A Practical Green Vehicle Routing Solution – A Case in Ho Chi Minh City

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Abstract

Energy overuse in transportation is recently generating harmful effects to the environment. Green logistics is becoming a prospective trend in the growing logistics industry. This paper investigates the green vehicle routing problem (Green-VRP), with two objectives: minimizing combined fuel emissions and minimizing distance traveled with capacitated vehicles. An improved K-means clustering method is employed to group demand nodes to reduce the size of the problem. The model is then verified using a set of customers in Ho Chi Minh city, computational results show 3 clusters of customers. In addition, a real application for mobile phones namely “Control Fleet Vehicle” is created to help users control their fleets of vehicles and connect easily to customers.

Keywords

Green vehicle routing problem, Improved k-means clustering, Fuel emission minimization

1. Introduction

Transportation really plays a particularly vital role in logistics and this role will increase because the cost of transport accounts for an increasing proportion of logistics. Therefore, the logistics organizations try to bring higher production efficiency and competitiveness of logistics by reducing transportation costs. However, quick development of transportation sector also comes along negative impacts on society, health, and environment which are the consequences of increases in the abundance of hazardous emissions. Due to the rapid development of e-commerce, which leads to the presence of the transport occur more and more, the transportation industry has been one of the main sources of increased energy consumption and carbon emission in recent years. This urges the governments and scholars to deploy a new green-logistic supply chain system, reducing fuel emissions in transportation service.

Inspired by the traditional Vehicle Routing Problem (VRP), which was first formulated mathematically by (Dantzig & Ramser, 1959) thereby studied by numerous researchers throughout the field of transportation, this study extends the problem to Green Vehicle Routing Problem (G – VRP), aiming at contributing the recent environmental awareness in the field of transportation in logistic by combining fuel consumption and travelled distance optimization. More specifically, the G-VRP is applied within the scope of transportation service case in Ho Chi Minh city – one of the biggest cities in Vietnam. The is now producing huge wellspring of greenhouse gas emissions (GHG, accounting for about 16% of national emissions, in which GHG from the transport sector accounts for 45% ((MONRE) & DCC, 2015).

Objectives:

The purpose of the study is to minimize the total distance travelled and the total fuel consumption by vehicles to increase not only customer satisfaction but also sustainable development of company’s transportation service. The fuel utilization minimization is the significant goal along with the distance minimization. Therefore, appropriate weights are given to each of the sub-objective. The solution is a set of routes by that each customer will be served only once and concerning vehicle capacity constraints.

2. Literature Review

The vehicle routing problem is dealing with the problem of identifying the optimal series of routes with possible minimal travelling time or travelling total cost, considering a set of customer nodes and depot(s) from which the vehicle departs to visit each customer once, subjected to a set of constraints. The VRP has been developed to many variants such as Capacitated VRP, VRP with time-windows, VRP with Backhauls, VRP with Pickup and Delivery and some others. The Green Vehicle Routing Problem is also a variant of VRP, focusing on managing environmental effect of vehicles during transportation. There are a number of literatures working on the Green Vehicle Routing Problem which has been performed since 2006.

The VRP with green transportation was first developed by Sbihi & Eglese (2007) who consider the basic Vehicle Routing and Scheduling Problem model that relate to environmental problems with the time-dependent, the transportation of hazardous materials. Kara et al., (2007) introduced the so-called Energy-Minimizing Vehicle Routing Problem which is an extension of the VRP where a weighted load function (load multiplied by distance), rather than just the distance, is minimized. The authors present a model for this problem, based on a flow formulation of the VRP with a load-based objective function derived from simple physics. However, the cost function lacks further measurement of fuel consumption or emission. Palmer (2007) developed an integrated routing and carbon dioxide emission model for a goods vehicle. In the transportation problem, the main objective is to minimize the total distance travelled by trucks, ships, planes, and trains to transport the goods. This kind of transportation generates a lot of carbon dioxide in the environment. The especially urban city is more polluted due to large carbon dioxide, which has been received significant attention from social participants.

