January-February 2020
ISSN: 0193-4120 Page No. 12640 - 12649

Minimizing Fuel Emissions and Cargo Travel Time using Green Logistics

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Abstract:
Sustainable transportation has become a critical issue for conserving the environment (ozone depletion, acid rain, and smog). Mass cargo transporters are in urge to find solutions for decreasing emissions (sea and road) and to improve the cargo transit time, by implementing green logistics. This study develops a decision-making model, which provides smart results by multi-proportion principle (60/40, 70/30) from source to destination. Based on the data, the model estimates the emission quantity and the time required to reach destinations. The findings show that increasing the usage of ships for cargo transit services has a positive impact on the emission of an entire supply chain (i.e. CO_2 emissions reduced to 25% of the original value).

***Keywords**: decision-making models, fuel emission optimization, green logistics, mass cargo transporters, sustainability.*

1. INTRODUCTION

Sustainable practices are defined as ‘development that meets the needs of the present without compromising the ability of future generations [1]. It is also described as ‘the ability to smartly use natural resources for manufacturing by creating products and solutions that satisfy both economic and social objectives [2].

Sustainability strategies in logistics needs formulation, by considering the health of young society. The strategy may also include the measurements of pollution in every process, habitat protection, eco-friendly energy, material inclusion, and product redesign [3]. Eventhough transport industry is responsible for greenhouse gas emissions (8-10%) globally, sustainability strategies adoption using: traffic congestion, urban road conditions, lane width, limit of permissible trucks within urban zone, allowable speed in peak and non-peak times, the type of the pollutants emitted can mitigate the emissions [4] gradually.

The objective of this research is to identify the solutions for the research question: what are the effective measuring practices, to validate a sustainable transport? The sea and road transport is considered for this study whereas the air transport is ignored [5] due to high cargo transit-cost per tonne-kilometre.

2. LITERATURE REVIEW

A. Green Logistics

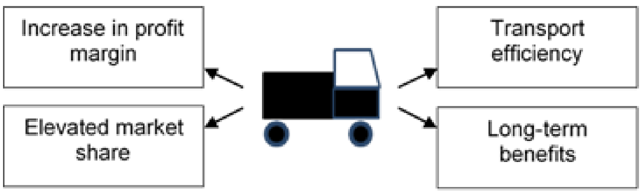

Figure-1: Effects of green logistics.

Green logistics was a tool for establishing environmental & economical goals, formulated by sustainablity [6]. It was defined as the practice of validating each micro-decision in the context of product mobility within eco-friendly sphere [7]. Green logistics comprised of the elements namely (Fig.1): training truck drivers, optimising routes, eliminating partial-filled truck trips, operating in low fuel consumptions, reducing hydrocarbon emissions, bio-compatible packaging, and advocating third-party logistics.

Logistics department also had to: use appropriate vehicle (bikes/light vehicles/trucks) in urban zones, evaluate its transporters sustainable performance, contributing suggestions to transporters for enhancing sustainability. The greening of logistics would decrease emissions by altering transport demand, and vehicle use [8].

Moreover, organisations were converting environmental problems into business opportunities by reinventing green logistic initiatives [9]. The sustainable dimension added to green logistics [10] had contributed to the evolution of products, processes, technologies, and applied business models.

Table-1: Potential dimensions of green logistics

S No.	Green term	Potential dimension	References
1.	Green logistics	Forward and reverse logistics	Text Book: Green Logistics (McKinnon et al. 2010)
2.	Green logistics	Environmentally friendly and efficient transport distribution system	
3.	Sustainable logistics	Green production and marketing consumption	Article (Rodrigue et al. 2001)
4.	Green logistics	Green purchasing, green materials, management and manufacturing, green distribution, marketing, and reverse logistics	Article (Business world, 2017)

Green initiatives could shape the purpose of green logistics [11]. Initiatives included were: environmental certifications [12], environmental education for employees, formulating corporate greenhouse gas emissions targets, determining waste recycling methods of logistic materials (Tyres, glass, cartons), and raising awareness of energy use.

B. Fuel emission and its influencing factors

Vehicle fuel emissions were defined as the amount of residual gases emitted while propelling a vehicle for a unit distance [13]. The main residues emitted were: carbon monoxide (CO), carbon dioxide (CO2), nitrous oxide, (NOX) volatile organic compounds (VOC), and particulate matters (PM) among other elements. Emission control agencies promoted a goal for: mitigating mono-oxides, dioxides; and particulate matters. The emissions attributed to freight companies are around 8% of global CO2 emissions, whereas factory and warehouse emissions contribute approximately 2%. Moreover, the influencing factors [13] of vehicle fuel emissions were: dead weight of the vehicle, fuel economy, the payload of a vehicle, idle running hours and fuel use.

