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Impact of Covid-19 on Employees Transportation in Morocco: Optimization using OCVRPTW

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Abstract

This Study aims to show the impact of covid-19 on employees' transportation in Morocco, particularly in industrial field, the daily routes between homes and workplace. Moroccan government is led to make strong decisions unexpectedly with immediate turnaround time depending on pandemic state in function of the propagation speed of the virus and its mutated versions and capacity of the health ministry to hold the active and serious cases. These decisions should be made taking into consideration the economic situation, defining restriction to manage the pandemic situation and at the same time avoid hindering of slowing the industrial activity. The frequency of changing the restrictions is not known, it is revealed at unexpected time which make the transportation planning a difficult task. Besides, these decisions have huge impact on transport management for both sides, companies, and service providers. Through this work we will quantify the impact of restrictions on transport budget (20% up to 96% of increase) and propose a decision-making tool to plan daily routes of vehicles using a sequential coupling of vehicle routing problem (VRP) and Bin packing problem in a real case study. This tool have allowed to limit the increase of budget by optimizing the routing process.

Keywords: covid-19, vrp, bin-packing, transport management

1. Introduction

Covid 19 is among the highly contagious respiratory disease around the world. In Morocco the first case was detected on 2 March 2020 and since then, the country has launched a state of emergency which lasts until these lines are written. Morocco has experienced total confinement for several months, and to lift this confinement it has taken barrier and restriction measures to control the pandemic situation. We find that public transport and employee transportation are the highly impacted sectors due to these decisions. In function of the pandemic situation the government authorizes a maximum capacity load of vehicles switching from 50% up to 100% in all means of transport with the respect of distancing and regular disinfection. This rate have direct impact on transportation cost which is likely to increase. In the literature, the problem of the transport of employees arouses a strong interest from the researchers in logistics, it is seen as a NP-Hard problem because it stands for a variant of Vehicle Routing Problem (VRP) that can be shared into two sub-problems: routing & scheduling (mixture between Traveling Salesman Problem (TSP) & Bin-packing). Each point of pickup must be visited once and served by the same vehicle & the vehicles don't have to come back to the company knowing that the fleet is not in its propriety, this model is called an Open VRP, in which all vehicles follow a Hamiltonian path rather than a Hamiltonian cycle in the case of the real VRP. They pick up employees from their home and drive them back using the same path.

The rest of this paper is organized as follows; we will present the important phases of the pandemic in Morocco and the decisions taken regarding the speed of propagation of the virus, then approach the state of art regarding the VRP and its variances, then, the problem and formulation. We will propose a resolution demarch to quantify the impact of those decisions on transportation budget using OCVRP model. By the end we will discuss the obtained results and conclude the subject

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1.1 Pandemic numbers in Morocco

The fight against the spread of the Covid19 virus has forced all states to take urgent and exceptional measures to face the risks that the World Organization Health has called it a pandemic. The Kingdom of Morocco has reacted proactively and has taken several decisions to this effect according to current pandemic situation (from Rapport du Conseil Economique, Social et Environnemental/Conseil Economique Social et Environnemental du Royaume du Maroc (cese.ma))

- 09/03/2020 Border closures

- 13/03/2020 Closure of schools and universities

- 14/03/2020 Ban on all public gatherings of more than 50 people

- 16/03/2020 Closure of public places

- 20/03/2020 Declaration of health emergency

- 21/03/2020 Travel prohibition between cities- Suspension of rail lines

- 07/04/2020 Introduction of compulsory mask wearing

- 23/04/2020 No night-time travel during the month of Ramadan from 7:00 p.m. to 5:00 a.m. except for people working in specific sectors

- 11/06/2020 Gradual lifting of containment and distribution of the national territory into 2 zones 1 and 2 with different relief from restrictions.

