Capacity sharing among truck owners: A collaborative approach to overcome overloading

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Abstract
Capacity shortage is a serious problem for the Indian trucking industry for which overloading is followed as a solution by the carriers. However, this practice is legally banned as it gives rise to many other problems. A collaborative approach has been proposed to overcome capacity shortage problem without overloading.

Keywords: Capacity exchange price, Overloading, Collaboration.

INTRODUCTION

A strong logistic sector serves as the backbone for the overall economic development of any country. In a vast country like India, it is vital to have an efficient logistic system, which enables connecting the remote parts of the country. India's economy is growing at a brisk pace. It has been predicted that in coming years, there will be a huge boom in both manufacturing as well as retail sector in the country as shown by Deloitte survey report [1]. To add to that India has a very large agricultural sector, with most of the agricultural land being located far away from the main market and consumers. For proper distribution of goods manufactured or produced, the country should have a highly efficient logistic system.

In India freight movement is carried out through all three means of transport, namely, road, water and air. However, roads are the most preferred means of freight movement, as they are much cheaper as compared to the other means of transport. The roadways carry a higher percentage of freight as compared to rail, as every part of the country is connected by roads. There are over 40lakhs trucks and lorries as on 31st March, 2012 operating across the country [2]. This number is gradually increasing at an enormous rate. Though the trucking industry is large, it is totally fragmented and unorganized. About 75% of the trucking sector is owned by those people, whom we can call micro-truck owners [3] having less than five trucks. With such less number of trucks, a very small amount of capacity is available with them. Due to this reason, these truck owners cannot take large orders. In case a truck owner gets a large order, he has to resort to overloading in order to carry out the order. Overloading decrease the life of the truck and increases the maintenance cost of the truck.

RELATED WORK

Collaborative logistics (CL) has become an important part of supply chain management studies. CL can be broadly classified into two classes, namely, horizontal and vertical collaborative logistics. Vertical collaborative logistics traditionally refers to linkage between the members at different level of the same supply chain in order to improve the performance of the supply chain. Horizontal collaborative logistics on the other hand has the collaborating partners working at the same level of supply chain, performing almost similar type of functions as shown by Cruijssen et. al. [4].The concept of horizontal collaborative logistics has been used in maritime and aviation industry, which is well documented. However, Leitner et.al. showed in their paper that, it has not been used in road transport industry to that extent[5]. Horizontal collaboration in logistics can be achieved through sharing of orders, sharing of information and sharing of resources. Cruijssen and Salomon [6] have shown that by sharing of information about their individual orders can allow the transport companies to reduce up to 15% of their total transportation costs and sometimes even more.

Literature exists, which shows the use of this concept in Mari-time and aviation industry. Aggarwal and Ergun [7] developed a mixed integer programming model for the carrier collaboration in ship liners. The authors developed a multi commodity flow problem using the concept of network flow. A similar model was developed by Houghtalen et.al. [8] and applied for carrier collaboration in airlines. They formulated the problem as multi commodity flow problem. The utilization of unused spaces for less-than-truck load through carrier collaboration has been taken up by Zhou et. al. [9]. They considered two collaborative modes, namely, strategic alliance and full collaboration and tried to identify the factors which affect the profit and thereby the collaborative decisions.

PROBLEM BACKGROUND

The high fragmentation of the trucking industry results in various problems for the truck owners. The micro-truck owners have to compete for getting orders with other micro-truck owners. With less number of trucks, capacity shortage becomes a major problem for these truck owners. These truck owners are dependent on transporters (brokers) to get orders, which also don't have any certainty of arrival. These problems cause the truck owners to accept orders more than their capacity and in order to fulfil the order they have to resort to overloading.

MATHEMATICAL MODEL

In this study a collaborative practice of capacity sharing among carriers has been proposed, which would not only allow them to accept orders larger than their capacity but also fulfil the order without overloading. The concept of capacity exchange price is being used in trucking industry for the first time in this paper. Two mixed integer linear programming mathematical models using network theory have been formulated. The first model depicts the present scenario in the Indian trucking industry considering overloading and the second model has been formulated using the concept of capacity sharing and collaboration. A comparative study has been carried out between the two practices on the basis of profit earned. The development of the mathematical models is based on the following notations and assumptions:

Notation:
Sets and indices:
E- Set of all edges in the network,
Eo- Set of overloaded edge,
m,l$\in$ L- Set of carriers,
$d_{ij}^{l} \in$ D- Set of demand,
t$\in$ T- Set of Trucks,
K_e - Set of capacity of each edge,
i – Origin node in the flow,
j- Destination node in the flow,
γ- Fraction of capacity of each node allocated to each carrier,
R- Revenue per unit flow in each edge,
Ro- Revenue per unit overloaded flow in each edge,
Ce- Capacity exchange price,
Cap- Capacity of each truck considered to be 9 Tons.
d_{ij}^{l} - Demand of carrier from node i to node j,
Decision variables:
$x_{ij\in E}^{l}$ - Flow from ith node to jth node for carrier l, (i, j) $\in$ E, l $\in$ L,
$x_{ij\in E^o}^{/l}$ - Excess flow from ith node to jthnode for carrier l while considering capacity sharing, (i,j) $\in$ Eo, l$\in$ L,
$x_{ij\in E^o}^{ol}$ - Excess overloaded flow from ith node to jthnode for carrier l, (i,j)$\in$ Eo, l$\in$ L,
$x_{ij\in E^o}^{/m}$ - Excess flow from ith node to jthnode for carrier m, while considering capacity sharing (i,j) $\in$ Eo,
m$\in$ L,
X^{l}_{ij} - Binary number when carrier l has demand more than the capacity of the edge,
$X_{ij}^{/l}$ - Binary number when carrier l has demand less than the capacity of the edge.

Assumptions:
All the carriers have same no. of trucks, 5 trucks.
All the trucks return on the same day to the carrier's depot.
There is full information sharing among all the carriers.
Demand is deterministic.
Objective function:
Model 1: Considering overloading

Maximize

$$\text{Profit}=\sum_{t\in T}\sum_{(i,j)\in E} x_{ijt}^{l} * R + \sum_{t\in T}\sum_{(i,j)\in E^o} x_{ijt}^{ol} * R^o) * X^{l}_{ij} - Fuel\ Cost \quad (1)$$

Constraints

$$\sum_{t\in T}\sum_{(i,j)\in E} x_{ijt}^{l} - \sum_{t\in T}\sum_{(j,i)\in E} x_{jit}^{l} \le 0, \quad \forall (i,j),(j,i)\in E \tag{2}$$

$$x_{ijt}^{l} \le Cap, \quad \forall l\in L,(i,j)\in E \tag{3}$$

$$\sum_{t\in T}\sum_{(i,j)\in E} x_{ijt}^{l} + \sum_{t\in T}\sum_{(i,j)\in E^{o}} x_{ijt}^{ol} \le \gamma K_e, \quad \forall l\in L,(i,j)\in E^{o},(i,j)\in E \tag{4}$$

$$\sum_{t\in T}\sum_{(i,j)\in E} x_{ijt}^{l} + \sum_{t\in T}\sum_{(i,j)\in E^{o}} x_{ijt}^{ol} * X^{l}{}_{ij} \le d_{ij}^{l}, \quad \forall l\in L,(i,j)\in E^{o}, d_{ij}^{l}\in D,(i,j)\in E \tag{5}$$

Equation (1) gives the objective function in which profit has been maximized considering the practice of overloading. The flow balance across nodes has been taken care of by equation (2). The flow balance equation has been considered only when carriers have to pass through the depot of other carriers, eg. when carrier A has to move through the depot of carrier B or C. The constraint guarantees that no material will be unloaded or added while passing through the depot of other carriers. Equation (3) represents the capacity constrain of flow through a truck. It guarantees the maximum flow through one particular truck cannot exceed the maximum capacity of the truck. Constraint on capacity of an edge has been shown using equation (4). The capacity of the edge is divided among all the carriers. The total flow for a particular carrier cannot exceed the fraction of edge capacity allocated to him. This constraint has been used to put a limit to the amount of overloaded quantity that can be carried by a particular carrier. Equation (5) ensures that the flow through an edge is never higher than the demand of the corresponding node for a particular carrier.

Model 2: Considering Capacity sharing

Maximize

Profit= $$\sum_{t\in T}\sum_{(i,j)\in E} x^{l}{}_{ijt} * R + \sum_{t\in T}\sum_{(i,j)\in E^{o}} x^{/l}{}_{ijt} * (R - C_e) * X^{l}{}_{ij} + \sum_{t\in T}\sum_{(i,j)\in E^{o}} x^{/m}{}_{ijt} * C_e * X^{/l}{}_{ij} - Fuel\cos t \tag{6}$$

