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SUSTAINABLE VEHICLE ROUTING FOR SIMULTANEOUS PICKUP AND DELIVERY IN LAST MILE PROBLEM

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ABSTRACT

The paper proposes a variant of Green Vehicle Routing Problem (VRP) with simultaneous pickup and delivery within time windows. The back- bone of the e-commerce industry is the direct involvement of consumers in product delivery known as last mile delivery. The last mile delivery is the most inefficient, expensive and significant emitter of greenhouse gases in the road freight transportation. The model here is an extension of classical vehicle routing problem which minimizes the total cost function comprising of distance cost, fuel cost, driver cost and most important car- bon emission cost to serve a set of customers within the time window. It sheds light on trade offs between certain parameters like load, traffic, velocity and eco-friendly vehicle routing via nonlinear programming for- mulation with a set of valid constraints. The optimal solutions can be found out via heuristic approach, genetic algorithm or tabu search algo- rithm. The main purpose is to show the importance of fuel consumption as compared to distance minimization. In contrary to the classical VRP, this model is difficult to solve to optimal but has the potential of yielding savings in total cost.

Keywods:- *sustainability, last mile, carbon footprints, Vehicle Routing, Supply Chain.*

1. INTRODUCTION

Supply chain and logistics management have mainly focused on saving money and increase profitability by considering internal costs only and leaving out environmental concerns. Greenhouse gases have become an important issue due to global warming due to which sustainability in a supply chain is getting a great deal of attention. Last mile delivery is one of the greatest contributors to increasing carbon emissions in the transportation sector.

Vehicle routing problem is a generic name given to a class of problems which determines optimal routes for vehicles to serve the customers in the best possible way. In former times, the VRP mainly focused on minimizing the total distance traveled to serve the customers and didn't care much about other aspects like load, fuel, and carbon footprints. As economies emerged, environmental con- cerns started and sustainability gained relevance. CO_2 emission is one of the major concerns as it directly affects human health. Freight transport in the UK is responsible for 21% of the total emissions from the transportation sector. Similar figures of US where 78% contributor to CO_2 emissions is road transport out of all means of transportation. A significant increase every year in the emis- sion values forces us to take carbon footprints into account while solving this vehicle routing problem.

One of the prevalent variants of VRP is VRP with time windows. The E-Commerce industry is having a major boost since last decade and last mile delivery is a troublemaker for them. In order to satisfy the customers, tactical ways have emerged to please them. Customers have now the freedom to give proper timings for the product to be delivered so that they don't need to wait the whole day. The model takes care of delivering within the time windows provided by customers to avoid multiple comebacks.

The Green Vehicle Routing Problem with simultaneous pickup and deliveries within time windows deals with optimal routing to serve the customers during allotted time and also accompanying the carbon footprints. To the best of my knowledge, traditional studies have only dealt with a specific case in vehicle routing problems like focusing on distance traveled,fuel consumption or maxi- mizing profit. However, this model tries to mark every aspect dealt in VRP and make the model more realistic.

The remainder of the paper is structured as follows. The next section deals with the existing literature on VRP and various variants. Section 3 presents a mathematical formulation of the Green VRP. Section 4 discusses various al- gorithms

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and expected results for the formulation. Section 5 concludes the research and suggests future direction and scope.

2. LITERATURE REVIEW

The vehicle routing problem was introduced by Dantzig and Ramser in the year 1957. Since then variants of VRP for different transport situations have been studied. In the traditional VRP, the focus is concentrated on the economic impact of vehicle routes on the organization that carries out the distribution service. The present world witnesses the dominating factor of sustainability in the supply chain. To solve the issue of "last-mile" becoming a bottleneck for e-commerce (Xuping Wang et al. 2014), various models have been developed in recent years as per the requirements.

The VRP is an extension of tradition traveling salesman problem. Traveling Salesman Problem was a limited and specific case of VRP. One of the earliest formulations is from Ghodsypour and O'Brien (1998) explaining the role of sup- plier selection in a supply chain. The model helped to identify the key suppliers from economic point of view but nowhere mentions sustainability proving that it wasn't much of a concern during that period for private companies. However, Beamon (2010) in her article on "Designing a Green Supply Chain" discussed environmental regulations and redefined supply chain by taking into considera- tion of environmental issues. A hierarchy of all the regulations, acts, and policies launched by the government in the States from the period of the 1970s to 2000 is present in her article signifying that at least government got a glimpse of the problem they were going to face in the near future.