The gradual lifting of the lockdown began with an authorization of 50% of the capacity of public and private transport, then 75% and after total easing of the restrictions, the state authorized a capacity of 100%. However, this decision is not stable over time, you can go straight back to 50% after being at 100%. Each change in authorized occupancy rate generates a new organization of staff transport, their allocated budget, etc. Hence the need for robust route planning to meet state restrictions in the 'state of emergency' phase. Then quantify the financial impact to see the possibility of integrating it into the framework of the major forces and having support funds from the state. Finally, it is imperative to have improved responsiveness since the time between the announcement of decisions and their execution does not exceed 24 hours. The government's latest extension decision of emergency state is set to expire on November 30/2021 (a total duration of 18 months), but it was extended again before it expired which is becoming a common decision of the government to curb the spread of the COVID-19.

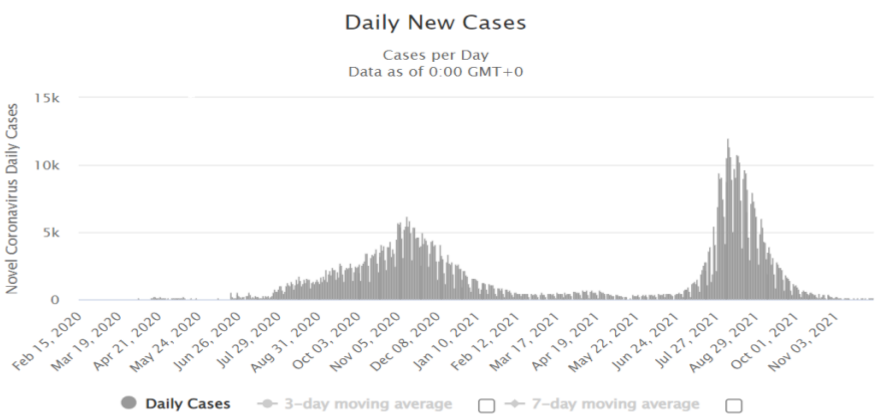

Figure 1: daily covid cases in Morocco

1.2. State of art

The Vehicle Routing problem is a class of the combinatorial optimization problems that has drawn much research attention, it was introduced first by [1] and it is one of the NP-Hard problem [2] [3] [4]. VRP has more than 20 variants, the objective is to define routes for vehicles to serve customer demands; this is expressed by the following parameters:

- An edged weighted directed graph: G = (V, A), where V is the set of customers, including the also the depot, and (A) is the set of arcs.

- The weighting function that defines the cost between an arc i and j (distance of travel or duration).

Since the work of [1], there was different applications of VRP in the literature. Particularly, the Capacitated VRP (CVRP), the vehicles must respect the constraint of capacity. The VRPTW the vehicle routing problem with time windows, the vehicles have the constraint of the total travel time or the driving hours. The transport of employee is one of its special applications which are similar to the bus routing problem introduced by [5] and it is an application of the well-known Open capacitated vehicle problem, that was firstly solved by [6] where vehicles don't have to return to the depot and follow a Hamiltonian path described also as NP-Hard [7]. We can find an optimal solution for small instances using exact methods, but if we consider a big instance, we have to opt for an approximate method to have a solution that is near to the optimal and with a good quality.

2. Problem: Formulation and modelling

2.1. Assumptions and objectives

Through this work, we aim to define a model to:

• Develop a dynamic model solving the scheduling and routing of the transport of employees in pandemic situation,

• Respect the restriction of Covid 19 in terms of capacity and evaluate the impact.

• Respect the total route duration: 45 Min.

• Optimize the daily routes travelled by vehicles.

The assumptions considered for the treatment of this problem are as follows:

1. The service provider has a homogenous fleet.

2. We have various pick-up points.

3. The management constraints are the global route time, the capacity of the bus and the number of used vehicles.

4. The route of each vehicle can be modified for the reasons below:

    a. Resignation/ Recruitment.

    b. Shift rotation.

    c. Extra hours/ Special events.

    d. Modification of restrictions by government

5. No new transport request arrives when executing the assignment problem.

6. Each bus has only one route for transporting employees to the company in the morning and driving them back to their home after working hours.

7. If the bus visiting a pickup point it must pick up all the employees at that point.

8. The driving time of the bus from one pick up point to another includes jams, road condition, and waiting time in traffic light, those data are extracted from a GIS web system.

