Vehicle Allotment and Route Optimization for Transportation Services Using Logistics Techniques in Supply Chain Management

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Abstract

Transportation plays an important role in supply chain management. To meet customer demands and reduce transportation costs, vehicle needs to be allocated to the optimal route. Vehicle allotment and route optimization are the critical factors for transportation service providers while providing best possible services. In this proposed model, optimization algorithm is developed to address the pain points of transport service providers, which will aid in making critical decisions. The algorithm uses the transactional data of the organization to calculate the loads to be transferred between two hubs/locations. Maximum load to be transferred, available vehicle type and its capacity are used as factors to determine the vehicle allotment. Simultaneously the algorithm allocates the vehicle to a route in such a way that the assigned vehicle is completely utilized. The algorithm is designed to consider cases with load availability less than the full capacity of allocated vehicle between two hubs by assigning touch points on the route in order to maximize the capacity utilization of the vehicle. By using this hub-to-hub optimization model, load factor of vehicle has improved. Operation efficiency has improved through this optimum model. The results of model calculation show that after using this model cost saving of 8% is calculated. Thus, this hub-to-hub model gives the best vehicle placement for available load at each hub in vehicle allotment and route optimization for transportation services.

Keywords
Supply chain optimization, route optimization, transportation problem, hub to hub optimization, transportation cost reduction

1.Introduction
In today's fast-moving world where cost has become one of the major factors to be controlled for a profitable business, Indian logistic business has witness exponential growth in these last years. Road transportation contributes more than 50% of freight movement in India and has becoming an important sector in recent years. Rapid industrial development & increased trade has created pressure on the logistics industry to deliver at faster speeds.

At the same time to reduce the transportation cost and meet customer satisfaction is big challenge for the companies as transportation costs accounts for approximately 36% of total logistics costs. Customer satisfaction can be defined by speed and convenience. Consumers want products to be delivered to their doorsteps in the short time. Thus time is a key factor which was highlighted even in a PwC's consumer survey where 41% of consumers were ready to pay extra rates for fast deliveries.

In this paper we address a real-life hub to hub movement problem faced by road transportation industries. Normally all the transportation companies have their own operation network where all their branches are set. All these industries generally work on three type of operation network that is hub and spoke operation network, hybrid hub and spoke operation network, direct transportation operation network. It is very difficult to make decision about which operation network to be selected. As in direct transportation operation network, all branches are connected with each other directly. This type of operation network is advantageous in short transport area where fast speed delivery is required. But when less than truck load transportation is there then there is high operation cost faced by the industries which can lead to loss in the business. To overcome these types of challenges, hub and spoke operation network are used. In this type of operation network, all the spokes are connected to the nearest hub and hub are connected to each other. Here, the loads are moved from spoke to nearest hub then from this hub to the nearest hub of the destination and then to spoke. Sometimes according to the routes assigned, loads can move to multiple hub locations. The disadvantage of this type of operation network is that when loads to be transferred between two spokes has less distance cost of transfer of load if sent directly which is cheaper than transferring it via hub. To overcome this type of challenge, hybrid hub and spoke operation network is used which is hybrid of hub and spoke operation network and direct transportation operation network in which small distance spoke are connected directly. In this paper we have tried to deal with the hub-to-hub problem where the challenge like which vehicles to be placed at each hub and are these vehicle's load carrying capacity completely utilized. For this, a model has been developed in MS Excel macros. The main purpose of this hub-to-hub model was to reduce the operation cost and optimize the total hub to hub transportation.

2. Literature Review

Baligil et al. (2011) stated in their paper that the main purpose of optimization is to have an efficient distribution network to meet customer demands. They have optimized this process in two stages, first they have assigned the load using mixed integer programming by using GAMS 21.6/CPLEX and result of this stage is used as input in second stage where they have assigned all the routes by developing a genetic algorithm by using C#. they have found that with the help of this tool a optimal solution is found. Chen et al. (2014) stated in their paper that the main aim was to minimize the total operation costs, truck load capacity, and uncapacitated road transportation. They have optimized this process by mixed integer linear programming model (MILP) for optimizing the hybrid hub-and-spoke network operation for a less-than-truckload transportation service. They found that hybrid hub and spoke network operation is better than hub and spoke network. The result shows that there is cost saving of 8% and total trips has been reduced by 15.3%.

