A STUDY OF COST AND EMISSIONS CONSIDERING SPEED OPTIMIZATION IN TRANS EURASIA TRANSPORTATION BASED ON INTELLIGENT TRANSPORTATION

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Abstract-People attach much importance to greenhouse gas emissions, and there is an increasing concern on cost and emissions on account of speed reduction for international shipping. Low steaming encountered these challenges of time constraint and technical requirements, while the cost and emissions of railway transportation distinctly differentiate from international shipping and it is a good substitute for international shipping to some extent. Intelligent transportation system (ITS) has proven to be a useful tool in providing efficient, environmentally friendly and safe transportation systems within inland and shipping. The paper focus on the selection and cooperative process between the shipping and railway, and discusses the cost and emissions by speed optimization for international shipping and railway transport aiming to select effective and environmental transportation mode based on ITS infrastructure. Firstly this paper reviews ITS and investigates the relationship of cost and speed along with the relationship of energy consumption and speed respectively for shipping and railway transportation, and then presents the speed optimization both shipping and railway transportation based on ITS so as to minimize cost and emissions. Subsequently it compared and analyzed the cost and emissions for mode selections, and it found that it is more effective and environmental to employ railway transport to some route leg. Finally A numerical case is presented and the results showed that it is necessary to shift model from sea to land on some section.

Index terms*: cost effectiveness, CO2 emission, intelligent transportation, railway transportation, international shipping, green logistics.

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_2 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_2 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_2.

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.

This paper is organized as follows. Section 2 introduces intelligent transportation, and reviews the effect of sailing speed reduction on emissions and cost along with train speed on emission and cost. Section 3 redesigned and presented the relationship of emission and speed in maritime and railway transport besides the relationship of cost and speed, and demonstrated the foundation of sea-railway intelligent transportation system. And then this paper proposes emissions and cost model for railway and shipping transport, which determines the speed-optimization combination aiming to minimize emission and cost. Meanwhile this paper compares and analyzes the impact of speed optimization on costs and emission in respect to maritime and railway transport. The last section designs and applies the model to trans-Eurasia transportation and attains the optimal results of total costs and emission. It concludes that it may be cost-effectiveness and environmental to transfer mode from sea to train freight on some condition depending on ITS.

II.   LITERATURE REVIEW

2.1 INTELLLIGENT TRANSPORTATION

Intelligent Transportation System (ITS) is a method of combining information technology and other advanced methods to address transportation problems involving a complex interplay between technology; cognition and behavior; and social, economic, and political systems. ITS uses different types of sensors to convert physical world quantities outside the vehicle (such as line markings, signs, other vehicles, road conditions, etc.) and inside the vehicle (such as capacity, break, other mechanical failures, etc.) to electronic signals which are then used for decision making. Intelligent Transportation System (ITS) infrastructure is fundamental conditions and makes a contribution to cost savings[7]. With environmental and economic requirements of transportation, various issues in ITS range from real time traffic information system to cost and emission optimization. Some articles focus on the impact of ITS on vehicle emissions and energy, a modal emissions model integrated with several traffic simulation models was presented to quantitatively determine the effects of ITS technology on vehicle emissions [8]. KIM J provided transportation system (ITS) strategic planning and implementation to meet the need for a sustainable energy future [9]. The use of intelligent transportation system and intelligent vehicle system technologies to reduce vehicle fuel consumption and emission levels is possible [10]. In the development of ITS, integration of the different modes of transportation is very necessary.

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 CO2, 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

CO2 emission. It shed light on the sustainability of slow steaming on the conditions of high bunker price and/or tax levy as well as cap-and trade systems in a long run.