9. Each pick up point is assigned to only one vehicle.

10. The model developed will yield just a one-sense itinerary: from the company to initial pick-up points, knowing that a single bus follows the same path, but in a reverse way.

The assumptions 1,4,5,6,9,10 are counted as limits of the method proposed.

2.2. Problem formulation

To formulate our COVRPTW problem, we present a mixed integer programming model that aims to maximize the net profit, by maximizing the load of the bus times the united cost, minus the total trip cost. All variable and parameters are summarized in the table below:

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Table 1. Problem variabes

Variable	Description
V_D	The set vertex of depot
V_C	The set vertex of customers (employee)
G= (V, A)	Complete directed network $V = V_D \cup V_C$
p_i	Cost of picking up a customer $i \in V_C$
q_i	Pick up amount for the customer $i \in V_C$
$\hat{}q_i$	The delivery amount for a customer $i \in V_C$
S_i	Service time for the customer $i \in V_C$
$[a_i, b_i]$	Time interval for the customer $i \in V_C$
K	The set of vehicles $k \in K$
o^k	The origin depot for the vehicle $k, o^k \in V_D$
T^k	Work start time for the vehicle $k \in K$
f^k	Fixed cost using the vehicle $k \in K$
Q^k	The capacity of the vehicle $k \in K$
D^k	The distance limit of the vehicle $k \in K$
$\hat{}D^k$	Driving time limit for the vehicle $k \in K$
W^k	Working time limit for the vehicle $k \in K$
$d_{i,j}$	Distance associated with the arc $(i, j) \in A$
$\hat{}d_{i,j}$	Driving duration associated with the arc $(i, j) \in A$
$C_{i,j}^k$	Travel cost on the arc $(i, j) \in A$
$x_{i,j}^k$	Decision variable equals 1 if the vehicle k traverses the arc$(i, j) \in A$; 0 otherwise
y_i^k	Equals 1 if the vehicle k visit i and serve it; 0 otherwise
$w_{i,j}^k$	Pick up number of people carried by the vehicle k
$z_{i,j}^k$	Delivery number of people carried by the vehicle k
t_i^k	Time when k arrives at the vertex i

The objective function is defined as:

$$F = MAX \sum_{i \in V_C} \sum_{k \in K} p_i y_i^k - \sum_{(i,j) \in A} \sum_{k \in K} C_{i,j}^k x_{i,j}^k \tag{1}$$

Following are the constraints:

$$\sum y_i^k = 1 \; \forall i \in V_C \tag{2}$$

$$\sum_{j \in V \setminus \{i\}} x_{i,j}^k \leq \sum_{j \in V \setminus \{i\}} x_{j,i}^k \; \forall j \in V_C, k \in K \tag{3}$$

$$\sum_{p \in S, q \in V \setminus S} x_{pq}^k \geq y_i^k \; \forall i \in V_C, k \in K, o^k \in V; i \in V \setminus o^k \tag{4}$$

$$\sum_{j \in V_C} x_{o^k,j}^k \leq 1 \; \forall k \in K \tag{5}$$

$$\sum W_{i,j}^k - \sum W_{j,i}^k = q_i y_i^k \;\; \forall i \in V_C, k \in K \tag{6}$$

$$\sum_{i \in V_C} W_{i,}^k = \sum_{j \in V_C} q_j y_j^k \quad \forall i \in V_C, k \in K \tag{7}$$

$$\sum_{j \in V \setminus \{i\}} Z_{ji}^k - \sum_{j \in V \setminus \{i\}} Z_{ij}^k = {}^\wedge q_i y_i^k \quad \forall k \in K \tag{8}$$

$$\sum_{i \in V_C} z_{o^k j}^k = \sum_{i \in V_C} {}^\wedge q_i y_i^k \quad \forall k \in K \tag{9}$$