Dead weight of vehicle referred to: engine weight, mass of chassis, tyres, differentials, and miscellaneous equipment such as tools, spares, and seats. The dead weight of a vehicle had a key influence on its emissions, as it is directly proportional to fuel consumption. It would be reduced effectively by automobile manufacturers, by adopting carbon fibre or aluminium alloy metals into the newer models.

Fuel economy was defined as the ratio of distance driven by a vehicle to the unit quantity of fuel intake; and it was measured in kilometre per litre or miles per gallon. Fuel economy was influenced by multiple key parameters such as driving behaviour, traffic density, road surface conditions, tire inflation, and average speed.

Payload of vehicles was defined as the gross quantity of product or number of passengers transported in a vehicle. This is a seasonal variable, as it has variable proportionality with fuel emission, unlike the dead

January-February 2020
ISSN: 0193-4120 Page No. 12640 - 12649

weight of vehicles. Moreover, payload is a revenue-generating variable.

Idling hours was defined as an engine running time of a static vehicle. It may be attributed to warming time for the engine, waiting time in traffic signals, or running the engine while parked. It contributed to larger scale (20 to 30%) of vehicle emissions. Lower grade fuels used was a contributing factor for fuel emissions by: discharging greenhouse gases into atmosphere, whereas cleaner fuels such as compressed natural gas, petrol, and electricity (electric or hybrid vehicles) were preferred for minimizing emissions.

B. Fuel emission Terminology

i) Total Emission of trucks $(TE)^t$

The total emission of trucks comprises three sub-elements: vehicle emission during preliminary starting time (E_{start}), vehicle emission when the engine is at a high temperature due to continuous running or parked in high-temperature areas (E_{evap}), and vehicle emission while moving the vehicle in a fully-loaded condition (E_{hot})L. The total emission is:

$$(\mathbf{TE})^t = E_{start} + E_{evap} + E^L_{hot}$$

ii) Total emission of ships $(TE)^s$

As stated before, the total emission of ships comprises three factors: the notations used for these factors are EC for cruising emission; EM for manoeuvring emission; and EH for hoteling emission. Therefore, the total emission is:

$$(\mathbf{TE})^s = EC + EM + EH$$

iii) Unit emission demand of ships and trucks (UE)

The unit emission demand of ships and trucks is defined as the amount of emissions (CO, CO_2, NO_X, VOC, and PM) released into the air for transporting a tonne of pay load, for a unit distance of 1 km in g/T/km (i.e., grams/Tonnes/Kilometre).

The formulae for calculating both truck and ship unit emissions are:

$$UE^t = (TE^t/TW^t)$$

$$UE^S = (TE^S/TW^S)$$

iv) Emission equivalence of ships and trucks

Emission equivalence is a relative term used to compare the emissions between two modes. We particularly consider a container ship and a BS-III truck. Thus, emission equivalence is the amount of emissions emitted from a truck equivalent to 1 kg of ship emission. A decision-making model for associated land and sea routes (DEALS) is then used to determine the emission equivalence between these two modes.

v) Cargo travel time

Cargo travel time is defined as the time period required for cargo to complete a unit of distance (i.e. 1 km). Cargo can be carried either by truck, ship, or a combination of both. It is measured in seconds per kilometre or minutes per kilometre.

3. DATA COLLECTION

Data for analysis were extracted from the World Shipping Council online database [14] for a commercial year. The survey includes the twenty global exporting countries, which were the major contributors to greenhouse gas emissions. Their respective cargoes included: electronic goods, food grains, fertilisers, and coal transported between source-rich countries and demand regions. The cargo type acts as a reference for calculating the emissions from trucks and ships during transportation. Emissions from ships and trucks are compared and the optimal use of both modes are measured and validated using DEALS model.

4. METHODOLOGY

The process flow of this model is captured in the following figure (Fig.2). Figure depicts the schematic view of the DEALS model.