Baykasoğlu and Subulan (2016) stated in their paper that the main purpose of optimization is to satisfy transport demands of customers and many other related issues. They have optimized this process by a mixed-integer mathematical programming model for a multi-objective, multimode and multi-period sustainable load planning problem by considering all the type of import/export load flows. The simultaneously decisions consider while solving are transportation mode/service type selection, load allocation, and outsourcing. The result show that there is overall cost savings and customer satisfaction has increased. Bhattacharya et al. (2014) stated in their paper that the main purpose of the model is strategic transport planning involving a network wide intermodal transport system. Traffic flow estimation is performed by kernel-based support vector mechanisms. They have optimized schedules for intermodal transport network process by mixed integer programming (MIP) considering various costs and additional capacity constraints. With this model they have developed an optimal schedule for intermodal transport network, also they were able to optimization roads and intermodal transport cost.

Arnold et al. (2004) stated in their paper that the main aim is optimally locating rail/road terminals for freight transport. They have optimized this process by using a linear 0-1 program is formulated and solved by a heuristic approach. The result shows that Intermodal transport can be a worthwhile alternative to unimodal transport, they also stated that intermodal transport is more competitive for long distances. He (2020) stated in their paper that the main purpose of optimization is to reduce long distribution time, reduce high distribution cost and overcome small distribution scope. They have optimized this process by intelligent information processing technology for regional logistics distribution integration method. They have considered distribution time, distribution cost and distribution distance as experimental indicators. The results states that intelligent information processing has achieved certain results, but the actual logistics distribution integration is more complicated and there are still certain influencing factors.

Cho et al. (2012) stated in their paper that the main purpose was savings in both transport cost and time by comparing single transport modes with intermodal transport paths. They have optimized this process by Weighted Constrained Shortest Path Problem (WCSPP) model. This model draws Pareto optimal solutions that can simultaneously meet two objective functions by applying the Label Setting algorithm. in second stage mathematical model and MADM model is applied to the multiple Pareto optimal solutions to estimate the solutions. The result was fount that cost has been saved and time required to transport has reduce. Abd El-Wahed & Lee, (2006) stated in their paper that the main aim is find the optimal solution. They have optimized this process by using interactive fuzzy goal programming (IFGP) approach. They found that combination of goal programming, fuzzy programming, and interactive programming in one methodology is a powerful tool for solving MOTP and other multi-objective optimization problems.

3. Model Development

The hub-to-hub optimization model is developed for scheduling of vehicle on each hub. Hub to hub optimization model consists of two stages. In first stage all the booked loads are arranged according to the routes in such a way that the result of this stage will give us that at what date the parcel will reach at each hub considering the transit days. In second stage vehicle are assigned by adding all the available load on that date according to the routes defined at each hub.

While developing a hub-to-hub optimization model following steps were performed:

1) As is analysis was done
a. Determining what type of vehicle used.
b. Determining the total transportation cost.
c. What are the routes followed for connecting all the hub?
2) Vehicle constraints were studied.
3) According to the loads all the routes were finalized.
4) Vehicle constraints were finalized based on minimum capacity to be used, distance to be covered, etc.
5) The formulation of calculating time required to complete one hub movement is as follow.
6) Total days = Total Distance to be traveled / 150 km/day
7) Standard hub to hub rules for each movement were finalized and Microsoft Excel VBA and macros were used to add constraints in hub-to-hub model.
The mathematical model to solve cost reduction Problem was formulated:
$G(N, A)$ be the network, where N is the set of all hub A is the set of links. The total operation costs consist of transportation cost. Transportation cost is related to the flow, which can be represented as incremental quantity function $f()$. Other notations are as follows:
a. b_{ij} : it's the total flow of load from node i to node j ;
b. c_{km}: its per kg per km unit transportation cost for link $k - m$;
c. h_{km}^r: it represents the flow for link $k - m$ that adopts discount of interval r, for link flow. The domain of the whole discount function is divided into R intervals, r=1,2, 3,…,R ;
d. d_{km}: it's the distance from node k to node m;
e. The optimization cost can be represented in equation (1) as follow:

$$\min c = \sum_{k\in N}\sum_{M\in N}\sum_{R} f(h_{km}^r) \quad \ldots\ldots (1)$$

