VEHICLE ROUTING MODEL FOR MILK RUN DELIVERY OF FRESH PRODUCE: THE CASE OF A 3PL SERVICE PROVIDER CATERING SUPERMARKETS

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ABSTRACT

Effective route cycle design and assignment of vehicles in a fresh fruit and vegetable delivery network is of major importance since it contributes to a significant amount of transportation cost in the supply chain. Manual vehicle routing is a complex task due to geographical dispersion of customers, delivery time windows, vehicle capacity and delivery volume constraints. The objective of proposed method is to design an algorithm and develop a computer program which minimizes the total cost of travelled distance adhering to aforementioned constraints. When constructing the model, a background study has been conducted on the operations of the 3PL service provider and defined the objective function subjected to constraints. Inputs and outputs of the model have been defined to derive the cost formulas and then the vehicle routing and scheduling algorithm was designed. The model was proposed to a single depot distributing fruits and vegetables to multiple customer locations having deterministic demand. Routes are directed with known origin and destination where the route cycle is fixed once the journey begins. The study proposes an automated vehicle routing solution comprised of vehicle capacity utilization, departure time assessment and vehicle route assignment components. The total cost calculation formula is derived considering both direct costs and opportunity costs. It utilizes the cost per distance, cost of time window violations and cost of empty space of contracted fleet. The proposed solution was validated by comparing with the manual assignment of a 3PL service provider supplying fresh produce to supermarkets. The proposed method resulted in 26% total cost reduction and 40% reduction in total distance travelled.

Keywords- Vehicle Routing Problem (VRP), Milk Run Logistics, perishable goods, time windows, equal capacity, truck scheduling

1. INTRODUCTION

Moving forward with emerging global trend, strategic focus is on developing proactive supply chains, where customers are viewed as the main driving force to achieve objectives. In this regard, modern focus is on fulfilling customer demand effectively and efficiently (Brar & Saini, 2011). Managing the distribution network play an important role to maintain preferable customer relationship while improving the triple bottom line in contemporary business sphere. Due to the growing complexity of logistics networks most companies invest on outsourcing the function to a 3PL provider or manage existing fleet and vehicle space utilization.

Global trends such as shorter life cycle products and complex customer relationships have impelled companies to deploy machine-learning algorithms to eliminate manual processing errors to enhance the effectiveness of operations. Vehicle Routing Problem (VRP) is a widely researched concept in Operations Research and Computer Science evolved with emerging trends in logistics subjected to diverse fields (Dharmapriya et al, 2012).

Fresh produce delivery of fruits and vegetables is characterized by perishability, delivery time and temperature controls. Route optimization and vehicle space utilization in such areas need to focus on cost reduction while delivering on time (Dharmapriya et al, 2010). Milk Run concept utilizes truck space and optimize route distance compared to the direct customer distribution. Empty collection in the returns journey is one of the prominent characteristics of milk run delivery (Brar & Saini, 2011).

This study develops an algorithm that **construct milk run routes, scheduling vehicles** for each route option and **assess departure time** for each vehicle with the objective of minimizing cost of travelled distance adhering to fresh produce delivery requirements. In the single depot distribution network observed, the demand for each node of the network is known at the beginning of the journey and it's constant until the end of the journey. Hence the study addresses Vehicle Routing Problem with Time Windows (VRPTW) under deterministic demand. Dijkstra's algorithm is used to obtain the initial feasible solution of shortest path. Secondly the basic feasible solution was improved adhering to homogeneous vehicle capacity requirements, the upper bound and the lower bound of the time window allocated to each node of the route cycle. Our objective was to minimize the cost of distance visited. Among these cost of empty space ensures truck utilization, cost per distance and cost of violating time windows considers opportunity cost of quality loss in fresh produce due to late deliveries.

Especially the proposed vehicle routing problem perform truck space utilization, in a practical aspect where it deep down to the crate/pallet level utilization stored in delivery vehicles. This is an important area addressed by this study which improves efficiency and cost-effectiveness of the entire delivery operation where lack of attention drawn in previous studies.