[15] stated the effect of speed reduction on reducing emissions, and proposed decreasing time in port so as to offset the increasing time on sea due to slow steaming. A berth policy was presented to reduce waiting time in port and its implication on emissions was analyzed. And they also addressed that speed reduction can be beneficial for shipper when bunker prices are high and market rates are depressed even if this is no waiting time. [3] summarize the importance of speed on CO2 emissions. Although this paper highlighted that ship speed reduction would reduce emissions, perhaps drastically, reducing speed may have other adverse ramifications such as entailed cost. At the same time they claimed that reducing speed may help a depressed market. It can be seen that speed reduction may helpful for reducing emissions in some circumstances such as high fuel price, tax levy depressed shipping market, oversupply shipping capacity[12,14,15,3]. More papers examined double emissions speed model, and the cost has different contents. The cost may relate to fuel tax [1], cost to avert one tonne of CO2 [5], inventory cost, fuel cost[16], cost of capital, etc. [16] presented speed reduction model and scenarios and investigated the effect of speed reduction on emissions and cost for fast ship, mainly container vessels and ferries. Meanwhile they indicated that the effect of speed reduction depended on other related factors, such as the decreasing in port time, and addressed the importance of port in intermodal supply chain. [1] examine the impacts of a fuel tax and a speed reduction mandate on CO2 emissions considering two scenarios, scenario Ⅰ is lower speed without additional vessels (and thus less frequent arrival) and scenario Ⅱ assumed speed reductions accompanied by additional vessels (to maintain arrival frequency). To study the impacts of a fuel tax and a speed reduction, they explored a profit-maximizing function, and finally indicated that lower speed could provide CO2 reduction on most routes whatever scenarios.

[5] observed the tradeoffs between reduction of speed, change of number of ships in the fleet and emissions (mainly CO2 and SO2). It extend the scope of emissions to SO2 relating to SECA (Sulphur Emission Control Areas) shipping. It concluded that speed reduction will result in a lower fuel bill and lower emissions; the cost to avert one tonne of CO2 by speed reduction relies on several factors; speed reduction to reduce sulphur emissions at SECAs will result in a net increase of total emissions (including sulphur) along a ship's route to maintain the same transit time. This paper pointed out cleaner fuel requirement at SECAs may lead to cargo shift from sea

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 roro vessels, container vessels, bulk vessels were selected to experiment on the impact, and these experiments was 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_2 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_2 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_2 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_2 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

time whilst reducing energy consumed mainly due to reduced use of the brake, that is the steepness of the rail line on both upward and downward slopes is a parameter which influenced the speed and therefore affected on energy consumption. From above statement, we can conclude that railway running line condition influence train speed, and have further effect on energy consumption.

[22] observed the relationship and balance of energy consumption reduction and duration time of travel. And an approach dealing with a bi-criteria optimization problem is presented and improved in order to provide patterns of speed control. By this approach, a set of solutions can be searched in a continuous space and the Pareto approach is used to assess and rank them. And fundamental function of this approach is to reduce energy consumption by speed tuning of railway. It is necessary to indicated that they divided four steps on a section from speed profile, including acceleration, cruising, coasting and braking, and the phase of energy-consumption refers to acceleration and cruising, namely dragging. In addition, according to newton's second law we learned that the most energy-consumption occurred when dragging.

[22] focused on the diesel locomotive and studied the relation between bunker consumption and rotating speed. In fact, the rotating speed effect the dragging and influence the train speed in further, the relationship of bunker consumption and rotating speed represents the relationship of bunker consumption and train speed to some extent. And then it can be understood that train speed impact emission and cost. [23] analyzed and estimated the savings of energy consumption as well as others related emissions of greenhouse gases for modal shift from truck to railway in Trans-European freight transport corridors. While the freight train consumed electricity instead of diesel fuel depending mainly on its weight (locomotive + wagons + payload), movement resistance, and route length.

By comparison, [22] emphasized the influence of speed on consumption for diesel locomotive, and [23] mainly pay attention to the influence of payload on energy consumption and related emissions for electrical locomotive. Besides, it deserved to discuss whether high-speed trains could reduce energy consumption as [20] studied or low average train speed consume less energy as indicated [22], and all of these freight train would emit less CO_2 emission and cost less compared to sailing speed reduction for shipping?