Xiao et al., (2012) assumed the fuel consumption rate be a linear function of load and built an integer programming model containing fixed cost and fuel cost. Bektaş et al., (2016) indicated that the amount of pollution emitted by a vehicle depends on its load and speed. They also considered the fuel cost, CO2 emission cost and driver's salary in the objective, and proposed an integer linear programming model along with a heuristic algorithm to deal with the Pollution-Routing Problem. Elbouzekri et al., (2013) reported the formation to estimate the emission of the trucks. Tiwari & Chang (2015) used clustering and genetic algorithms to solve GVRP. The objective function considered the minimum distance travelled by each vehicle as well as the total emitted CO2, which was directly assumed to be the product of mean distance, load and conversion factor. Jabali et al., (2012) proposed a model that considers CO2 emission-related costs, including fuel consumption, travel time, and time-dependent emissions, and the model is solved using a TS procedure. Qian and Eglese (2016) addressed the optimization of fuel emissions in VRPs with time-varying speeds, considering the capacities of the vehicles and the time constraints on the total length of each route.
As the G-VRP is NP-hard problem just like traditional VRP, the small-sized problem could be solved effectively within short time by exact solution methods, which have been researched and proposed by many scholars (Baldacci et al., 2010; Kallehauge, 2008; Qureshi et al., 2009; Toth & Vigo, 1998). For node sets of large-size G-VRP, various heuristics as well as metaheuristics have been investigated to achieve near-optimal results (Andelmin & Bartolini, 2019; Felipe et al., 2014; Montoya et al., 2016; Normasari et al., 2019; Olgun et al., 2021). Recently, many studies have been considered to the G-VRP by using various approaches : the hybrid heuristic algorithm of Hooshmand & MirHassani (2019) for a time-dependent G-VRP, differential evolution algorithm and Particle swarm optimization (Fallah et al., 2019), ant-colony optimization for multi-depot and multi-objectives G-VRP (Li et al., 2019), Non-Dominated Sorting Genetic Algorithm II (Dutta et al., 2021).

3. Mathematical Model

The G-VRP in this study can be expressed as a routes optimization problem with objective of minimizing fuel emissions and travelled distance over a set of customer service network G = (V, A), where V = {0, 1, …, n} is a set of n customer nodes, n = 0 is the depot from which each truck must start and return at the end of the journey after visiting and satisfying demand of customer nodes in set N = {1, …, n}. Each customer node is served exactly once by one truck, and all the trucks have the same capacity. Therefore, customer demand of each node must be less than the capacity of the truck. A daytime is split into many time periods p with different vehicle speeds due to different traffic conditions.

3.1 Comprehensive Modal Emission Model

In this section, fuel consumption is calculated by using the comprehensive modal emission model (CMEM - Niu et al., (2018))

$$F = \lambda * \left(\frac{k*N*V*d}{v} + Weight * \gamma * \alpha * d + \beta * \gamma * d * v^2\right)$$

where $\lambda = \frac{\xi}{\kappa*\psi}; \gamma = \frac{1}{1000*n_{tf}*\eta}$

and $\alpha = \tau + g * sin\theta + g * C_r * cos\theta$

$$\beta = \frac{C_d*\rho*A}{2}$$

τ is acceleration and $\boldsymbol{\theta}$ is the road angle inclination, assuming that acceleration and road inclination are zero (Niu et al., 2018).

Weight means the total vehicle weight including the weight of vehicle and goods, while $\boldsymbol{v}$ represents the vehicle speed, it can be calculated as the distance over the travelling time. Vehicle speed $\boldsymbol{v}$ is obtained by traveling distance and traveling time. Parameters are used to calculate fuel consumption are shown in Table 1. The specific parameters of the vehicle are listed in Table 2 (Niu et al., 2018). In the original model of Niu and colleagues, 3 types of vehicle duty are tested: light, medium and heavy duty. The results show that for 60-nodes problem and smaller, light-duty trucks give better results of smaller cost. As our problem is considering set of nodes smaller than 60, light-duty vehicles are assumed, given specific parameters in Table 2.

Table 1: Parameters for fuel consumption calculation

Notation	**Description**	**Typical values**
ξ	Fuel-to-air mass ratio	1
g	Gravitational constant (m/s2)	9.81
ρ	Air density (kg/m^2)	1.2041
C_r	Coefficient of rolling resistance	0.01
η	Efficiency parameter for diesel engines	0.45
fc	Fuel and CO2 emissions cost (RMB/liter)	12.0165
κ	Heating value of a typical diesel fuel (kj/g)	44
ψ	Conversion factor (g/s to L/s)	737
n_{tf}	Vehicle drive train efficiency	0.45

Table 2: Vehicle specific parameters

Notation	**Description**	**Typical values**
w	Curb weight (kg)	3500
Q	Maximum payload (kg)	4000
k	Engine friction factor (kj/rev/liter)	0.25
N	Engine speed (rev/s)	38.34
V	Engine displacement (liter)	4.5
C_d	Coefficient of aerodynamics drag	0.6
A	Frontal surface area (m^2)	7

3.2 Green Vehicle Routing Mathematical Model

The model was developed to satisfy all constraints about the customers' demand, the fuel consumption depending on the total distance vehicles travel and the time restrictions for trucks in Ho Chi Minh city. The fuel consumption objective is inherited from the CMEM of Niu et al., (2018) and adapted from Feng et al., (2017), being shown in the following section.