The remainder of the article is organized as follows. Section 2 discuss the applicable literature. Section 3 introduces the problem formulation with the background. Section 4 describe the solution approach and Section 5 presents the findings of the VRP model and concludes the entire research.

2. LITERATURE REVIEW

Du et al.(2007) presented a different viewpoint on the types of milk run deliveries as follows;

- Upstream milk runs – manages the inbound delivery network to a Distribution Center (DC)
- Downstream milk runs – refers to the outbound delivery network from a DC. This happens to be the center of attention of this study.
- Mixed milk runs-connects all the three echelons (customers, suppliers, and DC) of a supply chain.

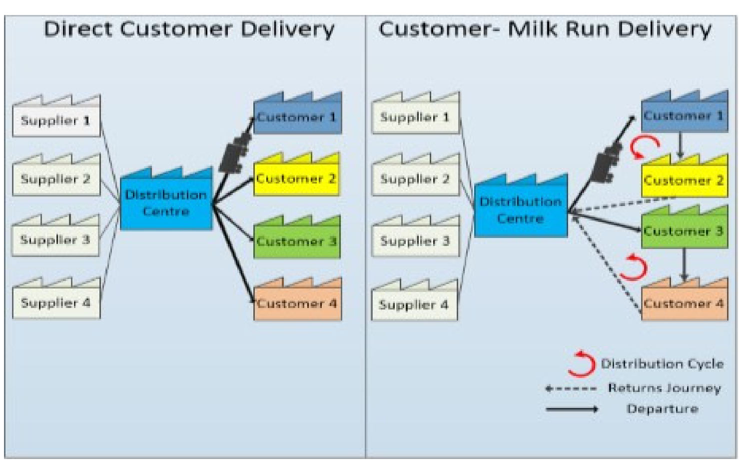

Figure 1. Customer milk run transportation network

Patel (2017) recently studied on the concept of milk run applied in Indian route estimation, referring an Indian state. The study has considered the VRP problem under three basic scenarios as common assignment problem, committed assignment and decided time periods assignment problem. Each heading is divided into sub headings according to the characteristics identified.

A classic VRP can be interpreted as "Assigning customers to optimum route cycles where each cycle is served by one vehicle and each customer is visited only once provided that each vehicle start and return to a unique single depot". According to the definition, it address a general case where real life scenarios are reported with multiple deviations (Dharmapriya et al, 2012).

Distribution networks for perishable foods are defined in broader aspects by scholars where fruits and vegetables, cut flowers, blood samples, products with putrefying nature such as petroleum, milk, pharmaceuticals, fresh meat, bakery items and food catering business were subjected to their studies. Due to the variability of quality from the point of production/preparation to the point of customer dispatch they face unique confronts in supply chain (Farahan et al, 2012).

Short-lived food delivery is significantly important in vehicle routing and assignment problems. Route planners being responsible for a perishable food delivery network required to focus more on responsiveness to customer requirements, delivery time variations, safe handling and transportation, operational flexibility and achieving delivery flexibility through proper communication. Amorim et al (2014) recently proposed a model for a food distribution company in Portugal experiencing high seasonality of customer demand. The proposed solution was heterogeneous fleet with the objective of minimizing costs subject to capacity constraints of the fleet split into compartments according to the temperature variations and time window constraint for each customer.

As Vidal et al (2014) discussed Column generation, Dijkstra's Algorithm and Branch-and-Bound methods bring in optimality focus while Genetic, Heuristic, Neighborhood Search,Tabu Search and Mix Integer Programming algorithms concentrate on feasible solutions. In contemporary Capacitated VRP (CVRP) focus merely on cost-reduction. But in practically modern business focus on effectiveness as well and the need of utilizing existing fleet is prominent rather than meeting capacity requirements of a single fleet. VRP with time windows (VRPTW) conceptually focus merely on timeliness but lost focus on the cost-effectiveness. Hence a combination of both VRP as address through this paper would ideally furnish an effective and efficient logistics operation (Jaegere et al, 2014).