It is clear that many researchers gave more attention on the impact of sailing speed reduction on cost and related emission, where minor people concentrated on the relationship of train speed and

emission as well as cost. This paper will give a comparative analysis on CO_2 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 positon 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.
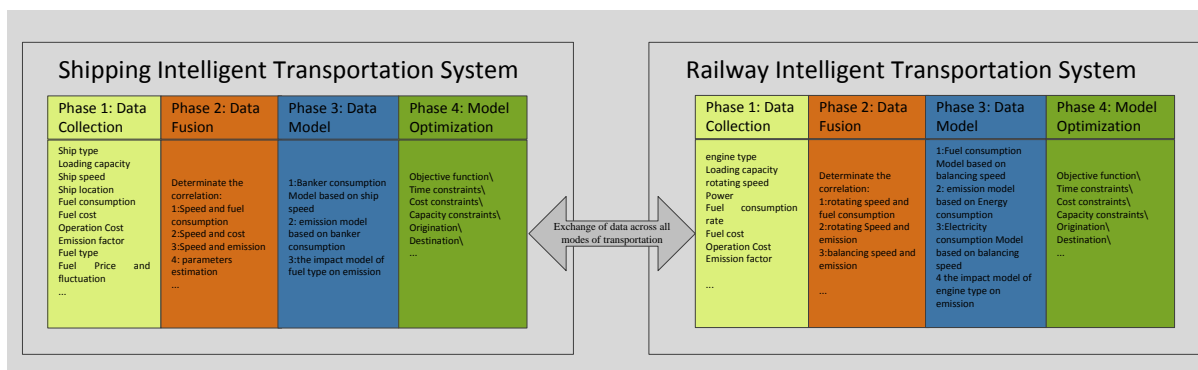

Figure 1 The configure of intelligent transportation system within shipping and railway

3.2   EXPANDING THE TRADITIONAL MODEL OF SHIPPING

The emissions and cost is mainly subjected to energy consumption, and energy consumption is close related to sailing speed, and therefore it is necessary to indicate the relationship of sailing speed and energy consumption. We assumed the power relationship between bunker consumption and sailing speed according to [25].

$$F = \alpha \times v^{\beta} \tag{1}$$

F represents the daily bunker consumption (tons/day), v is a sailing speed(knots); α and β are parameters which can get regression depending on real data. Although the value of often is assumed to third power in most extant researches, it vary with different ships, loading condition and weather condition etc. We will attain the formula depending on regression analysis for time charter. And the data collection is acquired by shipping intelligent system.

As in [1], we assume that the CO2 emission factor of marine fuel is equal to 3.17, thereby the average daily quantity of CO2 emission is equal to $3.17 F$. Assuming the price of bunker fuel unit price P , the average bunker daily cost is $F \times P$. Given days of travel time, and total CO2 emission and total bunker consumption cost is respectively equal to:

$$TCO_{2e} = 3.17F \times T \tag{2}$$

$$TC_b = F \times P \times T \tag{3}$$

As for (1), we can transform it into following form by taking the logarithm:

$$\ln F = \ln \alpha + \beta \times \ln v \tag{4}$$

Therefore, we can consider $\ln v$ as the independent variable and $\ln F$ as the response variable, and use the conventional linear regression method to attain parameters $\ln \alpha$ and $\ln \beta$.

This paper will discuss bulk cargo transport, and the data of sailing speed and bunker consumption on bulk cargo ships are given in Table 1, thereby we can attain bunker consumption-sailing speed relation function:

$$F = 0.0043 \times v^{3.358} \tag{5}$$

Assuming the sailing distance is nautical mile s^{sail} , and the travel time of T (day) is equal to:

$$T = \frac{s^{sail}}{24v} \tag{6}$$

For time charter, the travel time of round trip is limited. And we set the average speed of forward direction and backward direction v_f and v_d . T_l is the maximum allowable sailing time for

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.

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

$$T_f \le T_l \tag{8}$$

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.

$$TC_r = R \times T_c \tag{9}$$

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

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

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

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

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

Subject to

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

$$T_f \le T_l \tag{14}$$

$$24 \times T_f = s^{sail} / v_f \tag{15}$$

$$24 \times T_d = s^{sail} / v_d \tag{16}$$

$$v_l \le v_f, v_d \le v_u \tag{17}$$

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)

14.3	33	14.0	32
14.4	36	14.0	30
11.2	12	11.9	14
11.0	11	13.8	30
14.2	32	10.0	14
13.7	28	13.8	27
13.0	25	13.5	27
12.8	22	12.3	20
12.1	18	12.9	26
12.5	23	12.0	17

3.3   EMISSIONS AND COST MODEL OF FREIGHT TRAIN

Freight train covers two modes of traction, namely diesel locomotive and electrical locomotive. They have different forms in emission and cost. Freight train of diesel locomotive is closed related with speed when dragging, while electrical locomotive is strongly coupled with loading weight.