Constraints

$$\sum_{t\in T}\sum_{(i,j)\in E} x_{ijt}^{l} - \sum_{t\in T}\sum_{(j,i)\in E} x_{jit}^{l} \le 0, \quad \forall (i,j),(j,i)\in E \tag{7}$$

$$x_{ijt}^{l} \le Cap, \quad \forall l\in L,(i,j)\in E \tag{8}$$

$$\sum_{t\in T}\sum_{(i,j)\in E} x_{ijt}^{l} + \sum_{t\in T}\sum_{(i,j)\in E^{o}} x^{/l}{}_{ijt} * X^{l}{}_{ij} + \sum_{t\in T}\sum_{(i,j)\in E^{o}} x^{/m}{}_{ijt} * X^{/l}{}_{ij} \le \gamma K_e, \quad \forall l\in L,(i,j)\in E^{o},(i,j)\in E \tag{9}$$

$$\sum_{t\in T}\sum_{(i,j)\in E} x_{ijt}^{l} + \Big(\sum_{t\in T}\sum_{(i,j)\in E^{o}} x^{/l}{}_{ijt}\Big) * X^{l}{}_{ij} \le d_{ij}^{l}, \quad \forall l\in L,(i,j)\in E^{o},(i,j)\in E \tag{10}$$

$$X^{l}{}_{ij} + X^{/l}{}_{ij} = 1 \tag{11}$$

Equation (6) gives the objective function which maximizes profit considering capacity exchange. Constraint shown in equation (7) considers balance of flow through nodes. The flow balance equation has been considered only when carriers have to pass through the depot of other carriers, eg. when carrier A has to move through the depot of carrier B or C. The constraint guarantees that no material will be unloaded or added while passing through the depot of other carriers. Equation (8) represents the capacity constraint of flow through a truck. The flow through a truck or the amount carried by a truck cannot exceed the maximum capacity of that truck. Constraint on capacity of an edge has been shown using equation (9). The total capacity of an edge has been divided among the truck owners depending upon the no. of trucks that they have. The total flow through any edge for a particular carrier must be less than the fraction of edge capacity allocated to him. The demand constraint has been shown by equation (10). The total flow through any edge for a particular carrier should not exceed the demand of the corresponding node for that carrier. Equation (11) represents the binary number constraint.

ILLUSTRATIVE EXAMPLE

The mathematical model developed in the previous section has been solved using an illustrative example. Figure 2 shows the network of the illustrative example. The data set for the problem was randomly generated. Three carriers have been considered and their demand for one week has been shown in Table1. In the example five working days have been considered in one week. The body weight of a 9 tons truck is 4 tons and its load carrying capacity is 5 tons. Eight destination nodes were considered for each carrier. Table2 shows the distances of each node from the carrier's depots. The capacity of fuel tank of a 9 ton truck is approx. 200lts. It has been considered in the example that each carrier has customer base in every node. The demands from the eight different nodes for each carrier have been shown in Table 2.