S. No	Data description
1.	Road freight mode factors: Emissions of vehicles when the engine is at cold condition (start), hot condition (hot); emissions due to fuel evaporation while parked in the open in hot temperatures, and

January-February 2020
ISSN: 0193-4120 Page No. 12640 - 12649

	at fuel filling times where the tank is opened; average speed of a vehicle in different regions
2.	Marine freight mode factors: *Cruising emission*: While running at high speeds between two harbours at maximum cruising speed (80% of maximum speed) *Manoeuvring emission*s: Vessels runs at moderate or low speed when the vessel changes direction or enters a narrow channel; *hoteling emission*s: Emissions when vessel is docked at berth, but runs generators for essential on-board systems
3.	Optimised mode output (road and marine modes in ratios): The DEALS provides an optimised output with the following options: *minimising emissions, available critical paths/route, customer demands: speed of the cargo to be delivered, and cost and care for the cargo*; based on these options, cargo transporters should determine the proportion of ship and truck utility to deliver goods

Table 2. Decision-making model for associated land and sea routes (DEALS): inputs and output

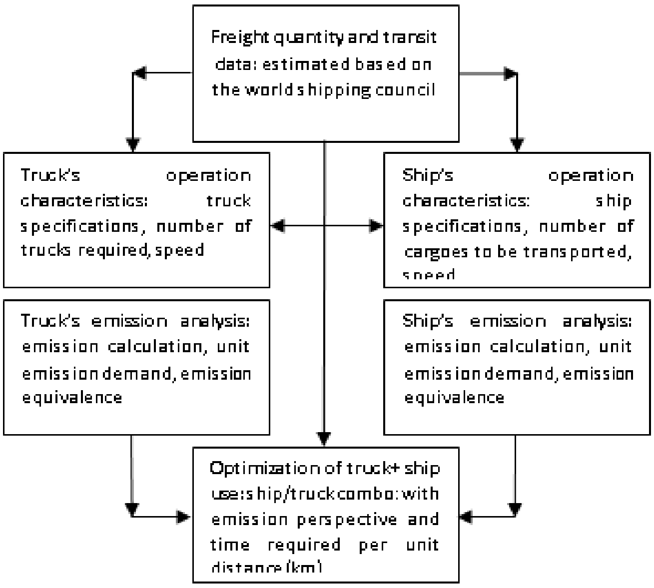

Figure 2: Schematic view of the decision-making model for associated land and sea routes.

Table 2 displayed the technical parameters for the DEALS inputs for both road freight mode and marine freight mode. The output row specified the balanced use of ship and trucks

5. DATA ANALYSIS

Data analysis was done to calculate the optimal use of multi-modes to transport the cargo for reducing emissions and decreasing transport time. The DEALS calculated the emissions (CO, CO2, NOx, VOC, and PM) for container ships and two-axle trucks (BS-III) based on primary parameters (fuel usage, average speed, and payload). The formulae for calculating emission of trucks were derived from transport Research Laboratory project report [15] and ship emissions were derived from [16]. Based on the emission output, further values of unit emission demand, ship emission equivalency, the optimal use of ships and trucks relative to emission and transport time were calculated and plotted.z

Table 3. Specifications of example ship and truck for the purposes of this study.

S NO	Technical data	Ship specifications	Truck specifications
1.	Vessel/vehicle type	Two-stroke steam engine	Two-axle six-wheeler (BS-III)
2.	Average speed	37 to 46.3 kmph	12 to 20 kmph
3.	Gross weight (tons)	66,677	25
4.	Payload (tons)	161,020 (5,714 containers)	22 (one container)
5.	Fuel used	Bunker and diesel oil	Diesel oil
6.	Fuel consumption: (tons/day)		
	At sea At manoeuvring At port	229.3 165.3 19.2	190.385 litres/day

Table 3 showed the technical specifications of a ship and a truck used for this study. The ship considered for this model was *OOCL San Francisco* and the truck was the BS-III two-axle truck.

EMISSION FORMULAE OF TRUCKS

$(TE)_t$= E(hot) +E(Start)+E(evap)--(1)

$E(hot)_L$=LC*EM(hot-U)------------(2)

(For LC, please refer to the Appendix for formulae)

EM (hot-u) =RG*E(hot-u) -------(3)

(For EM (hot-U), RG please refer to Appendix-I.)

In the above equations, $(TE)^t$ is the total emission of trucks; $E(hot)_L$ is the emission of trucks in loaded condition in g/km; LC is the load correction factor; EM(hot-U) is the emission of unloaded trucks with the road gradient function in g/km; RG is the road gradient; and E(hot-U) is the emission of unloaded trucks with zero road gradient in g/km.