In the recent years, the problem of last mile delivery gained significance and various variants discussing specific problems and algorithms came out. Xuping Wang et al. (2014) proposed a mathematical model to minimize the total time spent on road so that faster delivery is available to customers. However, some assumptions like only one vehicle, no mention of carbon footprints make this model invalid for real case scenario. Although an experimental study from them regarding carbon emission shows that electric tricycle and light weighted van had approximately the same time spent in delivery with less emission in the former case. Kim and Jeon (2010) formulation also minimizes the total time spent but also considers the case of time window for serving the customers which is prevalent in the present world. The model not only takes care of multiple vehicles but also considers traffic congestion in some quantifiable way. Gevaers, Van de Voorde, and Vanelslander (2014) compared the routes of the vehicle with and without time window and results show that the route becomes too complex when time window is taken into account. Their models lack analysis on extra cost suffered because of neglecting the total distance traveled and fuel consumed in delivery.

The major focus has been in reducing the cost from the economic point of view and carbon footprints from the environmental point of view. Some online retailers claimed that online shopping yields better environmental benefits as compared to consumer pickup (Edwards, McKinnon, and Cullinane 2010) which might appear a bit untrue to consumers on the fact they don't incur the extra harm to the environment by home delivery. However, Edwards, McKinnon, and Cullinane (ibid.) proved the statement of online retailers to be right by giving a comparative study of the carbon footprints of conventional and online retailing on a research based in the UK on small non-food items. The paper includes data on distance traveled by different means of transport in case of customer pickup, CO_2 emission for all the types defined and no. of articles bought by a customer in a single trip. The comparative study between the emission values per item in case of online retailing and conventional method shows that a person would need to buy 24 non-food items in one standard car-based trip for this method of shopping to be less CO_2 intensive than having one non-food item delivered (on the first attempt) to their home by a parcel carrier. However, this result is based on certain assumptions about the type of vehicles (van), customer trips are exclusively meant for shopping and successful first time delivery which isn't the case in real world. The work does show us that online market with some judicious steps might leave far away from the retails market in terms of environmental

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safety.

The problem with carbon emission is how to incorporate it with factors such as time or cost. In order to beat that problem, Hsieh and H. W. Huang (2015) proposed a solution by minimizing the distance traveled by the vehicle. Less traveled distance will not only reduce the cost of fuel for the company but will result in less environmental damage. However, that case is not valid every time. Peng and Xiaofeng Wang (2009) gave a relative study of minimizing distance and minimizing fuel consumption. The different solutions of the two functions i.e. distance minimization and fuel consumption illustrate that the two situations are different. Fuel consumption varies with the load of the vehicle and so is the carbon emission. The statement is backed by numerical example in the paper. However, if we ignore the fact of variation of fuel consumption with varying load, the problem of fuel minimization is same as distance minimization.

As sustainability showed up in the VRP, terms like Green VRP and Pollution- Routing Problem (PRP) came into existence. Liu et al. (2014) model is very generic and considers every aspect like heterogeneous vehicles, multiple paths, time window and carbon emissions but fails to explain traffic congestion and simultaneous pickup and delivery. Y. Huang et al. (2012) did explain simulta- neous pickup and delivery but left the case of time window.

E Demir and Woensel (2013) idea of defining carbon footprints cost consid- ering engine's combustion efficiency, air resistance, acceleration etc for a multi- depot problem is remarkable but lacks other parameters like traffic congestion and multiple paths option. Bektaş and Laporte (2011) used the same model and gave a sensitivity analysis of different parameters. Several models were then proposed specifically for the green VRP with objective of minimizing the carbon emissions but absence of other aspects hinder the generality of the model (Adiba, Aahmed, and Youssef 2014).

Another way of defining the PRP is by defining the fuel tank level (Erdogan and Miller-Hooks 2012). The model dynamically considers fuel level in the tank and includes alternative fueling stations for refueling. This model can also be extended for electric vehicle with recharging stations which will prove out to be a sustainable solution for this long term problem. Edwards, McKinnon, and Cullinane (2010) extended their previous research and in 2011 did mention that carbon footprints for electric vehicles as compared to fuel based is significantly low.