For return calculation of the total cost and the total flow, α is used is represented in equation (2) as follow

$$\alpha = \begin{cases} \alpha_1, & l_1 \le h_{km}^1 \le u_1 \\ \alpha_2, & l_2 \le h_{km}^2 \le u_2 \\ & \vdots \\ \alpha_R, & l_R \le h_{km}^R \le u_R \end{cases} \quad \ldots\ldots (2)$$

where l_R and u_R are the lower and upper interval r. In this paper a decreasing rate is used to add more freight volumes, therefore we can write $\alpha_R < \alpha_{R-1} < \cdots < \alpha_1$. Then we can obtain the average of $\bar{\alpha}$ is represented in equation (3) as follow

$$\bar{\alpha} = \begin{cases} \alpha_1, & l_1 \le h_{km}^1 \le u_1 \\ \dfrac{\alpha_1(u_1 - l_1) + \alpha_2(h_{km}^2 - l_2)}{h_{km}^2}, & l_2 \le h_{km}^2 \le u_2 \\ \vdots & \\ \dfrac{\alpha_1(u_1 - l_1) + \alpha_2(u_2 - l_2) + \cdots + \alpha_R(h_{km}^R - l_R)}{h_{km}^R}, & l_R \le h_{km}^R \le u_R \end{cases} \quad \ldots\ldots (3)$$

Transportation cost has an direct relation with the distance to be covered. we can formulize the transportation cost is represented in equation (4) as follow as

$$f(h_{km}^r) = \bar{\alpha} c_{km} h_{km}^r d_{km} \quad \ldots\ldots (4)$$

Thus, we can rewrite optimization function is represented in equation (5) as follow as:

$$\min c = \sum_{k \in N} \sum_{M \in N} \sum_{R} \overline{\alpha} c_{km} h_{km}^{r} d_{km} \quad \text{………(5)}$$

4. Results

The results of model calculation are in three stages that is cost saving, load factor improvement on each leg (link) and on time delivery improvement. Following are the result shown:

Cost Saving: After running the tool following are the routes where cost savings potential are found. Total of 7.92% of cost saving is found after comparing cost with as-is case.

- Table 1 shows the cost at each route before optimization
- Table 2 shows the cost at each route after optimization
- Table 3 shows comparison between as-is case and to-be case.
- Table 4 & 5 shows the cost Calculation for Route 2.

Table 1. As is cost details

Route	One way		Return way		Total cost in Rs
	Weight in KG	Rs/kg As Is cost	Weight in KG	Rs/kg As Is cost	
Route 1	515,916	4.33	558,226	6	5,611,184
Route 2	378,534	5	540,177	5	4,528,345
Route 3	307,996	6.26	-	-	1,928,055
Route 4	372,554	5.89	-	-	2,194,343
Route 5	380,790	5.54	193,149	3	2,756,626
Route 6	188,917	6.07	-	-	1,146,726
Route 7	774,684	6	-	-	4,779,800
Route 8	384,289	6.72	172,746	5	3,377,054
Route 9	493,615	7.39	513,608	8	7,813,176
Route 10	493,373	7.39	387,091	6	6,022,765
Route 12	528,625	8.45	220,474	-	4,466,881
Route 13	330,015	3.69	--	-	1,217,755
				Total	45,842,710

Table 2. To be cost details

Route	One way		Return way		Total cost in Rs
	Weight in KG	Rs/kg To be cost	Weight in KG	Rs/kg To be cost	
Route 1	515,916	3.75	558,226	5.23	4,854,207
Route 2	378,534	4.6	540,177	4.54	4,193,660
Route 3	307,996	5.52	-	-	1,700,138
Route 4	372,554	5.78	-	-	2,153,362
Route 5	380,790	4.85	193,149	4.7	2,754,632
Route 6	188,917	5.93	-	-	1,120,278