EMISSION FORMULAE OF SHIPS

$(TE)^s$ = EC*+EM*+EH*----(4)

(For *, the formulae are given in Appendix-I.)

In the above equation, $(TE)^s$ was the total emission of ships; EC was the cruising emission in kg/km; EM was the manoeuvring emission in kg/km; and EH was the hoteling emission in kg/km.

The unit emission demand of ships and trucks referred to the pulling capacity of cargo by both modes and the amount of emissions associated with it. These graphs were plotted in figure (Fig.2a). The

January-February 2020
ISSN: 0193-4120 Page No. 12640 - 12649

ship's emission was exponentially lower in relative to truck emission for all pollutants and they were in proportion of one-twentieth of truck's emission for Carbon dioxide (CO_2) and particulate matter (PM); but for other pollutants (CO, VOC & NO_X) it was more than one fiftieth.

Table-4: Total Emission Calculation for Trucks & Ships

S no	Emission	Emission parameters for trucks	BS III trucks	Emission parameter for	Container ship (g/km)
1	CO	E(hot-U) in g/km	4.825	EC	66.95
		RG	1.1648	EM	14.75
		EM (hot-U) in g/km	5.62016	EH	0
		LC	1.305		
		$E(hot)_L$ in g/km	7.3343		
		E(Start) in {g/Cold start}	6		
		$(TE)^{t1}$	**15.3343**	**TE**	**81.7**
2	CO_2	E(hot-U) in g/km	1045.95	*C*	497088
		RG	1.12389	*M*	248032
		EM (hot-U) in g/km	1175.53	*H*	74565
		LC	1.534		
		$E(hot)_L$ in g/km	1803.26		
		E(Start) in {g/Cold start}	500	***E***	**819685**
		$(TE)^{t2}$	**2303.26**		
3	NOx	E(hot-U) in g/km	13.9704	*C*	1084.2
		RG	1.0887	*M*	474.1
		EM (hot-U) in g/km	15.2095	*H*	106.01
		LC	22.245		
		$E(hot)_L$ in g/km	-5		
		E(Start) in {g/Cold start}	**17.245**	***E***	**1664.31**
		$(TE)^{t3}$			
4	VOC	E(hot-U) in g/km	3.122	*C*	13.2
		RG	0.0304	*M*	65.6
		EM (hot-U) in g/km	0.094	*H*	9.32
		LC	1.01274		
		$E(hot)_L$ in g/km	0.0951		
		E(Start) in {g/Cold start}	-5		
		E(eva, VOC) in g/km	13651.2	***E***	**88.48**
		$(TE)^{t4}$	**13653.71**		
5	PM	E(hot-U) in g/km	0.9449	*C*	388.35
		RG	1.16585	*M*	195
		EM (hot-U) in g/km	1.1016	*H*	29.25
		LC	1.40548	***E***	**612.475**
		$E(hot)_L$ in g/km	1.54827		
		E(Start) in {g/Cold start}	0.6		
		$(TE)^{t5}$	**2.14827**		

January-February 2020
ISSN: 0193-4120 Page No. 12640 - 12649

NOTE: CO: CARBON MONOXIDE; CO_2: CARBON DIOXIDE; NO_X: NITROUS OXIDE; VOC: VOLATILE ORGANIC COMPOUNDS; PM: PARTICULATE MATTERS

Table 4 calculated the total emissions of ships and trucks based on the formula derived from article [15][16]. The total emissions of ships and trucks are discussed in section 2.3 (terms used in Fuel emission) of this article.

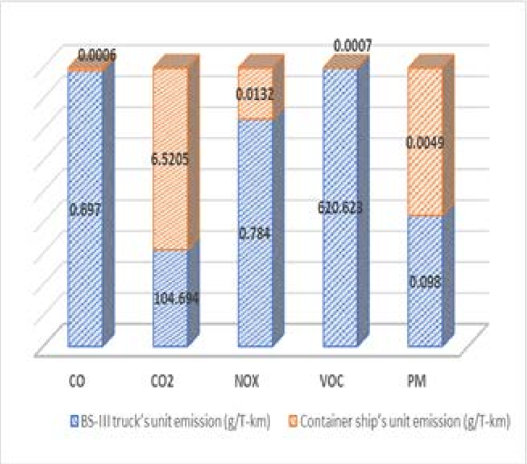

Figure-2a: Unit emission demand of ship and trucks.