Ozsoydan et al (2013) compared performance of the genetic algorithm, Tabu search, and nearest neighborhood-based initial solution technique for CVRP and their study considered multiple heterogeneous vehicles, real-time demand, and dynamic travel time between destinations. However practically supermarket chain perishable deliveries does not cater real time demand fluctuations and the existing concept becomes obsolete where a new algorithm need to be developed.

Recent researches by Cooray et al (2017) have directed towards Green VRP where environmental performance prevail over economic performance promoting green logistics practices. Main objective was to minimize energy consumption of the entire fleet involved in the operation supported by carbon emission calculations. In terms of commercially developed software, Erdoğan (2017) recently introduced an excel add-in to solve Vehicle Routing problem considering wide range of constraints practically encountered by route planners. Few Scholarly attention has been drawn in Sri Lankan context for the network optimization or specifically vehicle routing optimization encouraging new researches in diverse fields. Dharmapriya et al (2010) investigated the delivery operations of a production firm. The study has blended traditional vehicle routing problem considerations with practical scenarios by allowing a single customer to be served by multiple suppliers to accommodate varying demand. Global minimum solution was achieved using Simulated Annealing (SA) and Tabu Search (TS) based combined algorithm. But vehicle utilization has calculated without considering goods allocating to crate/pallet inside the vehicle which is identified and extended through the proposed model.

3. PROBLEM FORMULATION

The main objective is to minimize the cost of traveling distance with vehicle utilization. It assist in defining the different variables affecting to the total cost. Further according to the milk run distribution method the return journey of empty crate collection is considered as well.

Table 1. Summary of fleet operation attributes

Attribute	Description
Type of Fleet	20ft Contracted Refrigerated Trucks
Nature of fleet operation	All trips are started from a single depot
Nature of products distributed	Fresh fruits and vegetables
Nature of customer demand	Deterministic daily demand (known) with a seasonal variation according to the sales of supermarket outlets
Type of Network	Directed routes with known origin and destination
	Static routes where the cycle is fixed once the journey started.
Nature of distribution	Delivery using milk run concept
Time Windows	Limited time duration for each outlet

The model is developed under the assumptions that there are no back orders involved in truck assignment, a vehicle is assigned to each route cycle and responsible for distributing only among the assigned outlets. The time window for each outlet is pre-determined. The average speed of a vehicle is constant and average service time at each outlet is equal.

Let o be the origin of all route cycles which represent the distribution center. Random nodes of the route cycles are denoted by (i , j) and the distance between the nodes are denoted by d_{ij}. The volume of fresh produce demanded by node i, is determined by qi while the earliest delivery time (upper bound) is a_i and the latest delivery time (lower bound) is l_i respectively. The goods are distributed by homogeneous vehicles with capacity V_c and the volume delivered to node i by vehicle k is denoted by P_{ik}.

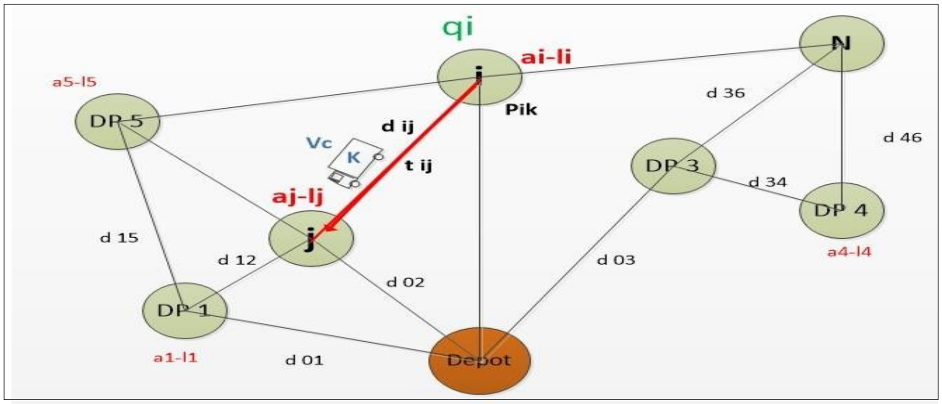

Figure 2. Network diagram of route assignment

Three major cost components are involved in the objective function of the model. They are as follows,

1. Cost of Empty Space of the vehicle
2. Cost per distance travelled; includes fuel consumption. Driver and helper wage costs
3. Cost of Violating Time Windows; opportunity cost of the quality loss due to early or late delivery of fresh produce.