3.3.1   EXPANDING EMISSIONS AND COST OF DIESEL LOCOMOTIVE

As for diesel locomotive, [22] presented the energy consumption on some balancing speed during the progress of dragging.

$$E = \rho \times N_e \times t / 1000 \, (kg) \tag{18}$$

E is the energy consumption, ρ represents fuel consumption rate, N_e represents power, and t represents travel time(hour).

$$t = s / v_i \tag{19}$$

Wherein s is travel distance, v_i represents the speed on the condition of ith rotating speed. Table 2 showed the balancing speed, fuel consumption rate and power in different rotating speed for the type of trains DF7G.

Table 2 Rotating speed, balancing speed and fuel consumption rate, power

Rotating speed(r/min)	600	700	800	900	1000
Balancing speed(km/h)	35.04	47.88	61.33	72.91	87.61
Fuel consumption rate g(kW.h)	247.489	240.999	236.09	232.475	229.917
Power (kW)	500	760	1050	1450	1840

Source[22]

In terms of speed discretization, we introduce the set $\Phi = (\varphi_j(v_i), i = 1,...5, j = 1,2,3)$, and function $\varphi_j(v_i)(j = 1,2,3)$ stands for the respective value of ρ, N_e, t corresponding to some balancing speed v_i. Eq(18) and eq (19) indicated that train speed influence energy consumption by means of travel time, power and energy consumption rate also influence energy consumption, and all of which show that function $\varphi_j(v_i)$ act on carbon emission and cost.

We discretized eq(18) corresponding to five speed scenarios on the different rotating speeds and transform it as following:

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

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:

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

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

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

Objective function

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

3.3.2   EMISSIONS AND COST OF ELECTRICAL LOCOMOTIVE

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

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

Where M_{jm} is a train of weight operating along the segment d_m; R_{jm} is the train's resistance along d_m; η_{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].

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

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:

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

The cost of electric power is electricity price p_e multiplied by energy consumption. That is formulated as:

$$TC_e = EC_{jm} * p_e \qquad (27)$$

For electrical locomotive we could attain the value of carbon emission and cost depending on eq (26) and eq (27). And the objective function is

$$\min\{0.145 * M_{jm}^{0.6} * d_m(kWh); 0.315 * M_{jm}^{0.6} * d_m(kWh) \times p_e\} \qquad (28)$$

We will consider both diesel locomotive and electrical locomotive for freight train and compare the emission and cost with shipping.

IV. NUMERICAL EXPERIMENTS

4.1 LINES AND RELATED DATA

We assumed that the origin and destination are Shenzhen and Rotterdam, and there are two transportation modes of railway and shipping.

For shipping, the shortest sailing distance is approximate 10021 nautical miles by way of Suez canal, GIBRALTAR and English Channel in Figure 2 [30]. The average charter rate of Panamax bulk carriers of dwt 60000 is assumed 10250$/day according to period rate [31].For sailing speed, the ordinary v_f and v_d range from 10 to 20 knots and another low steaming ranges from 5 to 20 knotts; the value of T_l is less and equal to 28 days and T_c is no more than 60 days. The cubic power relationship of fuel consumption and speed is based on main engine, and marine diesel oil(MDO) supply main engine with energy, thereby we assume the average fuel price of is 900 USD/TON [32].

As for railway line, it is described in Figure 3, and the total length of travel line is approximate 15,000 kilometers.

- Scenario Ⅰ for diesel locomotive Average haulage weight is 5000 tons, and it needs 12 trains to transport 60000 cargoes. The average value of diesel fuel is 1.28USD/liter , p_d equivalent to 1.52USD/kg [33].