Route 7	774,684	5.58	-	-	4,322,737
Route 8	384,289	5.44	172,746	4.98	2,950,807
Route 9	493,615	6.62	513,608	6.57	6,642,136
Route 10	493,373	6.38	387,091	5.65	5,334,784
Route 12	528,625	6.97	220,474	6	5,084,526
Route 13	330,015	3.33	-	-	1,098,950
				Total	42,210,216

Table 3. As-is and To-be Comparison

Route	As Is cost	To be cost	Saving	Percentage of saving
Route 1	5,611,184	4,854,207	756,977	13%
Route 2	4,528,345	4,193,660	334,685	7%
Route 3	1,928,055	1,700,138	227,917	12%
Route 4	2,194,343	2,153,362	40,981	2%
Route 5	2,756,626	2,754,632	1,994	0%
Route 6	1,146,726	1,120,278	26,448	2%
Route 7	4,779,800	4,322,737	457,064	10%
Route 8	3,377,054	2,950,807	426,246	13%
Route 9	7,813,176	6,642,136	1,171,040	15%
Route 10	6,022,765	5,334,784	687,981	11%
Route 12	4,466,881	5,084,526	-617,645	-14%
Route 13	1,217,755	1,098,950	118,805	10%
Total	45,842,710	42,210,216	3,632,494	7.92%

Table 4. One way Cost according to vehicle and load factor

	Total weight in KG	**Attached Vehicle**	**Market Vehicle**				**PTL Adjusted load**	**Total cost Rs in**	**Total capacity**
Outbound	3,78,534	32 MXL	32 MXL	32 SXL	20 FEET	17 FEET	-	-	-
	Vehicle capacity	16500	16500	7500	6500	5000	1	-	463070
	Count of Vehicles	25	0	0	2	5	12570	--	**LF**
	Vehicle cost in Rs	57,000	-	-	40000	35000	5	-	82%
	Vehicle spend in Rs	14,25,000	-	-	80000	175000	62,850	17,42,850	-

Table 5. Return cost according to vehicle and load factor

	Total weight in KG	**Attached Vehicle**	**Market Vehicle**				**PTL Adjusted load**	**Total cost Rs in**	**Total capacity**
Inbound	5,40,177	32 MXL	32 MXL	32 SXL	20 FEET	17 FEET	-	-	-
	Vehicle capacity	16500	16500	7500	6500	5000	1	-	508515
	Count of Vehicles	26	1	0	4	1	32015	-	**LF**
	Vehicle cost in Rs	74,000	86,000	-	60,000	45,000	5	-	106%
	Vehicle spend in Rs	19,24,000	86,000	-	2,40,000	45,000	160,075	24,55,075	-