3.1 Notations

Table 2: Notations and symbols of the model

Notations	Symbols
P_{ik} :Volume Delivered to node i visited by vehicle k	Z(d) : Total cost of travelled distance
q_i : Volume demanded by customer/outlet i	C_t : Cost of violation of time window
a_i : Earliest delivery time t customer/outlet i	C_e : Cost of empty space
l_i : Latest delivery time to customer/outlet i	C_d : Cost per distance
V_c :Capacity of the vehicle	P : Cost of empty travel per crate per km
d_{ij} : Distance between node i and j	ß : Cost of time value per hour per km
k : Vehicle Number	
N : Total Number of outlets	
u : Total number of vehicles	

Decision Variables

For each route combination (i,j), where i≠ j, for the vehicle k travelled, X_{ijk} and Y_{ik} are defined as,

$$X_{ijk} = \begin{cases} 1; \text{ if the vehicle k travel to node j directly from node i} \\ 0; \text{Otherwise} \end{cases}$$

$$Y_{ik} = \begin{cases} 1; \text{ if the demand point i is visited by vehicle k} \\ 0 \text{ ; Otherwise} \end{cases}$$

X_{ijk} ensure that the nodes assigned to same route cycle is visited by the same vehicle. Y_{ik} ensure that the order volumes are considered only for the nodes visited by the vehicle.

$$X1 = a_j - (ai + t_{ij}) = \begin{cases} 1; \text{ if } X1 > 0 \\ 0 \text{ Otherwise} \end{cases}$$

$$X2 = (ai + tij) - lj = \begin{cases} 1; \text{ if } X2 > 0 \\ 0 \text{ Otherwise} \end{cases}$$

3.2 The Model

$$\min Z(d) = (C_d \sum_{i=0}^{N} \sum_{j=0}^{N} d_{ij} \sum_{k=1}^{u} x_{ijk}) + C_t + C_e \tag{1}$$

Subject to:

$$\sum_{k=1}^{u} P_{ik} = q_i \tag{2}$$

$$P_{ik} \leq q_i \, y_{ik} \tag{3}$$

$$aj \leq a_i + t_{ij} \leq l_j \tag{4}$$

$$aj \leq l_i + t_{ij} \leq l_j \tag{5}$$

$$\sum_{i=1}^{n} y_{ik} * qi \leq Vc \tag{6}$$

Equation (1) represent the total cost of delivery considering opportunity costs of violating time windows and poor capacity utilization. It’s the objective function of minimizing cost of distance visited. In achieving the objective function, there are some constraints faced in practical instances. As Dharmapriya et al.(2010) mentioned in the study equation (2) and (3) assure that the vehicles deliver goods only to the outlets visited by them and totally supply the demand volume requested by the outlet. Hence it verifies that no matter how many vehicles supply to the same outlet the total volume delivered equal to the volume requested by the outlet.

Equation (4) and (5) verify that the trucks are visited to the outlet within the time frame not early nor late. In equation (4) if a truck arrive in the earliest arrival time to the outlet i, the travelling time between ij is added to get the delivery time to the outlet j and it should be within the time frame allocated for outlet j. Equation (5) defines the case of delivery time in the upper bound. Equation (6) confirm that total demand loaded to the truck does not exceed the capacity of the truck. Where Y_{ik} is an indicator to ensure that the truck visit outlet i, if not the indicator is 0 and the demand quantity of that outlet is not considered for the capacity utilization of vehicle k.