- 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.
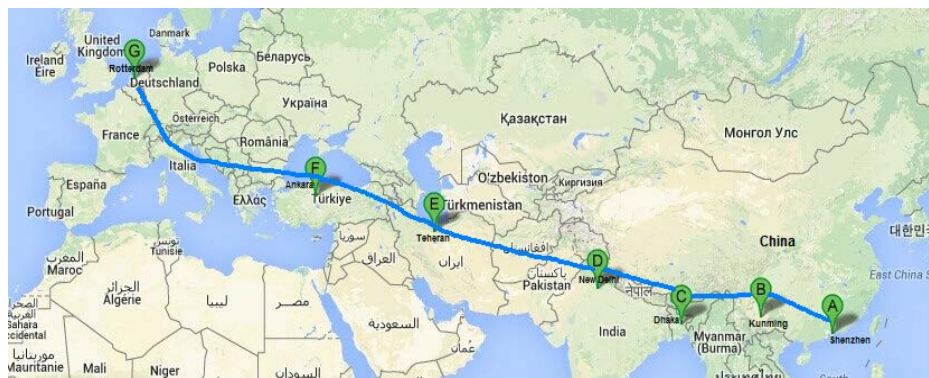

Figure 2 Shortest Shipping Route

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+006USD

(3) $T_l = 30$ Carbon dioxide: 5.6600e+003 tons, $v_f = v_d = 13.9$, total cost 2.2219e+006 USD

Once there is no constraint of T_l, and the shipping only satisfied the time constraint T_c for charter. The outcome for shipping is the same as $T_l = 30$, and that means the ship sail at average speed of 13.9 knots/ h for round trip.

The optimal results of emission and total cost subjecting to various T_l can be expressed in Table 3, and we know that there is a reciprocal relationship within the speed of forward and return until approaching to equal speed.

Further trends of CO2 emission and total cost according to v_f are showed in Figure 4 and Figure 5. It could be seen that CO2 emission and total cost have downward trend with decreasing speed of v_f, and the reduction of sailing speed can lead to less CO2 emission and total cost to some extent. The conclusion is the same as others extant researches.

Figure 6 and Figure 7 demonstrated that CO2 emission and total cost have a sharp decrease when v_f declined from a high value, and then both of CO2 emission and total cost decline slowly for relative low value of v_f. We could conclude that dropping from a high sailing speed has a more significant impact on CO2 emission and total cost.

Table 3 Optimal Results of Emission and Total Cost

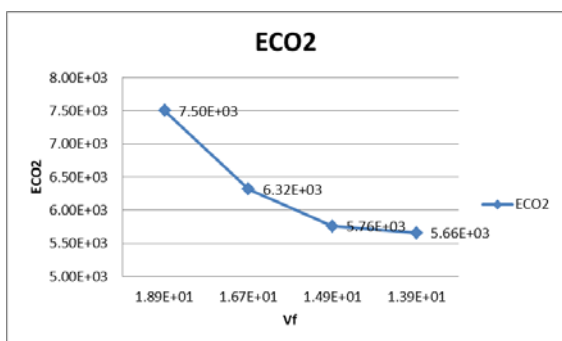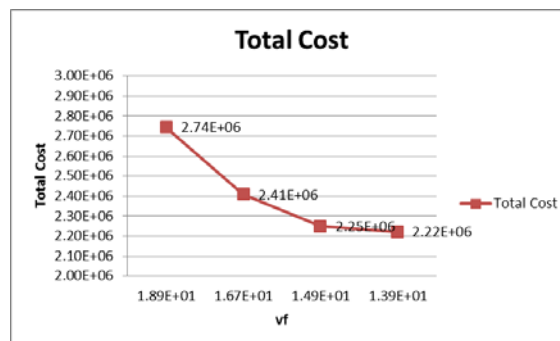| T_l (Day)	Emission(tons)	v_f (knot)	v_d (knot)	Total cost(USD)
22	7.5011e+003	18.9	10.9	2.7446e+006
25	6.3176e+003	16.7	11.9	2.4086e+006
28	5.7605e+003	14.9	13.0	2.2505e+006
30	5.6600e+003	13.9	13.9	2.2219e+006
Non*	5.6600e+003*	13.9*	13.9*	2.2219e+006*