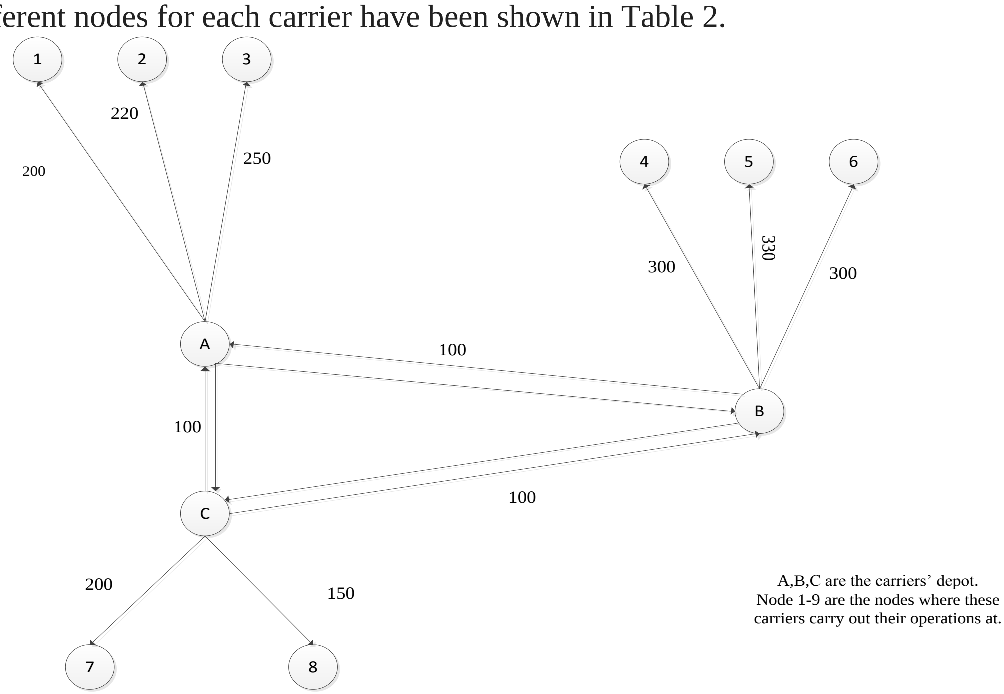

Figure 1-Network of operation for all the carriers

Table 1-Distance of the nodes from the depots of all the carriers

Carriers depots	Distance of the nodes from the depots of all the carriers							
	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8
Bhagwati Transporters	100	220	250	300	330	300	200	250
Hare Rama Hare Krishna Carriers	200	320	350	200	230	200	200	250
Kharagpur Transporters	200	320	350	300	330	300	100	150

Table 2-Demand of all the carriers for one week

Days, Nodes	Demand Of Bhagwati Transporters (Tons)					Demand Of HRHK Carriers (Tons)					Demand of Kharagpur Transporters (Tons)				
	Day1	Day2	Day3	Day4	Day5	Day1	Day2	Day 3	Day4	Day5	Day1	Day2	Day3	Day4	Day 5
Node1	9	0	0	8	0	0	9	0	7	9	9	0	0	12	0
Node 2	0	10	7	9	11	9	8	10	0	7	9	0	9	0	9
Node 3	17	8	9	8	12	8	0	0	0	8	7	10	9	0	6
Node 4	0	0	8	0	0	14	9	17	7	9	0	14	7	15	9
Node 5	12	16	0	0	8	7	14	9	0	0	8	6	0	0	0
Node 6	0	0	0	11	9	0	0	0	9	0	0	0	9	7	9
Node 7	6	9	10	9	7	0	0	11	9	9	11	0	6	0	10
Node 8	0	0	0	0	0	0	0	0	10	0	0	8	0	8	0

The mileage of a 9 ton truck which has been used for 3 years moving at an average speed of 40-50 kmpl has been shown in the Table 3. Table shows the change in mileage of a truck with increase in load. It can be seen there is a drastic fall in the mileage when we overload.

Table 3-Mileage breakup with load

Loads(tons)	0	1-4	5	6-8	9-11
Mileage(kmpl)	3.5	3.1	2.75	2.25	2

The fuel cost for all the carriers were calculated and have been shown in Table 4 and 5 respectively.

Table 4-Fuel cost of carriers 1, 2 & 3for one week with overloading

Days, Nodes	Fuel Cost of Bhagwati Transpor with overloading (Rs)					Fuel Cost of HRHK with overloading (Rs)					Fuel Cost Kharagpur Transporters with overloading (Rs)				
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 1	Day 2	Day 3	Day 4	Day 5	Day 1	Day 2	Day 3	Day 4	Day 5
Node1	2295	0	0	2391	0	0	6566	0	6115	6566	6566	0	0	7243.	0
Node 2	0	9173	8615	8987	9359	15495	15139	15850	0	14783	15495	0	15495	0	15495

Node	2112	8660	8871	8660	9506	14462	0	0	0	1446	14081	1522	1484	0	13701
N ode	0	0	1192	0	0	1481	6561	1582	6222	6561	0	2506	1158	25657	12263
Node	1876	3742	0	0	1731	1024	2320	1062	0	0	1730	16582	0	0	0
Node	0	0	0	1294	1226	0	0	0	6561	0	0	0	1226	11587	12263
Node	5889.	6566	7392	6566	6115.	0	0	7018	6566	6566	2644.	0	2221.	0	2560
Node	0	0	0	0	0	0	0	0	1226	0	0	5598	0	5598	0

Tables 6 and 7 show the fuel cost for each carrier after capacity sharing. It can be seen that there is a decrease in the total fuel cost after capacity sharing.