$$C_e = \rho * (V_c - \sum_{i=1}^{n} q_i) \tag{7}$$

C_d=(Priceperfuelliter*AverageFuelConsumptionperkm)+ (Driver wageperkm)+(HelperChargeperkm) (8)

C_t = Cost of early arrival + Cost of late arrival (9)

Cost of early arrival = $(aj - (ai + tij)) * \beta$ (10)

Cost of late arrival = $((ai + tij) - lj) * \beta$ (11)

Equation (7) explains Cost of empty space ensures that the truck is utilized maximum. Since milk run delivery system is involved the truck travel to the outlets in its return journey to collect empty crates. This cost component is in a way penalizing LTL (Less Than Truck Load) delivery to improve truck utilization. Equation (9), (10),(11) elaborate the cost of time window violation. When delivering fresh produce, time is a crucial factor. In case of early delivery to the outlet there's a chance of spoilage and wastage increase. In case of a late delivery the outlet may lose sales during the late time. Following diagram denote step-wise algorithm of the proposed model.

4. SOLUTION APPROACH

Proposed method consist of two phases and first phase defines the initialization procedure which determines the initial set of route cycles decided based on shortest path Dijkstra's Algorithm. Second phase optimizes the initial solutions according to vehicle capacity and delivery time windows applicable to each demand point. The best combination of routes are selected based on total cost of travelled distance.

Phase 1: Initialization

In this study initial feasible solution has been obtained from considering the shortest path among the given route combinations. All the routes are weighted using the distances, obtained from the OD (Origin-Distance) matrix developed for the outlets delivered. Since the existing vehicle routing of the company use a manual method, the algorithm could initially set path for finding the feasible route option.

At the beginning all the nodes are considered unreachable and having infinite distances. Then add nodes to the PQ by shortest path distance. Higher priority is given for minimum distances. In the next step remove nodes with minimum distance and add to the source (separate list). If a shorter path is discovered from source to nodes, update the PQ.

Phase 2: Optimization

After the initial solution has obtained it is developed based on the constraints and conditions to arrive at the optimum set of vehicle routes. The demand points included in the initial solution is removed from one route cycle and added to the next most feasible route combination until it is passed through every loop and conclude with the minimum cost route combination. Following diagram is the algorithm developed to arrive at the solution explained in the article.

5. RESULTS AND CONCLUSION

For the calculation of cost using existing manual method 14 outlets selected covering all the 10 zone of outlet distribution and manually assigned the volumes to vehicles and the route cycles

Table 3. Vehicle allocation of existing route assignment

Outlet No.	Outlet Name	Volume (Kg)	Number of Crates	Total Crates Loaded	Vehicle No.
1	Outlet A	1400	210	390	1
2	Outlet B	1200	180		
3	Outlet C	1800	270	571	2
4	Outlet D	2000	300		
5	Outlet E	1000	150	330	3
6	Outlet F	1200	180		
7	Outlet G	1220	183	345	4
8	Outlet H	1080	162		
9	Outlet I	2600	390	465	5
10	Outlet J	500	75		
11	Outlet K	2000	300	450	6
12	Outlet L	1000	150		
13	Outlet M	1758	264	452	7
14	Outlet N	1250	188		

Table 2 shows the outlets and the volume demanded. According to the existing route assignment method vehicles are allocated based on the experience of the route planner. As mentioned in methodology allocating 100% volume to the total vehicle capacity is having practical concerns. Hence to overcome weight is converted into number of crates using a standard crate measurement.

It is observed that most of the fleet are under-utilized according to the existing manual assignment method. In detail observation vehicles delivering to outlets in Colombo district mostly face the issue of under-utilization which is between 52%-55%. The main possible reason would be the highest concentration of outlets and high volume demand. But the case is different in outstations. Time windows are defined for each outlet considering their existing practice based on the availability of staff and average volume demanded by the outlet. In the proposed cost calculation formula the opportunity cost of violation of time windows are considered. Following is the basis used for calculations.