Let G = (V, A) be a customer service network, where V = {0, 1, …, n} is a set of n customer nodes, n = 0 is the warehouse.
N = {1, …, n} is a set of customer nodes
A = {(i, j) ∈ V x V} is the set of arcs
D = {dij | (i, j) ∈ A} is the set of travelling distance
M: a huge number
T: a set of period time

q_i: demand of customers
$capa$: Capacity of the truck

Decision variables:
x_{ij}^{p} = 1 if vehicle visits from customer *i* to *j* in period *p*
x_{ij}^{p} = 0 otherwise
u_{ij}^{p}: the quantity goods retained by vehicle from customer *i* to *j* in period *p*
t_i: the departure time at node *i*
$matrix\_time_{ij}^{p}$: the travelling time from customer *i* to customer *j* in period *p*

Objective function:

$$Min\ Z1 = Fuel\ consumption = \sum_{i \in V, i \neq j} \sum_{j \in V} \sum_{p \in T} \lambda * x_{ij}^{p} * k_1 * N * v_{1*}\ matrix\_time_{ij}^{p}$$

$$+ \sum_{i \in V, i \neq j} \sum_{j \in V} \sum_{p \in T} d_{ij} * Weight * \gamma * \lambda * g * C_r * x_{ij}^{p}$$

$$+ \sum_{i \in V, i \neq j} \sum_{j \in V} \sum_{p \in T} d_{ij} * x_{ij}^{p} * \frac{1}{2} * C_d * \rho * A * \gamma * \lambda * \left(\frac{d_{ij}}{matrix\_time_{ij}^{p}}\right)^2$$

$$+ \sum_{i \in V, i \neq j} \sum_{j \in V} \sum_{p \in T} d_{ij} * u_{ij}^{p} * \gamma * \lambda * g * C_r$$

$$Min\ Z2 = Travelling\ distance = \sum_{i \in V, i \neq j} \sum_{j \in V} \sum_{p \in T} d_{ij} * x_{ij}^{p}$$

Subject to:

$$\sum_{i \in V} \sum_{p \in T} x_{ij}^{p} = 1\ (\forall\, j \in V, i \neq j) \tag{1}$$

$$\sum_{j \in V} \sum_{p \in T} x_{ij}^{p} = 1\ (\forall\, i \in V, i \neq j, i \neq 0) \tag{2}$$

$$\sum_{j \in V} x_{ij}^{1} = 1\ (\forall\, i \in V, i \neq j, i = 0) \tag{3}$$

$$\sum_{i \in V, i \neq j} \sum_{p \in T} u_{ij}^{p} - \sum_{i \in N, i \neq j} \sum_{p \in T} u_{ji}^{p} = q_i\ (\forall j \in N) \tag{4}$$

$$\sum_{i \in V} \sum_{j \in V} \sum_{p \in T} u_{ij}^{p} \leq capa * x_{ij}^{p}\ (i \neq j) \tag{5}$$

$$t_0 = 0 \tag{6}$$

$$t_i - U_{p-1} * x_{ij}^{p} \geq 0\ (\forall i \in N, \forall j \in V, \forall p \in T, i \neq j) \tag{7}$$

$$t_i + M * x_{ij}^{p} \leq U_p + M\ (\forall i \in N, \forall j \in V, \forall p \in T, i \neq j) \tag{8}$$

$$If\ x_{ij}^{p} = 1, t_j = t_i + matrix\_time_{ij}^{p} \tag{9}$$

$$x_{ij}^{p} \in \{0; 1\} (\forall i \in V, \forall j \in V, i \neq j) \tag{10}$$

$$t_i \geq 0\ (\forall i \in V) \tag{11}$$

$$u_{ij}^{p} \geq 0\ (\forall i \in V, \forall j \in V, \forall p \in T, i \neq j) \tag{12}$$

The first objective is to minimize the fuel consumption considering the speed of the vehicle related to the traffic jams on the road, while the second one minimizes the total distance that vehicle moves between customers during the trip. Constraint 1 defines that the vehicle must return to depot from the last customer. Constraint 2 shows that each customer is served exactly once. Constraint 3 defines that the first customer must be visited from the depot in period one. Constraint 4 shows the flow of goods containing on the vehicle when it leaves depot until it returns depot. Constraint 5 guarantees that the goods retain on a vehicle always less than its capacity. Constraint 6 sets the departure time at the depot is 0. Constraint 7 and constraint 8 identify that the departure time at customer i belongs to the upper and lower bound of a period time. Constraint 9 calculates the time of the departure time of customer depending on the state of the traffic jams. While constraint 10, constraint 11 and constraint 12 restrict the condition of all decision variables.