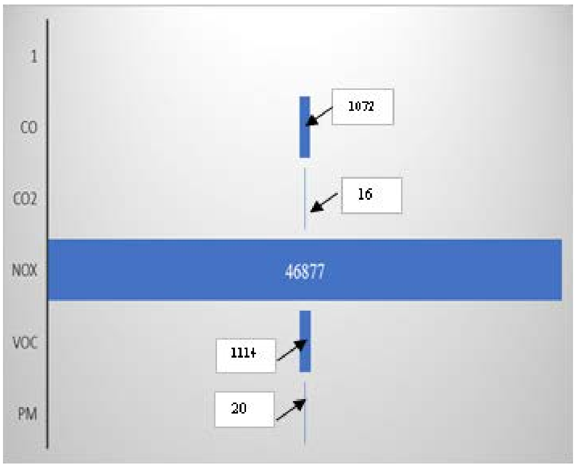

Figure-2b: Trucks emissions equivalency with unit emission (1 Kg) of ship

The above graph (Fig.2a) derives a relation of unit emission demand between truck and ship emission. Moreover the next graph (Fig.2b) estimated the maximum emission of trucks [Nitrous oxide -46877 kg] for equivalent 1 kg of ship's emission. But, the trucks were considered as the lowest emitter of carbon dioxide (16 kg) for ship's unit emission (1 Kg).

UNIT EMISSION OF A TRUCK {KG/T/KM}

For BS-III trucks

A = {Total emission of a truck/total weight of a truck}

UNIT EMISSION OF A CONTAINER SHIP {KG/T/KM}

For a container ship

B = {Total emission of a ship/total weight of a ship}

The following table (Table 5) served as a ready reckoner to provide a deviant perspective between two modes (ships and trucks). The second column presented proportions (60/40 to 95/5) of ships and trucks, sharing a same route between the source and destination. In the third column, the emission distribution details were tabulated; columns four to eight illustrate the emissions of CO, CO2, NOx, VOC, and PM separately. Column nine shows the time taken to reach the destination by the various combinations of the two transportation modes.

Table 5. Optimising parameters (emission and time duration) of ship-truck combination

S NO	Bimode utility (ship: truck)	Pattern combination	CO in g/km	CO_2 in g/km	NO_X in g/km	VOC in g/km	PM in g/km	Time taken per km (minutes)
1	60:40	SHIP (N^1)	49.0	491811	998.6	53.1	367.5	0.7826
		BS-III truck (M1)	6.1	921.3	6.9	5461.5	0.9	1.2
		Total emission (N^1+M^1)	**55**	**492732**	**1005**	**5515**	**368**	**1.9826**
2	70:30	SHIP (N2)	57.2	553779.5	1165	61.9	428.7	0.9130
		BS-III truck (M2)	4.6	691	5.2	4096.1	0.6	0.9
		Total emission (N2+M2)	**62**	**574470**	**1170**	**4158**	**429**	**1.813**
3	80:20	SHIP (N3)	65.4	655748	1331.4	70.8	490	1.0434
		BS-III truck (M3)	3.1	460.7	3.4	2730.7	0.4	0.6
		Total emission (M3+M3)	**68**	**656209**	**1335**	**2802**	**490**	**1.6434**
4	90:10	SHIP (N4)	73.5	737716.5	1497.9	79.6	551.2	1.1739
		BS-III truck (M4)	1.5	230.3	1.7	1365.4	0.2	0.3
		Total emission (N4+M4)	**75**	**737947**	**1500**	**1445**	**551.4**	**1.4739**
5	95:5	SHIP (N5)	77.6	778700.8	1581.1	84.1	581.9	1.2391
		BS-III truck (M5)	0.8	115.2	0.9	682.7	0.1	0.15
		Total emission (N5+M5)	**78**	**778816**	**1582**	**767**	**582**	**1.3891**