- Fuel cost per kilometer: price per fuel liter average literate of a vehicle per kilometer.
- Driver wage per kilometer: existing amount paid for drivers.
- Helper charges per kilometer: existing amount paid.

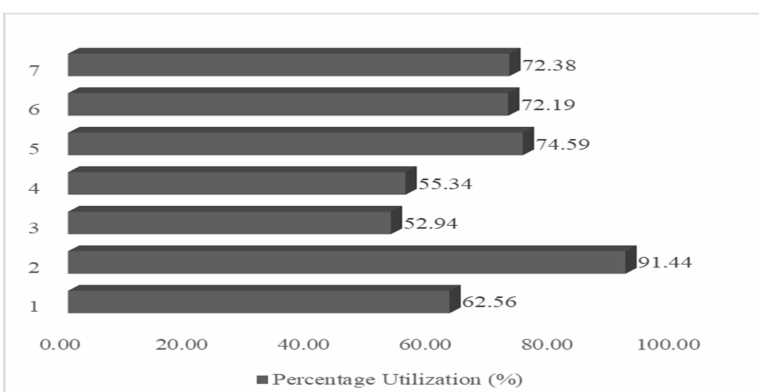

Figure 3. Percentage truck utilization

Table 4. Percentage vehicle utilization

Vehicle Number	Percentage Utilization (%)
1	62.56256
2	91.43759
3	52.93755
4	55.34381
5	74.59382
6	72.18757
7	72.38007