4. Methods

Instead of solving a large problem, Geetha et al. used the approach for capacitated clustering for dividing the big cluster to many smaller clusters (Geetha et al., 2009). To find the routing for each vehicle, the weight-sum technique is applied to solve the multi-objective model. The weight of each objective can be defined by decision makers depending on their strategies.

5. Numerical Example

In this study, the instance set is provided to illustrate the efficient of model. This data set includes 76 customers who are in Ho Chi Minh City and only 4-ton truck is considered. The demand customers are shown in Table 3.

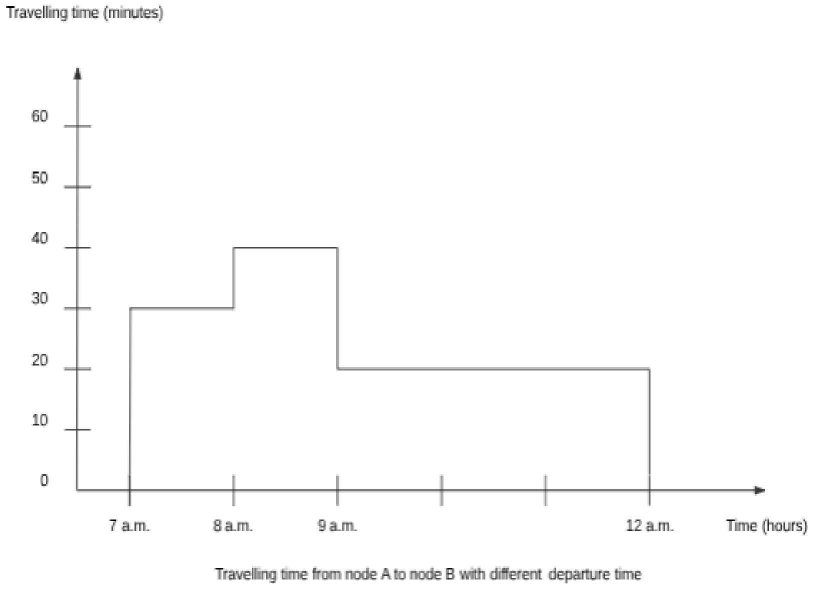


Figure 1: Traveling time from node A to node B with different departure time

Table 3. Customer demand

No.	Customer demand (ton)	No.	Customer demand (ton)	No.	Customer demand (ton)
1	0.13	27	0.15	52	0.15
2	0.19	28	0.2	53	0.12
3	0.12	29	0.12	54	0.13
4	0.17	30	0.18	55	0.17
5	0.11	31	0.12	56	0.15
6	0.1	32	0.19	57	0.19
7	0.16	32	0.18	58	0.19
8	0.19	33	0.17	59	0.11
9	0.11	34	0.12	60	0.18
10	0.15	35	0.11	61	0.18
11	0.19	36	0.14	62	0.14

12	0.11	37	0.16	63	0.13
13	0.12	38	0.15	64	0.2
14	0.11	39	0.11	65	0.11
15	0.17	40	0.16	66	0.13
16	0.12	41	0.16	67	0.16
17	0.17	42	0.16	68	0.15
18	0.14	43	0.19	69	0.19
19	0.11	44	0.11	70	0.19
20	0.16	45	0.12	71	0.19
21	0.1	46	0.15	72	0.11
22	0.11	47	0.1	73	0.16
23	0.19	48	0.18	74	0.13
24	0.1	49	0.17	75	0.19
25	0.2	50	0.2	76	0.17
26	0.14	51	0.18		

Illustrated by Figure 1, the departure time of vehicle changes during the daytime and starts at 7.am. The travelling time from depot to customers and from customers to customers with different departure time is obtained through Google Application Programming Interface (Google API). Traveling time may be changed depending on vehicle departure time because of traffic –jam. If a vehicle leaves node A from 7 a.m. to 8 a.m., traveling time is 30 minutes to reach node B. While the departure time at node A is from 8 a.m. to 9 a.m., it takes 40 minutes for a trip AB (see Fig 1).