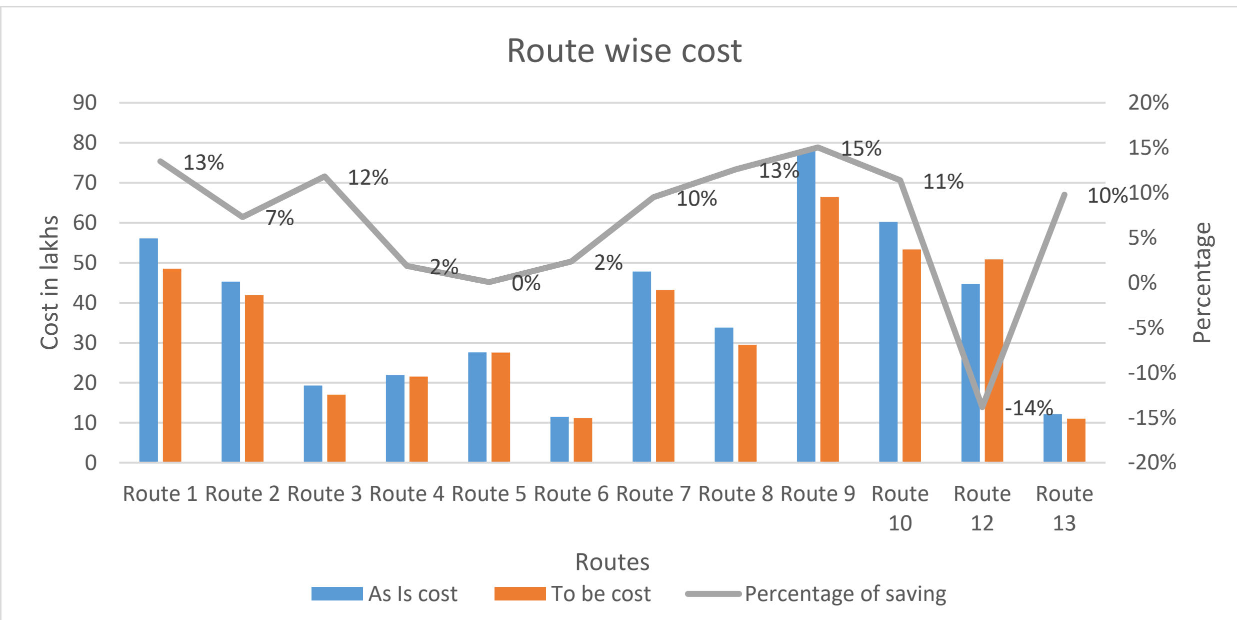

Figure 1. As is and to be cost comparison for routes

From the analysis of the cost comparison in as is cost and the to be cost for transportation is shown in the figure 1. Following two important conclusions are derived from the route and cost optimization and are discussed as below.

Load factor improvement: With the help of this tool load factor improvement on each leg is achieved due to the optimal placement of vehicle on each route depending upon the load movement in both directions. After running the tool its observed that more than 10% of load factor improvement is there.

- Table 6 shows the load factor improvement on forward movement
- Table 7 shows the load factor improvement on return movement

Table 6. load factor improvement on forward movement

Route	**One way**				% of Improvement
	Weight in KG	**Rs/kg**	**Weight in KG**	**Rs/kg**	
		As Is LF		**To be LF**	
Route 1	515,916	81%	515,916	92%	14%
Route 2	378,534	65%	378,534	82%	26%
Route 3	307,996	80%	307,996	86%	7%
Route 4	372,554	90%	372,554	115%	28%
Route 5	380,790	77%	380,790	76%	-1%
Route 6	188,917	83%	188,917	93%	12%
Route 7	774,684	91%	774,684	102%	12%
Route 8	384,289	88%	384,289	102%	16%
Route 9	493,615	71%	493,615	97%	37%
Route 10	493,373	89%	493,373	92%	3%
Route 12	528,625	88%	528,625	106%	20%
Route 13	330,015	71%	330,015	86%	21%