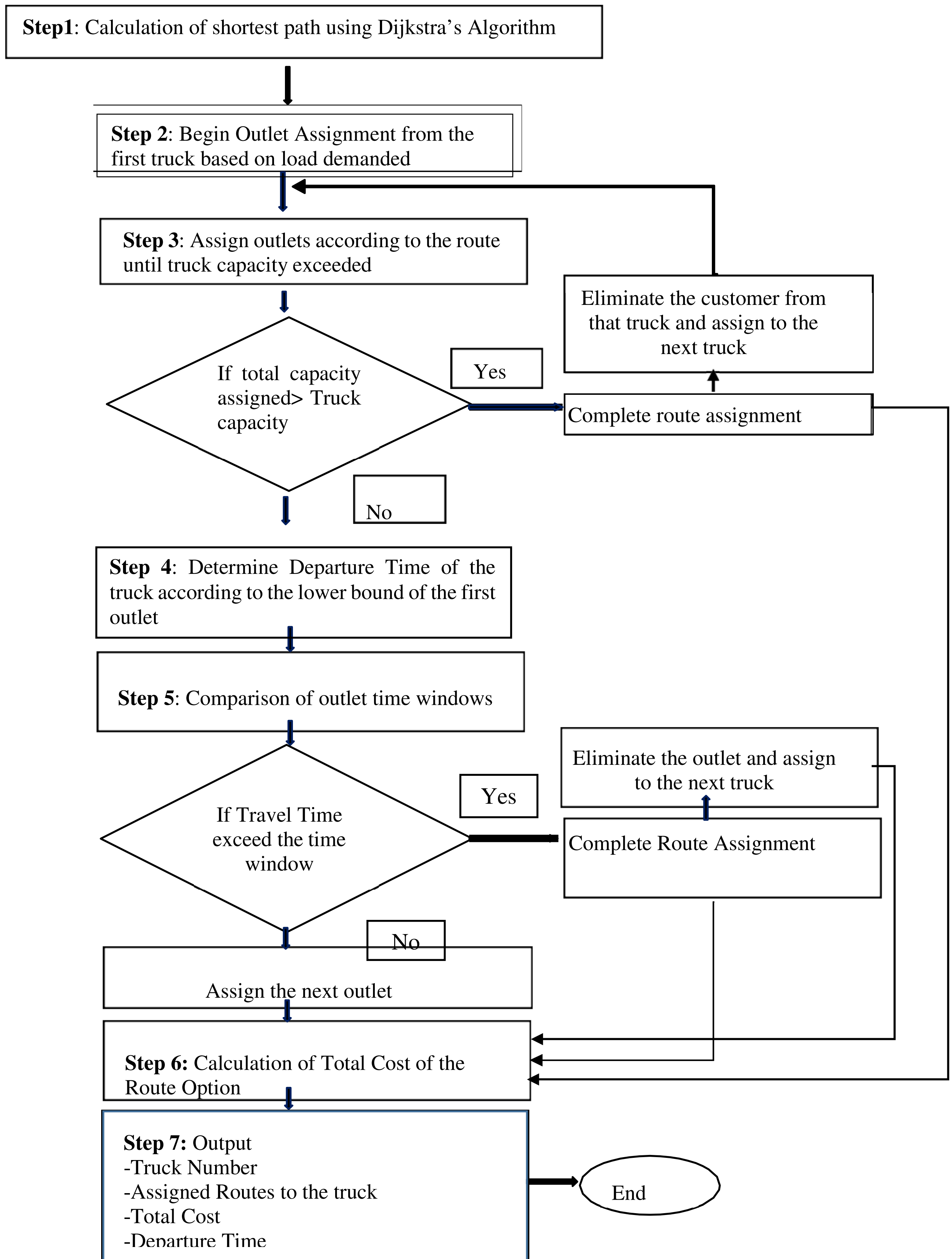

Figure 4. Algorithm of mathematical model

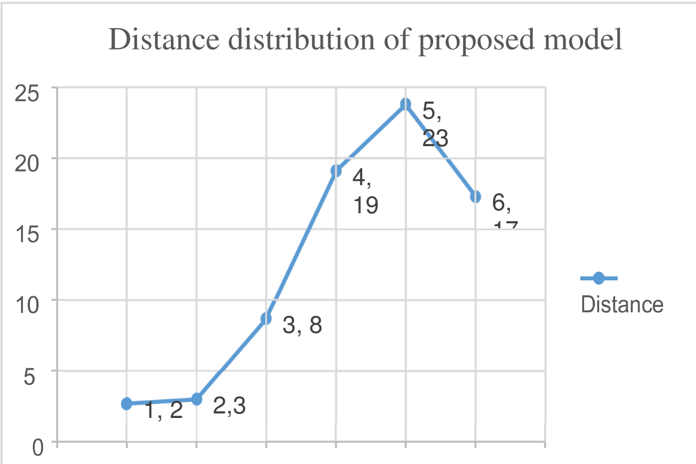

Figure 5. Distance distribution of route cycles in proposed model

As figure 5 indicate the variance between the lengthiest route and the shortest route in the existing assignment is 300km while proposed model has a variation of 211km where 30% reduction in variance in the new system.

Table 6 shows the route cycle wise cost calculation provided by the system with a proposed vehicle departure time and distance of the route. Compared to the existing model,

Percentage of Total Cost Saving =26%

Table 5. Cost of existing route assignment

		Cost Components(Rs.)			
Vehicle No	**Outlet Name**	**Travel**	**Empty Space**	**Arrival Early**	**Arrival Late**
1	Outlet A	14916.9	11680.5	0	2250
	Outlet B			0	0
2	Outlet C	23894.8	2671.5	0	750
	Outlet D			140	0
3	Outlet E	14640.7	14683.5	0	1500
	Outlet F			140	0
4	Outlet G	7182.2	13932.7	0	750
	Outlet H			0	0
5	Outlet I	3314.9	7926.7	0	0
	Outlet J			0	0
6	Outlet K	3176.8	8677.5	0	0
	Outlet L			0	0
7	Outlet M	20027.4	8617.4	0	0
	Outlet N			0	3500
Total Cost		164,373.51			
Total Distance		1242km			

Table 6: Results of the system generated model

Vehicle No.	**Outlet Name**	**Total Cost**	**Total Distance (km)**	**Departure Time**
1	Outlet K	3,954	27	03:49
	Outlet I			
	Outlet J			
2	Outlet L	7,744	30	03:43
	Outlet F			
3	Outlet M	16,466	87	02:42
	Outlet G			
4	Outlet H	29,681	191	03:37
	Outlet E			
	Outlet B			
5	Outlet A	38,548	238	03:28
	Outlet N			
6	Outlet D	25,245	173	04:09
	Outlet C			
Total Cost		121,638		
Total Distance		746km		