6. Results

By using Improved K-Mean Clustering approach, 76 customers are grouped to 3 clusters around the city. There are 25 nodes in cluster 1 and 2, while 27 nodes in group 3. In this case, as the focus of this G-VRP is more about the environment, the weight chosen for the first objective is 0.7, while the second one is 0.3. The objective weights can be defined based on the importance of objective. The optimal routings for vehicles, the minimized distances and minimized fuel consumptions from 3 vehicles throughout 3 clusters are shown in Table 4. The first vehicle is expected to finish more than 90 kilometers when generating 9.619 litters of gases, while the second is expected to generate 6.28 litters of gases after traveling a route of 63.8 kilometers. For cluster 3, even though the number of nodes is the highest among 3, travel distance and emission amount is lower than that of cluster 1. However, computing time of the optimizer for this instance is 3.39 minutes, the longest among 3 cases.

Table 4. The optimal routings of the 3 clusters

	Routing	Minimize Distance (km)	Minimize fuel consumption (litter)
Cluster 1	depot, 48, 56, 70, 64, 52, 49, 65, 77, 75, 36, 42, 61, 41, 39, 43, 35, 33, 31, 34, 66, 38, 37, 28, 25, 10, depot	90.794	9.619
Cluster 2	depot, 44, 73, 4, 3, 1, 60, 68, 59, 9, 12, 45, 76, 47, 74, 7, 67, 58, 57, 8, 69, 46, 51, 50, 72, 62, depot	63.836	6.28
Cluster 3	depot 32, 29, 27, 30, 40, 53, 55, 71, 54, 17, 19, 18, 16, 26, 14, 15, 5, 13, 24, 20, 22, 23, 21, 6, 63, 11, 2, depot	82.771	8.14

6. Practical Implications

To support for drivers and managers, an android application called "Control Fleet Vehicle" is created. Interface of this application is shown in Figure 2.

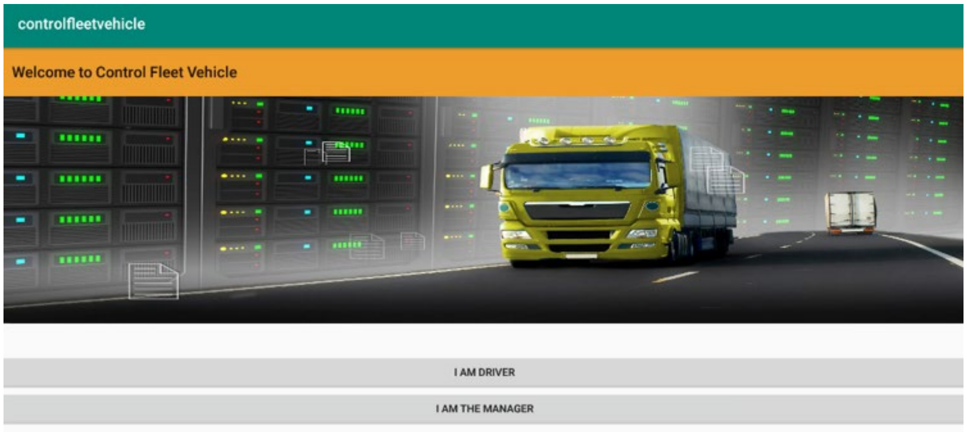
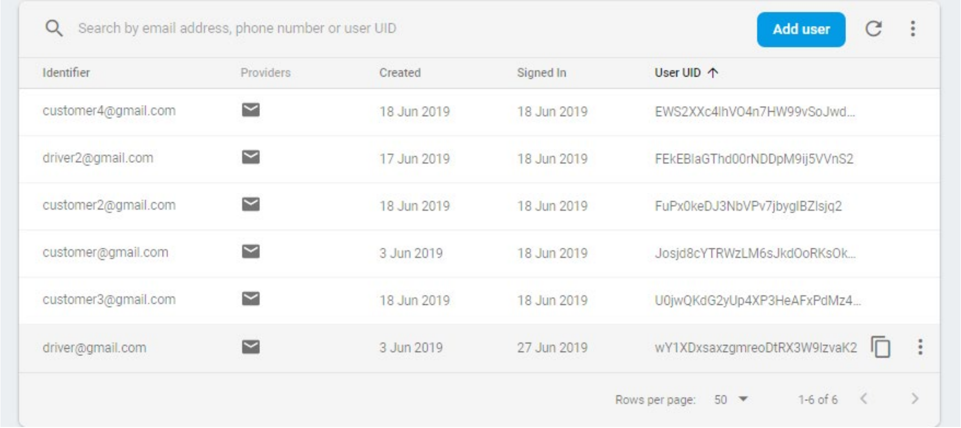