As the objective became clear to minimize the overall cost as well as car- bon emissions, various algorithms were developed for faster computational re- sults. The bi-objective problem (Emrah Demir, Bekta, and Laporte 2014) was solved via adaptive large neighbourhood search algorithm whereas Ai and Ka- chitvichyanukul (2009) used particle swarm optimization for the simultaneous pickup and delivery problem. However, as the complexity of model increased, it was difficult to find optimal solutions and heuristics and meta-heuristics were used to reach near optimal point (Karaoglan et al. 2012). Xiao et al. (2012) favored search algorithms where Franceschetti et al. (2013) used CPLEX soft- ware with Disjoint Sum of Product (DSOP) algorithm. The results from every model proved that optimization may lead to significant decrease in cost as well as greenhouse gases emissions.

3. MATHEMATICAL MODEL

This section deals with the mathematical formulation for green vehicle routing problem with simultaneous pickup and deliveries within time windows. The model is an extension of all models build and explained in Section 2 with certain assumptions as explained below.

3.1 Information

- There is only one depot in the model with fixed location.
- All vehicles start from depot and end at the depot.

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- Loading capacities of each vehicle is known along with emission rate and fuel consumption at different velocities.
- Distance of a path between two nodes is known.
- There are multiple paths between two nodes.
- Demand and Pickup requirements are known for each customer.
- Each customer node is visited only once.
- Total demand of an individual customer cannot exceed vehicle capacity.
- There are different types of traffic situations considered.
- Velocity at each type of traffic situation is fixed and known.
- There is a cost associated with distance traveled and the value is defined by the capacity of total distance vehicle can travel.
- There is a cost associated with the amount of fuel consumed.
- There is a cost associated with the driver and varies with the distance traversed.
- The case of delivery within time window is considered.
- Service time of each customer is fixed and known.
- There is a cost associated with the amount of carbon emission.
- Traffic Situation of each path is known and considered to be same through- out the working hours

3.2 Notations

- No of customer = N I = {c1 , c2 , . . . , cN } c0 = Depot
- I0 = c0 ∪ I
- No. of vehicles = K
- Capacity of each vehicle = Qk
- Fuel consumption per kilometer of vehicle k under traffic condition t =Fkt
- Velocity under traffic condition t = Vt
- No. of routes = R
- No. of paths between nodes i and j = zij
- Dijz = Distance between node i and node j via path z
- Traffic condition k
  - k = 1 : Smooth
  - k = 2 : Slow
  - k = 3 : Delaying
  - k = 4 : Stagnating
- Average Service time = λ (fixed)
- Time window for customer i = [ai , bi]
- Beginning of work = Tb
- End of work time = Te
- Demand value at node i = di
- Pickup value at node i = pi
- Maximum distance a vehicle can travel in one route = D
- Emission equivalent to one liter of fuel consumption = E
- Maximum allowable emission from a vehicle k = Emk
- Driver cost per kilometer = C0
- Cost of emission = Ce per unit of emission
- Cost of unit distance = Cd
- Cost of unit liter fuel consumption = Cf
- Fuel consumption with load = Flkt per km per kg

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3.3 Variables

- x^k_{ijz} = if arc (i, j) with path z is traversed by vehicle k
- Z^t_{ijz} = if arc (i, j) with path z is traversed under traffic condition t
- y_{1j} = time at which service starts at node j
- y_{2j} = time at which service ends at node j
- y_{3ijzt} = time consumed to travel on path z between node i and j under traffic condition t
- s_j = total time spent on the route that has node j as the last node visited
- f^k_{ij} = total load between node i and j on vehicle k

3.4 Objective Function

Minimize Z = Distance cost + fuel cost + emission cost + driver cost

Distance cost $= \sum_{i\in I_0} \sum_{j\in I_0} \sum_{z=1}^{z_{ij}} \sum_{k=1}^{K} C_d * D_{ijz} * x^k_{ijz}$

Driver cost = C_0*(Distance traveled)