In addition the total number of fleet is also reduced.
Comparably the existing system use 7 vehicles and the same volume of demand is fulfilled by 6 vehicles in the new system. **Reduction in total distance**:39.9%=**40%**

5.1 Conclusion

This paper developed a new computer program for VRPTW in fresh produce delivery network to determine the optimal route cycles, assess departure time and vehicle assignment with minimum transportation cost and optimum vehicle space utilization. The model is validated by comparing with the cost of an existing manual route assignment of a 3PL company catering fresh produce to a supermarket chain from a single depot. Features of perishable food delivery such as time-window constraints, travel time and vehicle capacity.

Initial solution is generated through Dijkstra's algorithm and obtained the optimized solutions based on vehicle capacity and soft-time windows. Total cost model outlines opportunity cost of time window violation, cost of empty space and cost per distance as well. The results reveal that total cost and total travelled distance can be reduced along with number of fleet used compared to the existing manual assignment. Further this study connect practical volume calculations using crates or pallets as well. Thereby it can be concluded that the developed algorithm achieve the objectives.

Possible extensions for this model is possible by integrating heuristic or exact algorithms in a stochastic demand situation. Moreover this study is developed based on soft- time windows where a penalty is charged for non-compliance and in a more realistic aspect this can be expanded based on hard-time windows as well.

6. REFERENCES

Amorim, P., Parragh, S. N., Sperandio, F., & Almada-Lobo, B. (2014). A rich vehicle routing problem dealing with perishable food: A case study. Top, 22(2), 489–508. https://doi.org/10.1007/s11750-012-0266-4

Cooray, P. L. N. U. and Rupasinghe, T. D. (2017) 'Machine Learning-Based Parameter Tuned Genetic Algorithm for Energy Minimizing Vehicle Routing Problem', Journal of Industrial Engineering, 2017,pp.

De Jaegere, N., Defraeye, M. and Van Nieuwenhuyse, I. (2014) 'The vehicle routing problem: state of the art classification and review', Research Report, p. 30. doi: 10.1016/j.cie.2015.12.007

Du, T., Wang, F. K., & Lu, P. Y. (2007). A real-time vehicle-dispatching system for consolidating milk runs. Transportation Research Part E: Logistics and Transportation Review, 43(5), 565–577. https://doi.org/10.1016/j.tre.2006.03.001

G. S. Brar and G. Saini, "Milk Run Logistics : Literature Review and Directions," Proc. World Congr. Eng., vol. 1, pp. 797–801, 2011

Ozsoydan, F. B., and Sipahioglu, A. (2013). Heuristic solution approaches for the cumulative capacitated vehicle routing problem. Optimization: A Journal of Mathematical Programming and Operations Research 62 (10), pp. 1321 – 1340

P. Farahani, M. Grunow, and H.-O. Günther, "Integrated production and distribution planning for perishable food products," Flex. Serv. Manuf. J., vol. 24, no. 1, pp. 28–51, 2012.

U. Dharmapriya, S. Siyambalapitiya, and A. Kulatunga, "Simulated Annealing and Tabu Search Based Hybrid Algorithm for Multi depot Vehicle Routing Problem with Time Windows and Split Delivery,"

U. S. S. Dharmapriya, S. B. Siyambalapitiya, and A. K. Kulatunga, "A new hybrid algorithm for multi-depot vehicle routing problem with time windows and split delivery," Int. J. Ind. Syst. Eng., vol. 11, no. 1/2, p. 110, 2012

Vidal, T., Crainic, T. G., Gendreau, M., and Prins, C. (2014). A unified solution framework for multi-attribute vehicle routing problems. European Journal of Operational Research 234 (3), pp. 658 - 673.