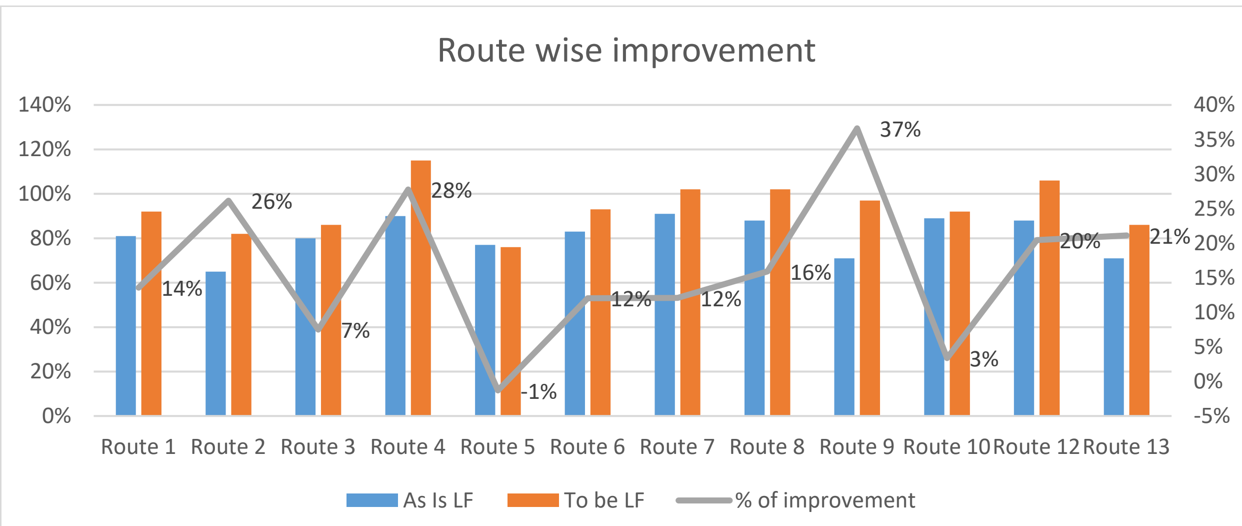

Figure 2. As is and to be Load Factor comparison for forward routes

From the analysis of the load comparison in as is case and the to be case for transportation is shown in the figure 2.

Table 7. load factor improvement on return movement

Route	**Return way**				**% of Improvement**
	Weight in KG	**Rs/kg**	**Weight in KG**	**Rs/kg**	
		As Is LF		**To be LF**	
Route 1	558,226	65%	558,226	76%	17%
Route 2	540,177	94%	540,177	106%	13%
Route 5	193,149	37%	193,149	41%	11%

Route 8	172,746	45%	172,746	50%	11%
Route 9	513,608	82%	513,608	91%	11%
Route 10	387,091	63%	387,091	79%	25%
Route 12	220,474	49%	220,474	58%	18%

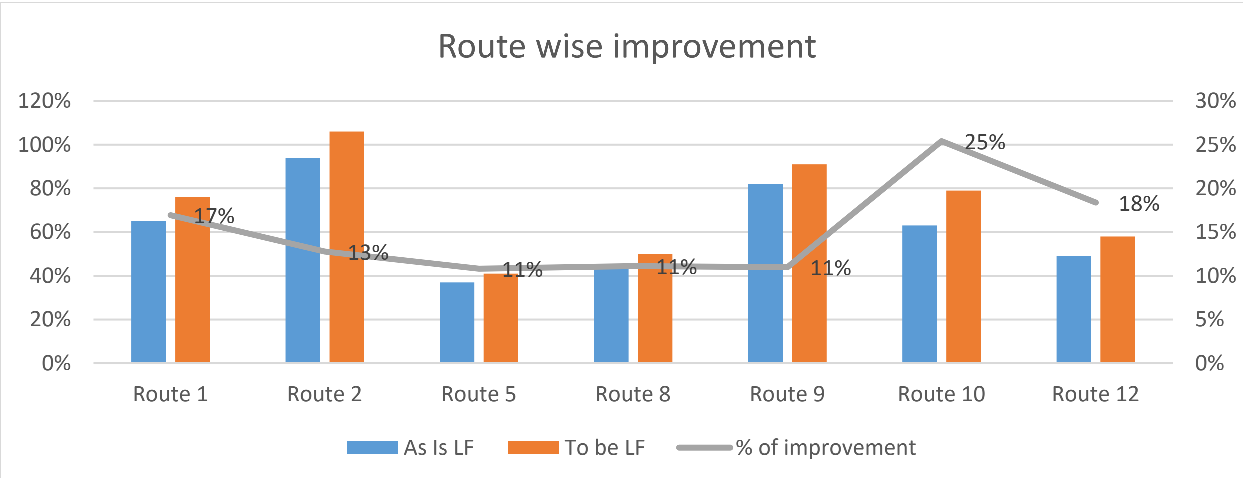

Figure 3. As is and to be Load Factor comparison for return routes

From the analysis of the load comparison in as is case and the to be case for transportation is shown in the figure 3.

On time Delivery: While as-is analysis it was found that the load used to get stuck at a hub. The reason behind this is that the hub would not know that at what time the connecting load to other hub would be reaching at their hub and at some point, the vehicle used to be sent before the connecting load reach at the hub. this case has been solved in above tool as it considers the overall load that is booked load at that hub and incoming load while placing the load, due to which overall service level has increased.