Fuel Cost = Cost of empty vehicle + Cost of loaded vehicle

Cost of empty vehicle $= \sum_{i\in I_0} \sum_{j\in I_0} \sum_{z=1}^{z_{ij}} \sum_{t=1}^{4} \sum_{k=1}^{K} F_{kt} * C_f * D_{ijz} * x^k_{ijz} * z^t_{ijz}$

Cost of loaded vehicle $= \sum_{i\in I_0} \sum_{j\in I_0} \sum_{z=1}^{z_{ij}} \sum_{t=1}^{4} \sum_{k=1}^{K} F_{lkt} * f^k_{ij} * C_f * D_{ijz} * x^k_{ijz} * z^t_{ijz}$

Emission Cost $= \frac{C_e}{E * C_f}$*(Cost of fuel consumed)

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3.5 Constraints

- Each node is met only once

$$\sum_{j\in I_0}\sum_{z=1}^{z_{ij}}\sum_{k=1}^{K} x_{ijz}^{k} = 1 \qquad \forall i \in I \qquad (1)$$

$$\sum_{i\in I_0}\sum_{z=1}^{z_{ij}}\sum_{k=1}^{K} x_{ijz}^{k} = 1 \qquad \forall j \in I \qquad (2)$$

- No. of vehicles entering = No. of vehicles leaving

$$\sum_{i\in I_0}\sum_{z=1}^{z_{ij}}\sum_{k=1}^{K} x_{ijz}^{k} = \sum_{i\in I_0}\sum_{z=1}^{z_{jk}}\sum_{k=1}^{K} x_{jkz}^{k} \qquad \forall j \in I \wedge \forall k \in I_0 \wedge i \neq j \qquad (3)$$

- Vehicle doesn't return back to the node

$$\sum_{z=1}^{z_{ij}}\sum_{k=1}^{K} x_{ijz}^{k} + \sum_{z=1}^{z_{ji}}\sum_{k=1}^{K} x_{jiz}^{k} \leq 1 \qquad \forall i,j \in I \wedge i \neq j \qquad (4)$$

- Only one path is chosen between two nodes

$$\sum_{z=1}^{z_{ij}}\sum_{k=1}^{K} x_{ijz}^{k} \leq 1 \qquad \forall i,j \in I \wedge i \neq j \qquad (5)$$

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- Total vehicles left the depot = No.of routes

$$\sum_{j\in I}\sum_{z=1}^{z_{0j}}\sum_{k=1}^{K} x_{0jz}^{k} = R \qquad \forall j \in I \qquad (6)$$

- Total Routes $\leq$ No. of Vehicles
- Total vehicles left the depot = Total vehicles returning

$$\sum_{j\in I}\sum_{z=1}^{z_{j0}}\sum_{k=1}^{K} x_{j0z}^{k} = R \qquad \forall j \in I \qquad (7)$$

- Load on Vehicle should be less than maximum capacity

$$f_{ij}^{k} \leq Q_k \sum_{z=1}^{z_{ij}} x_{ijz}^{k} \qquad \forall k \in K \wedge \forall i,j \in I_0 \wedge i \neq j \qquad (8)$$

- Difference in load after visiting a node should be equal to the difference between pickup and delivery demand

$$(f_{jl}^{k} - f_{ij}^{k}) * (\sum_{z=1}^{z_{ij}} x_{ijz}^{k} \sum_{z=1}^{z_{jl}} x_{jlz}^{k}) = (p_j - d_j) * (\sum_{z=1}^{z_{ij}} x_{ijz}^{k} \sum_{z=1}^{z_{jl}} x_{jlz}^{k}) \qquad (9)$$

- Boundary Conditions for loads

$$\sum_{j\in I}\sum_{k=1}^{K}\sum_{z=1}^{z_{0j}} f_{0j}^{k} * x_{0jz}^{k} = \sum_{j\in I} d_j \qquad (10)$$

$$\sum_{j\in I}\sum_{k=1}^{K}\sum_{z=1}^{z_{j0}} f_{j0}^{k} * x_{j0z}^{k} = \sum_{j\in I} p_j \qquad (11)$$

