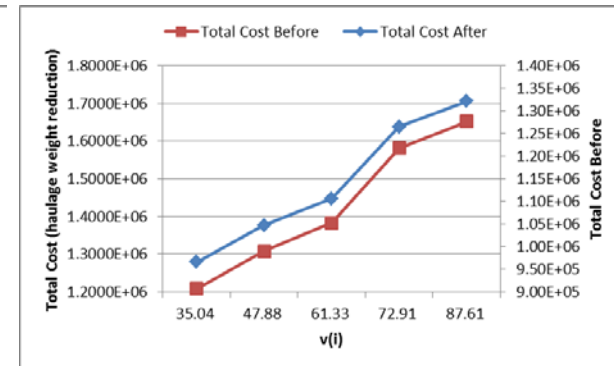


Figure 11 Total Cost Change

For scenario II of electrical locomotive, total CO2 emission and total cost is  $4.3254E+03$  tons and  $1.4095E+06$  dollars respectively. If we reduced gross weight of a train, namely reduction of haulage weight, emission and total cost will climb on account of the increase of train services listed in Table 7, the same as diesel locomotive. While a train of emission and cost will decrease when dropping in haulage weight, it can be deduced according to eq(28).

By comparison of Table 5 , Table 6 and Table 7, we know that total emission for electrical locomotive is greater than diesel locomotive under the same haulage weight of a train. Total CO2 emission with 12 trains (5000 tons haulage of a train) for electrical locomotive is  $4.3254E+03$ tons, while utmost total emission for diesel locomotive is  $2.8248E+03$  tons; total emission with 15 trains (4000 haulage weight of a train) for electrical locomotive is  $4.7292E+03$  tons,  $3.5310E+03$  tons for diesel locomotive. Total cost for electrical locomotive is greater than diesel locomotive in most cases; however, the total cost with 15 trains (4000 haulage weight of a train) for electrical locomotive is less than diesel locomotive when less than 70km/h of speed. It is clear that diesel locomotive is more environmental and economic than electrical locomotive when high haulage weight of a train, conversely, electrical locomotive is better than diesel locomotive. A train of emission and cost for diesel locomotive is no more than  $2.3540E+02$  tons,



For electrical locomotive, total CO<sub>2</sub> emission of 12 trains (5000 haulage weight of a train) 4.3254E+03 tons, and total cost is 1.4095E+06 USD. The results of total emissions and total cost are much lower than 5.6600e+003 tons and 2.2219e+006 USD of solution I for shipping, but higher than solution II. Once decreasing haulage weight of a train from 5000 tons to 4000 tons, total emission and total cost will increase because of additional 3 train services. Total emission added to 4.7292E+03, and total cost 1.5411E+06 USD. Electrical locomotive still stayed ahead of solution I of shipping in total emission and total cost, but it is worse than solution II of shipping. These results could be shown in Figure 11. The horizontal axis represents different conditions, including shipping (solution I and solution II) and railway (diesel locomotive and electrical locomotive (abbreviation EL)). And diesel locomotive consists of 10 modes according to five discrete speed multiplied two modes for haulage weight (5000tons/4000tons) of a train; electrical locomotive covers two modes of different haulage weight (EL/5000, EL/4000). The left vertical axis represents total CO<sub>2</sub> emission, and the right vertical axis shows total cost. And bar charts demonstrates total CO<sub>2</sub> emission, polyline shows total cost.

Wherein, both dark gray bars represent total CO<sub>2</sub> emission of solution I and solution II for shipping, and two red points of polyline above both dark gray bars demonstrate corresponding total cost of solution I and solution II respectively. Other gray bars represent total CO<sub>2</sub> emission of freight train, and the points of polyline above each light gray bar shows corresponding total cost.

Two dotted blue horizontal lines demonstrated the CO<sub>2</sub> emission baseline of solution I and solution II for shipping. It is evident that all of freight train emitted less CO<sub>2</sub> and consume less cost comparing to solution I of shipping, but only diesel locomotive run at lower speed with heavy-haul 5000 tons of a train is better than solution II.



## VI. ACKNOWLEDGEMENT

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