Figure 4 CO2 emission and v_f
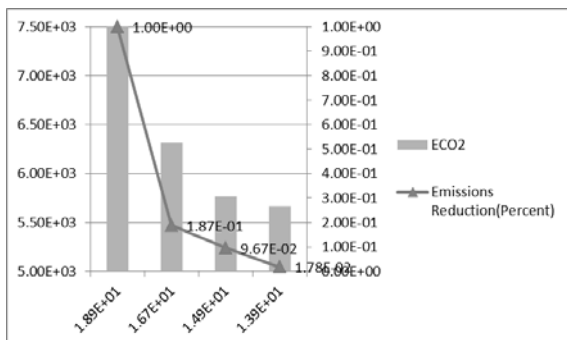

Figure 5 Total Cost and v_f
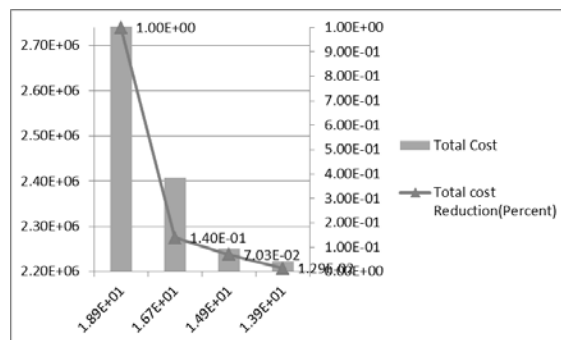
Figure 6 ECO2 Reduction Varying with v_f Figure 7 Total Cost Reduction Varying with v_f

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 13.9konts 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 $\varphi_j(v_i)(i = 1...5)$ and attained the final results in Table 5.

The running time reduced to aproximate7 days from 18days on account of increasing speed, while total CO2 emission and total cost increased continuously. The increase of total CO2 and total cost is not consistent with [18], and the main reason is that they assumed a train running on downward slopes which offer the possibility of reducing the power of trains and that of reducing energy consumption. However, it requires much more power to sustain high speed and need more energy consumption in ordinary railway condition. More energy consumption leads to high CO2 emission and cost, and it can be seen from a train of emission and cost. Therefore total emission and total cost will increase accordingly.

There is one limitation that it cannot conclude the relationship among running speed, power, haulage weight for diesel locomotive. We only assume the relationship of speed and power without considering the haulage weight. Once we reduced to 4000 tons for haulage weight, and it need 15 trains without changing other conditions.

We could compare the results of CO2 emissions and total cost within Table 5 and Table 6, and draw Figure 10 and Figure 11. Both blue lines represent total emission and total cost after haulage weight reduction, and both red lines demonstrate total emission and total with 12 trains for 5000 tons haulage weight of a train. It can be seen that total CO2 emission and total cost grow accordingly due to increasing times of train services from 12 to 15.

Table 5 Emission and Total Cost for Diesel Locomotive Corresponding to Five Discrete Speeds

Speed v_i (km/h)	35.04	47.88	61.33	72.91	87.61
Time (days)	1.7837E+01	1.3053E+01	1.0191E+01	8.5722E+00	7.1339E+01
Total Emission(tons)	2.0659E+03	2.2378E+03	2.3646E+03	2.7047E+03	2.8248E+03
Total cost(USD)	9.6622E+05	1.0466E+06	1.1059E+06	1.2649E+06	1.3211E+06
A train of emission(tons)	1.7216E+02	1.8649E+02	1.9705E+02	2.2539E+02	2.3540E+02
A train of cost(USD)	8.0519E+04	8.7219E+04	9.2157E+04	1.0541E+05	1.1010E+05

Table 6 Emission and Total Cost for Diesel Locomotive after Reduction of haulage weight