Table 6-*The fuel cost of carriers 1, 2 & 3 for one week with capacity sharing.*

Days, Nodes	Fuel Cost of BhagwatiTransporterswith Capacity sharing (Rs)					Fuel Cost of HRHK withCapacity sharing (Rs)					Fuel Cost of Kharagpur Transporters Capacity sharing (Rs)				
	Day1	**Day2**	**Day3**	**Day4**	**Day5**	**Day1**	**Day2**	**Day3**	**Day4**	**Day5**	**Day1**	**Day2**	**Day3**	**Day4**	**Day5**
Node1	2295	0	0	2391	0	0	6566	0	6566	6566	6566	0	0	6566	0
Node 2	0	8987	8801	8987	8987	15495	15495	15495	0	15495	15495	0	15495	0	15495
Node 3	21126	8871	8871	8660	8871	14462	0	0	0	12773.8	14081	14842	14842	0	14462
N ode 4	0	0	11925	0	0	14813	6561	15828	6222	6461	0	25065	11587	25657	12263
Node 5	17673	38710	0	0	17310	10629	23203	10629	0	0	17673	16582	0	0	0
Node 6	0	0	0	12263	12263	0	0	0	6561	0	0	0	12263	12263	12263
Node 7	6341	6566	6566	6566	6341	0	0	6566	6566	6566	2295.5	0	2295.5	0	2295.5
Node 8	0	0	0	0	0	0	0	0	11964	0	0	5598	0	5598	0

RESULTS AND DISCUSSION

The comparative results of the profit earned by each carrier over a period of one week with overloading and with capacity sharing after solving the problem have been shown in Table 8. Table also shows how the profit varies for different values of capacity exchange price. Capacity exchange price has been considered as a fraction of revenue charged by the carrier. Varying the fraction different results have been obtained and shown in the Table. From the Table it can be seen that there is an increase in profit with capacity sharing as compared to overloading. Figure 2 shows the variation of profit for various carriers with different values of capacity exchange price.

Table 8-Comparison of profit earned with overloading and capacity sharing

Carriers	Profit with overloading (Rs)	Profit with capacity sharing at different values of Capacity exchange price (Rs)						
		0.1*R	0.2*R	0.3*R	0.4*R	0.5*R	0.6*R	0.7*R
Bhagwati Transporters	350049	382065	382920	383775	384630	385485	386340	387195
Hare Rama Hare Krishna Carriers	347485	364731	365871	367011	368151	369291	370431	371571

Kharagpur Transporters	278275.7	288140	288425.5	288710.5	288995.5	289280.5	289565.5	289850.5

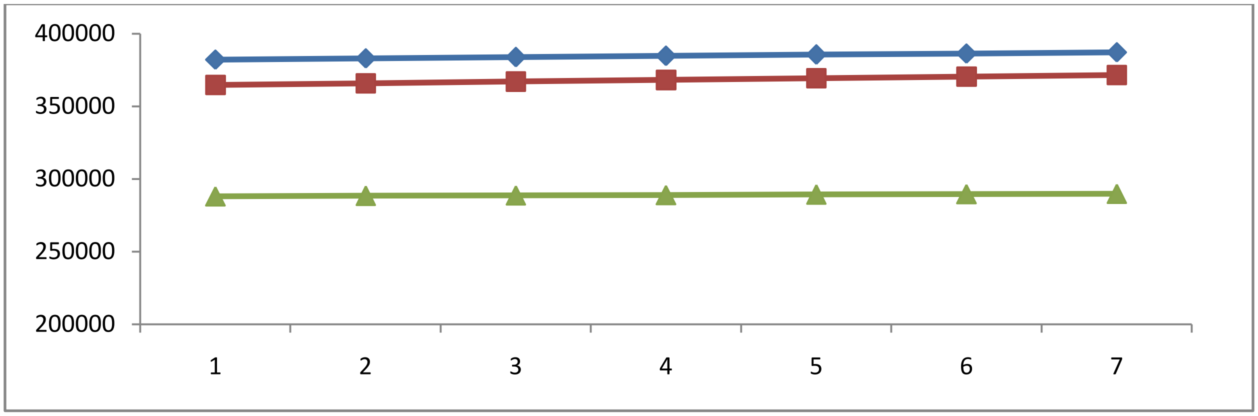

Figure 2-Variation in profit for various carriers with different values of capacity exchange price

CONCLUSION AND FUTURE SCOPE

In this paper a new approach of collaboration through sharing of load has been proposed in order to enable micro truck owners overcome the problem of overloading and capacity shortage. The concept of capacity exchange price has been used in trucking industry for the first time and it has been shown that there is an increase in profit if the carriers collaborate among themselves and share their unused capacity. Random data have been considered while solving the model. The future research work can be done using real time data and solving the model in real time scenario. The values of profit corresponding to various values of capacity exchange price changes differently for different carriers. A game theory based approach can be used to find out a particular value of capacity exchange price in which all the carriers will have optimum profit as a future work. It can be seen from Table 8 the value of profit for carrier 2 and 3 increases with increase in capacity exchange price, however for carrier 1 there is a decrease in profit. The reason behind difference in changes in profit for different carriers can be worked on in the future.

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