Figure 2. Login and Registration Screen for Drivers and Manager

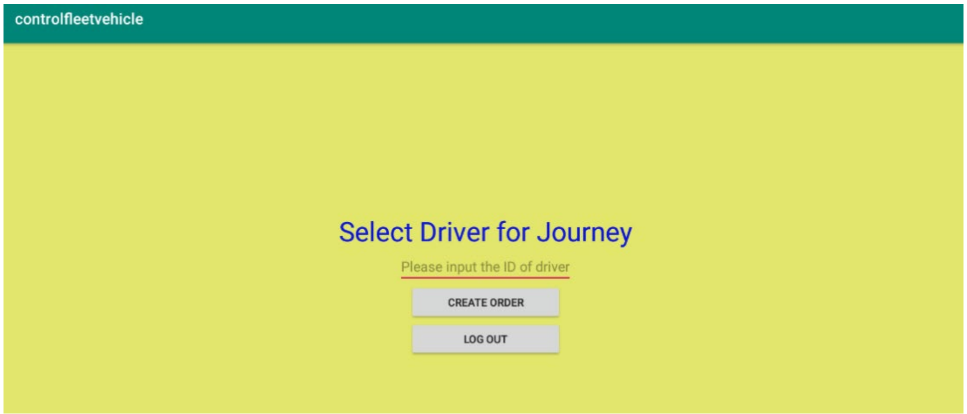
"Control Fleet Vehicle" allows users to register to become a driver or a manager. To be a member, emails and phone numbers are required and stored into firebase Authentication and Database. Firebase automatically creates UID for each account (see Fig 3).



Identifier	Providers	Created	Signed In	User UID ↑
customer4@gmail.com	✉	18 Jun 2019	18 Jun 2019	EWS2XXc4lhVO4n7HW99vSoJwd...
driver2@gmail.com	✉	17 Jun 2019	18 Jun 2019	FEkEBlaGThd00rNDDpM9ij5VVnS2
customer2@gmail.com	✉	18 Jun 2019	18 Jun 2019	FuPx0keDJ3NbVPv7jbyglBZlsjq2
customer@gmail.com	✉	3 Jun 2019	18 Jun 2019	Josjd8cYTRWzLM6sJkdOoRKsOk...
customer3@gmail.com	✉	18 Jun 2019	18 Jun 2019	U0jwQKdG2yUp4XP3HeAFxPdMz4...
driver@gmail.com	✉	3 Jun 2019	27 Jun 2019	wY1XDxsaxzgmreoDtRX3W9lzvaK2

Rows per page: 50 1-6 of 6

Figure 3. Firebase Real-time Database Authentication



Please input the ID of driver

Figure 4. Manager's screen Login

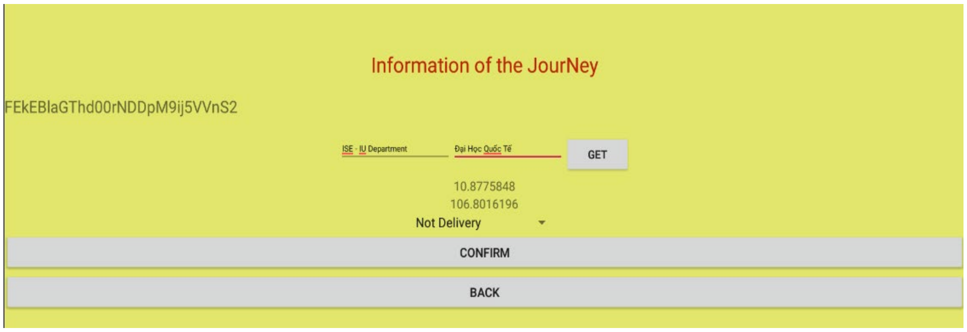
Function for Manager:
After logging in with the function of a manager, a new screen appears for a manager to select a driver who will serve the route. Managers input the sequence locations of the route which obtained from multi-objective model to the applications (see Fig 5, 6).