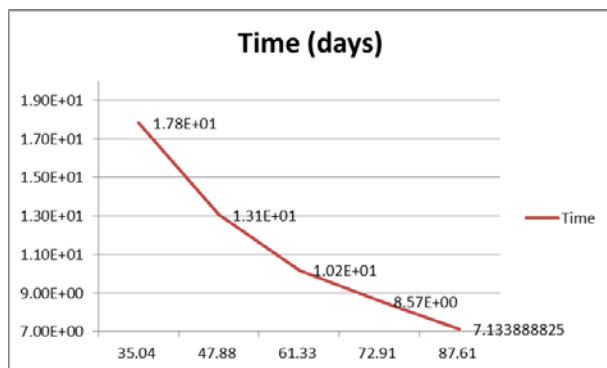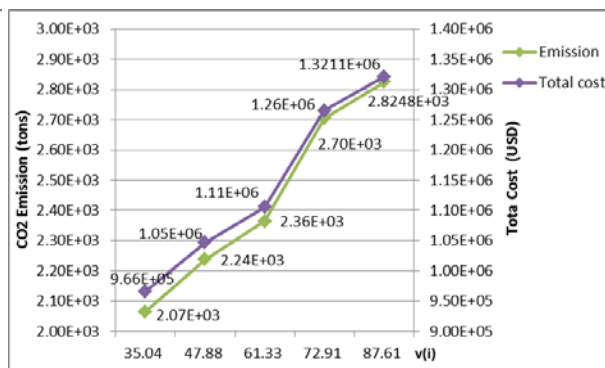| Speed v_i (km/h)	35.04	47.88	61.33	72.91	87.61
Time (days)	17.83675799	13.053467	10.19077124	8.572212317	7.133888825
Emission(tons)	2.5824E+03	2.7973E+03	2.9557E+03	3.3808E+03	3.5310E+03
Total cost(USD)	1.2078E+06	1.3083E+06	1.3824E+06	1.5812E+06	1.6514E+06

Figure 8 Running Time and v(i)
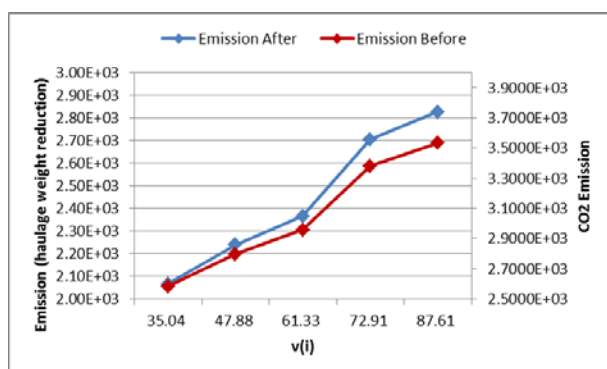

Figure 9 CO2 Emission and Total Cost for v(i)
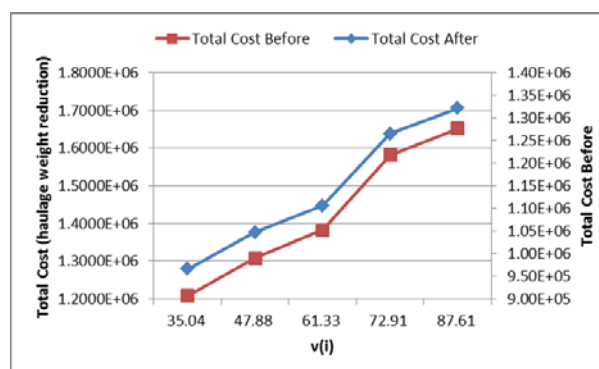

Figure 10 CO2 Emission Change

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+03tons, 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,

1.101.E+05 dollars when 5000 tons of haulage weight, but 3.6045E+02 tons and 1.1746E+05 dollars for electrical locomotive. For heavy-haul train, electrical locomotive need more power, therefore it is not an advised decision in long distance transport to some extent.

Table 7 CO2 Emission and Total Cost Depending on Gross Weight

Haulage weight (tons)	Train service (times)	Emissions (tons)	Total Cost (USD)	A train of Emission (tons)	A train of Cost (USD)
5000	12	4.3254E+03	1.4095E+06	3.6045E+02	1.1746E+05
4000	15	4.7292E+03	1.5411E+06	3.1528E+02	1.0274E+05
3000	20	5.3059E+03	1.7290E+06	2.6530E+02	8.6450E+04
2000	30	6.2402E+03	2.0334E+06	2.0801E+02	6.7781E+04
1500	40	7.0012E+03	2.2814E+06	1.7503E+02	5.7036E+04
1200	50	7.6549E+03	2.4944E+06	1.5310E+02	4.9889E+04

4.2.3 COMPARISON AND ANALYSIS

We have determined two solutions for shipping: solution I CO2 emissions 5.6600e+003 tons, total cost 2.2219e+006 USD, average sailing speed of 13.9konts, $T_c = 60$, $T_l = 30$; solution II CO2 emissions 2.1757e+003 tons, total cost 1.2327e+006 USD, average sailing speed of 9.3 knots, $T_c = 90$, $T_l = 45$.