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- Time Constraints

$$a_i \leq y_{1i} \leq b_i \qquad \forall i \in I \qquad (12)$$
$$y_{2j} = y_{1j} + \lambda \qquad \forall j \in I \qquad (13)$$
$$T_b \leq y_{1j} \leq T_e \qquad \forall j \in I \qquad (14)$$
$$T_b \leq y_{2j} \leq T_e \qquad \forall j \in I \qquad (15)$$
$$s_j + y_{3j0zt} \leq T_e \qquad \forall \text{ last visited node } j \qquad (16)$$
$$y_{3ijzt} = \frac{D_{ijz}}{V_{kt}} \qquad (17)$$

- Time Continuity Equation

$$y_{1j} * \sum_{z=1}^{z_{ij}} x_{ijz}^k \geq y_{2i} \sum_{z=1}^{z_{ij}} x_{ijz}^k + \sum_{z=1}^{z_{ij}} \sum_{t=1}^{4} y_{3ijzt} * z_{ijz}^t \sum_{z=1}^{z_{ij}} x_{ijz}^k \quad \forall i, j \in I \wedge k \in K \wedge i \neq j \qquad (18)$$

- Total distance traveled $\leq$ D

$$\sum_{i \in I_0} \sum_{j \in I_0} \sum_{z=1}^{z_{ij}} D_{ijz} * x_{ijz}^k \leq D \qquad \forall k \in K \wedge i \neq j \qquad (19)$$

- Emission from One vehicle

  Fuel Consumer by vehicle k without load =
  $\sum_{i \in I_0} \sum_{j \in I_0} \sum_{z=1}^{z_{ij}} \sum_{t=1}^{4} F_{kt} * D_{ijz} * x_{ijz}^k * z_{ijz}^t$

  Fuel Consumer by vehicle k with load =
  $\sum_{i \in I_0} \sum_{j \in I_0} \sum_{z=1}^{z_{ij}} \sum_{t=1}^{4} F_{lkt} * f_{ij}^k * D_{ijz} * x_{ijz}^k * z_{ijz}^t$

  Emission = $\frac{1}{E}$*(fuel consumed) $\leq E_{mk}$

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- Binary Variables and Non-negativity

$$x^k_{ijz} \in \{0,1\} \qquad \forall k \in K \wedge (i,j) \in I_0 \wedge z \in z_{ij} \qquad (20)$$

$$z^t_{ijz} \in \{0,1\} \qquad \forall t \in T \wedge (i,j) \in I_0 \wedge z \in z_{ij} \qquad (21)$$

$$y_{1j} \geq 0 \qquad \forall j \in I \qquad (22)$$

$$s_j \geq 0 \qquad \forall j \in I \qquad (23)$$

$$f^k_{ij} \geq 0 \qquad \forall i,j \in I_0 \wedge k \in K \qquad (24)$$

4. CONCLUSION AND FUTURE SCOPE

The article investigated the paramount aspects of vehicle routing problem with a focus on sustainability. A generalized formulation for the existing formula- tions in the literature is present incorporating the uttermost important aspect
i.e. sustainability. The major contribution of this paper is the model integrat- ing the economic and sustainability to build a real case scenario. Chaabane and Geramianfar (2015) multiobjective model gave different results for different ob- jective function concluding that some of the requirements do conflict with each other. It is hard to find solutions for both sustainability and economic factors simultaneously but a heuristic approach may help us to find a solution which won't be optimal but give us a solution which partially satisfy both conditions.

Sustainability plays an important role in the present world. Newer solutions are coming up to make the supply chain green and efficient. Reception and delivery boxes concept in last mile delivery resulted on 60% cost reduction as compared to standard solutions (Punakivi, Yrjölä, and Holmström 2001). The article's contribution lies in aggregating the publications on this topic to provide an overview of the different approaches taken and propose a more realistic model from the existing ones. However, the world is open to ideas and favorable to sustainable solutions to develop ideas that take into account the intricacies of supply chain structure.

The analysis of sustainable supply chain design and vehicle routing needs fur- ther expansion. Future research can take up some of the challenges like incorpo- rating multiple delivery solutions, more exhaustive model for traffic, stochastic modeling for service times etc. which are relaxed by taking assumptions. Very few papers take into account the social aspect of sustainability into account. Developing a more comprehensive model for sustainability with the help of em- pirical data is one of the potential future research direction. Cross country experiments and results can be compared to figure out the problems. These research directions and questions would help to develop the field further and give solutions to even more complex problems.

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