- Users
  - Customers
    - EWS2XXc4lhVO4n7HW99vSoJwd
    - FuPx0keDJ3NbVPv7jbyglBZIsjq2
    - Josjd8cYTRWzLM6sJkdOoRKsOk
  - Drivers
    - FEkEBlaGThd00rNDDpM9ij5VVnS

Figure 5. Drivers'UID in FRD

FEkEBlaGThd00rNDDpM9ij5VVnS2

Figure 6. Putting driver UID into space

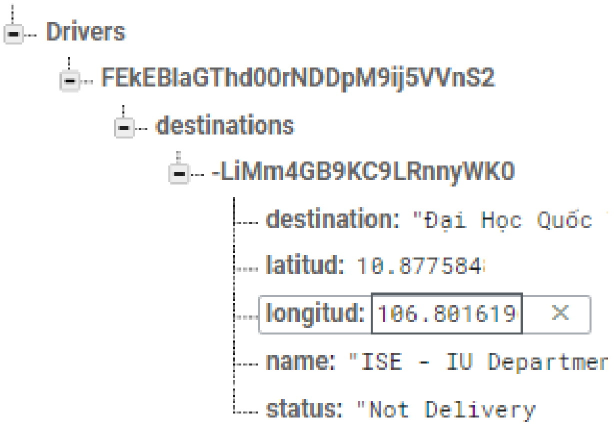


FEkEBlaGThd00rNDDpM9ij5VVnS2

ISE - IU Department
Đại Học Quốc Tế
10.8775848
106.8016196
Not Delivery

Figure 7. All information added by managers

A manager confirms all input information by pressing "CONFIRM". These data are automatically update into database (see Fig 8) and routing for delivery is shown for drivers (see Fig.9).



Drivers
FEkEBlaGThd00rNDDpM9ij5VVnS2
destinations
-LiMm4GB9KC9LRnnyWK0
destination: "Đại Học Quốc
latitud: 10.877584
longitud: 106.801619
name: "ISE - IU Departmer
status: "Not Delivery

Figure 8. Information have put into keys in FRD

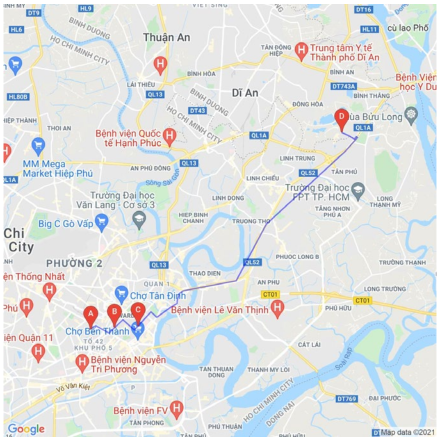


Figure 9. Routing for drivers

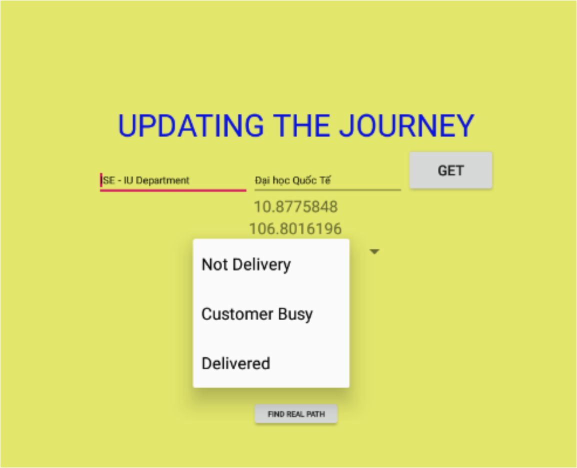
Function for Drivers:

Drivers can see the routing for picking up or delivery products after login. Drivers can accept or reject the journey. If the journey was finished, a driver selects "Update" to update it to a manager (see Fig 10,11,12).

Information of Customers

ISE - IU Department Đại học Quốc Tế Not Delivery

Figure 10. Screen after Login



UPDATING THE JOURNEY

ISE - IU Department
Đại học Quốc Tế
10.8775848
106.8016196

Figure 11. Screen "Updating The Journey"