We know that average sailing speed declined 33 percent, however, total CO2 emissions declined approximate 62 percent, and total cost declined 44.5 percent. The reduction of sailing speed led to significant decrease of total CO2 emissions and total cost at the expense of time relaxation, and delivery date extend 15 days.

For diesel locomotive, total CO2 emission of 12 trains (5000 haulage weight of a train) range from 2.0659E+03tons to 2.8248E+03 tons; total cost range from 9.6622E+05 USD to 1.3211E+06; running time range 18 days to 8 days at different speed. Compared with shipping, total emissions and cost is far less than solution I of shipping, and it has a decided advantage over solution II. Running time shortened greatly, and the longest time is no more than 18 days. If haulage weight of a train reduced to 4000 tons, it requires more train service, 15 trains. Total emission of 15 trains range from 2.5824E+03 to 3.5310E+03 tons; total cost range from 1.2078E+06 to 1.6514E+06. Compared with shipping, total emission and total cost is less than solution I of shipping evidently; total CO2 emission and total cost has no advantage over solution II of shipping except for less cost at speed of 35.04km/h.

It shows that heavy-haul train of diesel locomotive will be an appropriate substitution for shipping in most situations considering environment and economy on some leg.

For electrical locomotive, total CO2 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 CO2 emission, and the right vertical axis shows total cost. And bar charts demonstrates total CO2 emission, polyline shows total cost.

Wherein, both dark gray bars represent total CO2 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 CO2 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 CO2 emission baseline of solution Ⅰ and solution Ⅱ for shipping. It is evident that all of freight train emitted less CO2 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.
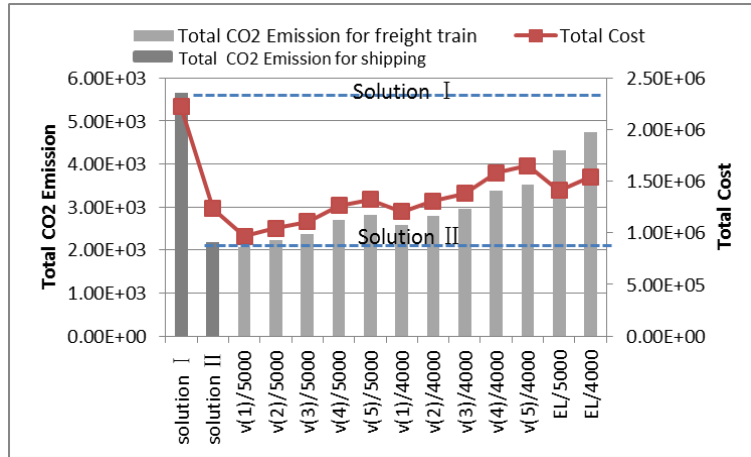
Figure 12 Results of Comparison between railway and shipping

Overall, whether diesel locomotive or electrical locomotive total CO2 emissions and total cost are far less than solution Ⅰ of shipping, and heavy-haul train of diesel locomotive has an environmental and economic advantage over solution Ⅱ of shipping when less than 50km/h. However, solution Ⅱ of shipping demand more sailing time, and it is not applicable under strict time constraint.

V. CONCLUSIONS

This paper offers an attempt on comparative analysis of freight train and shipping in CO2 emission and cost base on ITS, during which we find that freight train, especially heavy-haul train, is more economic and environmental than shipping to some leg. Freight train will be a good substitute of time charter in most cases unless the delivery date is free enough. Because the extended delivery date provides the possibility of reduction in sailing speed, and speed reduction cause less consumption, less CO2 emission and less cost.

Meanwhile this paper shows that diesel locomotive has considerable advantage over electrical locomotive in heavy-haul transport on long distance, for electrical locomotive need much power to haul the train, and emitted more CO2 emission and more cost than diesel locomotive. Although electrical locomotive is not better than diesel locomotive in CO2 emission and cost, freight train means reduction of CO2 emission and cost compared to shipping. It may be realistic to shift shipping to railway on some leg, such as trans Eurasia transport.

In addition, intelligent transportation across all modes of transport will be providing more effective and environmental decision support in future.

VI. ACKONWLEDGEMENT

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