5. Conclusion

A real-life hub to hub problem related to the transportation of load from one location to another is done. The optimization hub to hub model is developed for assigning optimal vehicle to the routes. The results of data processing by using hub to hub optimization model we found that the total cost was minimized, and total time required to complete the delivery was close enough to its standard sets. This model help in reducing the total time of assigning the vehicle at each hub by centralizing the overall process. This model has tested and successfully implemented in the transportation company. By using this hub-to-hub optimization model, load factor of vehicle has improved. Operation efficiency has improved through this optimum model. The results of model calculation show that after using this model cost saving of 8% is calculated. Thus, this hub-to-hub model gives the best vehicle placement for available load at each hub in vehicle allotment and route optimization for transportation services.

References

Abd El-Wahed, W. F., & Lee, S. M. Interactive fuzzy goal programming for multi-objective transportation problems. *Omega*, *34*(2), 158–166, 2006.

Arnold, P., Peeters, D., & Thomas, I. Modelling a rail/road intermodal transportation system. *Transportation Research Part E: Logistics and Transportation Review*, *40*(3), 255–270, 2004.

Baligil, H., Kara, S. S., Alcan, P., Özkan, B., & Gözde Alar, E. A distribution network optimization problem for third party logistics service providers. *Expert Systems with Applications*, *38*(10), 12730–12738, 2011.

Baykasoğlu, A., & Subulan, K. A multi-objective sustainable load planning model for intermodal transportation networks with a real-life application. *Transportation Research Part E: Logistics and Transportation Review*, *95*, 207–247, 2016.

Bhattacharya, A., Kumar, S. A., Tiwari, M. K., & Talluri, S. An intermodal freight transport system for optimal supply chain logistics. *Transportation Research Part C: Emerging Technologies*, *38*, 73–84, 2014.

Chen, W., He, K., & Fang, X. Optimization of hybrid hub-and-spoke network operation for less-than-truckload freight transportation considering incremental quantity discount. *Mathematical Problems in Engineering*, *2014*.

Cho, J. H., Kim, H. S., & Choi, H. R. An intermodal transport network planning algorithm using dynamic programming-A case study: From Busan to Rotterdam in intermodal freight routing. *Applied Intelligence*, *36*(3), 529–541, 2012.

He, L. Research on the Optimization Method of Regional Logistics Distribution Integration Based on Intelligent Information Processing. *Journal of Physics: Conference Series*, *1584*(1), 2020.

Biographies

Rohit Agarwal is presently student in second year of Master of Technology of Production Engineering in Veermata Jijabai Technological Institute, Mumbai, India and completed his B-tech in Industrial and Production Engineering in Manipal Institute of technology and published 1 paper in international journals. He completed his 1 year internship at Translytics which deals in Supply chain management (Sept 2021 - Aug 2022). Now he is working as senior analyst in Translytics.

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He has published 70 research articles/papers in international and national journals and in peer reviewed conference proceeding in area of Nanotechnology, nanomaterials, manufacturing, nanocomposites, and advanced composite materials. His area of interest is nanotechnology, nanomaterial, nanocomposite, advanced composite materials, design engineering, finite element analysis micro/nanofabrication, value engineering, lean manufacturing, and project management. Dr Shinde has delivered more than 20 Keynote addresses and workshop talk on Nanotechnology, additive manufacturing, composite manufacturing, and finite element analysis. Dr Shinde has 206 citation and 24540 downloads and reads from ResearchGate.

Dr. Shinde is lifetime member of ASME (USA), SAMPE (USA), WASET, SAE India, ISTE (India), and AMSI. SAVE International USA. He is recipient of Dr. Wadaran L. Kennedy Scholar Award for 2012-2013 form North Carolina A&T State University, recipient of Graduate Research Assistantship award from North Carolina A&T State University from August 2011 to Dec. 2014. Recipient of Scholarly Accomplishments and Excellence in Academic Performance Award, Division of Student Affair and International Student and Scholar's office, North Carolina A and T State University, NC 2012. Dr. Dattaji Shinde has awarded Best Dronacharaya Award for Innovative product Smart Navigation Band in the National level Entrepreneurship Generation –Y competition Hunar 2.0 organized by Jaro

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