RESULTS

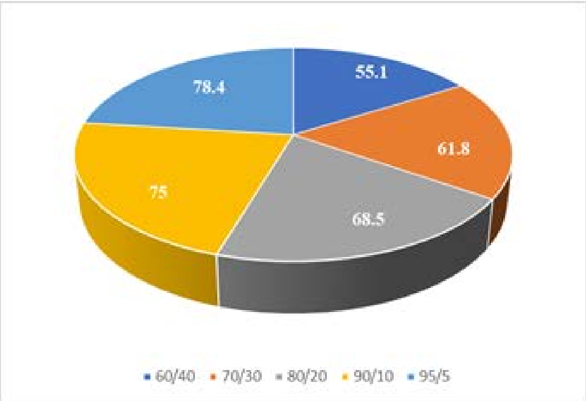

Figure-3: Total CO emission (g/km) of Bi-modes

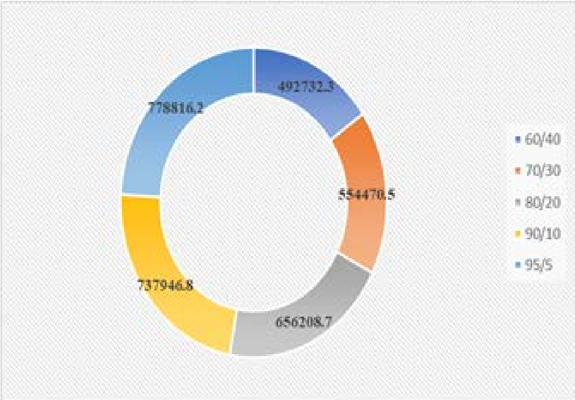

Figure-4: Total CO_2 Emission (g/km) of Bi-Modes

January-February 2020
ISSN: 0193-4120 Page No. 12640 - 12649

The above plots (Fig.3 and Fig.4) measures the differences in emissions (CO and CO_2) for variable utility proportions (60:40, 70:30 et al). Both graphs signify that, as the ships' contribution increases, the emissions are reduced. Based on the above statement, the operating relationship of emissions is E= C X S, where E is the emission of multi-modal transit, C is the coefficient constant, and S is the utility of ships in the multi-mode transit

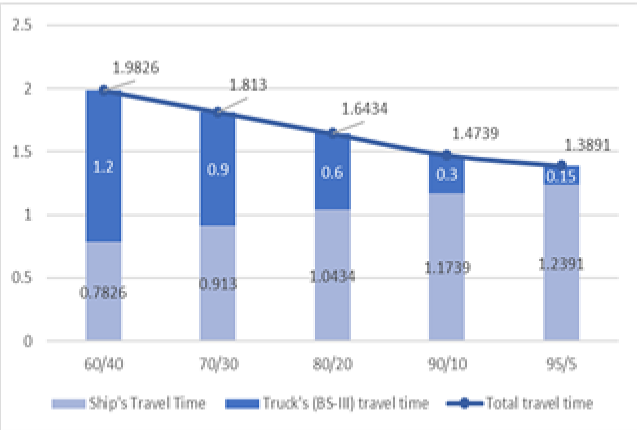

Figure 5. Travel Time required by ship and trucks (BS-III) to complete a unit distance (1 km).

The adjacent graph (Fig. 5) establishes the relationship between truck and ship's travel time for completing a unit distance (1 Km). Moreover, as the ship contribution proportion increased, the travel time of bi-mode gradually decline steadily (30%).

6. DISCUSSION

The tabulated values (Table 4) shows that CO, PM, and NOx emissions develop a linear relationship with the ship and truck combination. With trucks, the CO emission develops an equation with higher constant value:

$$Y= (0.000820\ X_1+67.076)$$

where **X1** is the monoxide (CO) emission of a BS-III truck and **Y** is the optimised multi-mode (ships and trucks) transit. But the estimate of Volatile compounds (VOC) and dioxides (CO_2) between trucks and ships establishes the dynamic relationship and it is:

$$Y= (5.8166 \times 10\text{-}6)X_2+53)$$

where X2 is the CO_2 emission (BS-III) of trucks and *Y* is the optimised multi-mode (ships and trucks) transit. The inferences that can be made from the above equations are: X1 and X2 are the dependent factors which depend on Y. Moreover, it exhibits direct proportionality with optimal multi-mode transit. Logistic planners can provide precise arrival date for end users based on the graph (Fig.5). The values provided in the graph (Fig. 5) are calculated based on the average speed of trucks.

7. CONCLUSION

The outcomes of this model (DEALS) have given the effective measuring methods for validating the sustainable transport. The container ship and two axle trucks are considered in this model. It tried with dynamic proportions of ship and trucks. The first mile and last mile connectivity are executed with trucks and the rest of the cargo transit with container ships. The average speed of trucks is measured in Indian road context. The speed of trucks is time-sensitive (peak/non-peak times) and the simulation is executed on non-peak times (0600PM to 0600AM). The same model can be extended for multiple combinations (air+trucks, air+ rail) as well as with cargo ships. It will help the end-user to estimate the time of delivery including the port clearance time.

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