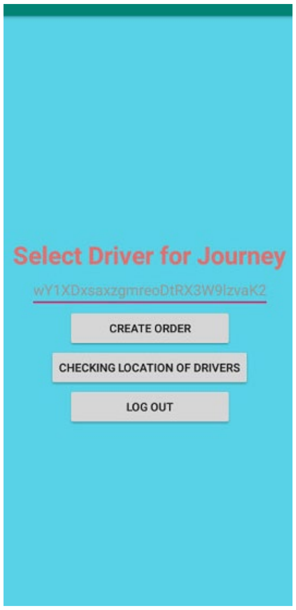
UPDATING THE JOURNEY

ISE - IU Department
Đại học Quốc Tế
10.8775848
106.8016196
Delivered

Update successfully

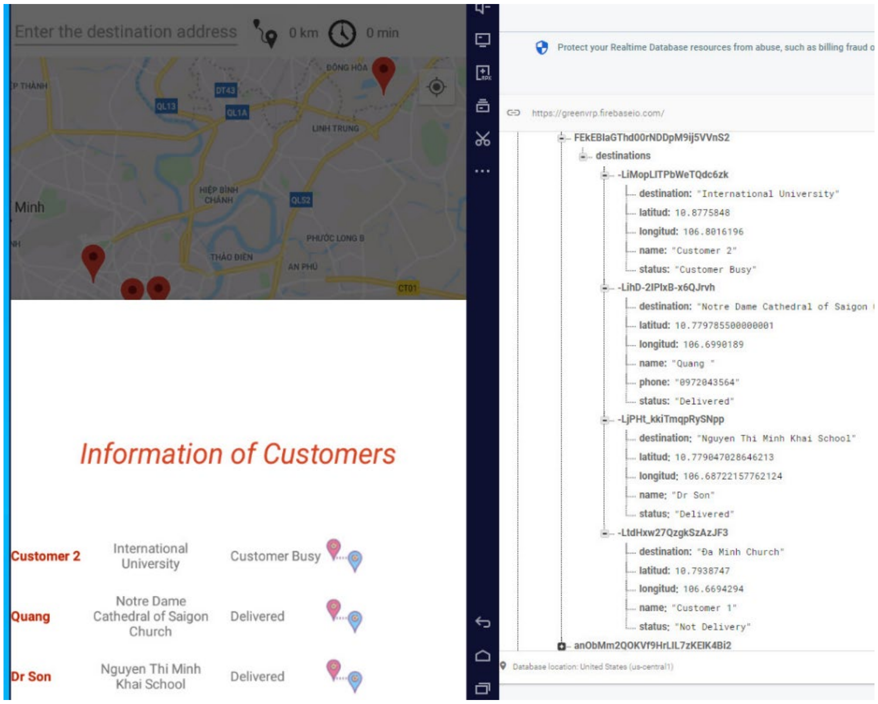
Figure 12. Update information successfully

In addition, "Control Fleet Vehicle" assissts managers keep tracking any drivers by clicking " checking location of drivers" function (see Fig 13) and delivery status (see Fig 14) .


Select Driver for Journey

wY1XDxsaxzgmreoDtRX3W9lzvaK2

Figure 13. Checking location of any drivers



Information of Customers

Customer 2	International University	Customer Busy
Quang	Notre Dame Cathedral of Saigon Church	Delivered
Dr Son	Nguyen Thi Minh Khai School	Delivered

Protect your Realtime Database resources from abuse, such as billing fraud o

https://greenvrp.firebaseio.com/

```
FEkEBlaGThd00rNDDpM9ij5VVnS2
  destinations
    -LiMopLITPbWeTQdc6zk
      destination: "International University"
      latitud: 10.8775848
      longitud: 106.8016196
      name: "Customer 2"
      status: "Customer Busy"
    -LihD-2IPlxB-x6QJrvh
      destination: "Notre Dame Cathedral of Saigon 
      latitud: 10.779785500000001
      longitud: 106.6990189
      name: "Quang "
      phone: "0972043564"
      status: "Delivered"
    -LjPHt_kkiTmqpRySNpp
      destination: "Nguyen Thi Minh Khai School"
      latitud: 10.779047028646213
      longitud: 106.68722157762124
      name: "Dr Son"
      status: "Delivered"
    -LtdHxw27QzgkSzAzJF3
      destination: "Đa Minh Church"
      latitud: 10.7938747
      longitud: 106.6694294
      name: "Customer 1"
      status: "Not Delivery"
anObMm2QOKVf9HrLIL7zKEIK4Bi2
```

Database location: United States (us-central1)

Figure 14. Delivery status

7. Conclusion

In conclusion, sustainable transportation and green logistics have been a widespread topic in the field, attracting continuous attempts of both industry and academia, to find better approaches to go towards environmentally friendly economy. This paper contributes a solution method for the Green Vehicle Routing Problem, compromising vehicle travelled distance and fuel emissions optimization. The computational experiment on a case of Ho Chi Minh city customer set shows that the above objective is achievable given acceptable computing time, bringing motives for future investment. This study also provides an application for supporting transportation companies implement reducing CO2 emission, saving cost and keep tracking fleets of vehicles.

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