$$w_{ij}^k + z_{ij}^k \leq Q^k \; \forall (i,j) \in A; k \in K \tag{10}$$

$$t_{o^k}^k = T^k \; \forall k \in K \tag{11}$$

$$\sum_{i,j} d_{ij} x_{ij}^k \leq D^k \; \forall (i,j) \in A, k \in K \tag{12}$$

$$\sum_{i,j} {}^\wedge d_{ij} x_{ij}^k \leq D^k \; \forall (i,j) \in A, k \in K \tag{13}$$

$$\sum_{i \in V_C} S_i y_i^k + \sum_{i,j} {}^\wedge d_{ij} x_{ij}^k \leq W^k \; \forall (i,j) \in A, k \in K \tag{14}$$

$$x_{i,j}^k \in \{0,1\} \; \forall (i,j) \in A, k \in K \tag{15}$$

$$y_i^k \in \{0,1\} \; \forall i \in V_C, k \in K \tag{16}$$

$$w_{i,j}^k \geq 0 \, ; \, z_{i,j}^k \geq 0 \; \forall (i,j) \in A, k \in K \tag{17}$$

• The function objective (1) tends to maximize the net profit; it contains a conflict between maximizing the load and minimizing the cost of usage. In fact, this objective function tends to amortize the cost paid by the company to ensure the transport, the maximum value of the objective function in our case will be 0, this means that the vehicle was fully loaded, and the cost was amortized.

• The constraint (2) ensures that a customer is visited just once.

• The constraint (3) ensures an inflow if there is an outflow (flow conservation).

• The constraint (4) ensures the connectivity between the customers visited and the depot.

• The constraint (5) ensures that each vehicle can be used just once.

• The constraint (6) & (7) ensure the flow conservation for pickup commodity.

• The constraint (8) (9) ensure the flow conservation for delivery commodity.

• The constraint (10) ensures the respect of vehicle capacity according to government decision.

• The constraint (11) ensures the working start for the vehicle.

• The constraint (12) (13) & (14) define respectively the distance, driving time, and working time limit.

• The constraint (15), (16), (17) ensure non negativity and integrity.

This model is valid only for small instances knowing that in our case we are facing a NP-Hard problem, thereby; it must be solved using approximate methods already proven their efficiency. We aim to have a simple and robust model with reasonable time of compilation, we will use the spreadsheet developed by Güneş Erdoğan with some modification related to our context:

Phase 1: Defining pick up points: Clustering of employees

- Forming the pick-up points using two steps clustering algorithm.

Phase 2: Routing

- Route construction using Local Neighbourhood Search (LNS).and Clark & Wright principle.

- Feasible solution maximizing the net profit.

Phase 3: Improvement

- Improvement of the solution using LNS incorporating the improvement heuristics: 2-Opt, Exchange (vehicle, routes), Remove/Add vertices.

3. Case Study

3.1. Input Data:

We will apply the model developed in a real case study from the automotive industry, bellow we have all the input data:

Table 2: The input data of the case study

Number of employees	80
Coordinates of each employee	X, Y issued from Bing map
Cost of pickup for one employee	10 MAD
Distances	issued from GIS WEB
Duration of travel between employees	issued from GIS WEB
Number of vehicles	8 (current)
Cost/Trip	190 MAD
Capacity	19
Total travel time limit	45 min + Flexibility of 5 min
Service time for each stop	15 s
Work starts time (Morning shift)	7:00 A.M
Arrival time preference (Morning shift)	Before 8:00 A.M

Pickup points and number of employees:

Table 1: Detail of pick-up points

ID	Pick up Description	X	Y	Number of Employees
0	Company	35,715639	-5,92679	
1	Quartier AOUAMA	35,725405	-5,80445	4
3	Quartier AZIB	35,743706	-5,84431	4
4	Quartier Ben Diban	35,758756	-5,818516	1
5	Quartier Barnes	35,760307	-5,832528	3
6	Quartier Casa barata	35,766376	-5,824878	5
7	Quartier 7 village	35,762965	-5,844532	1
8	Complexe - Moustakbal	35,73412	-5,870079	3
9	Complexe - Nour	35,730375	-5,853235	3
10	Complexe el Hassani	35,735574	-5,858088	1
11	Quartier Daradeb	35,785505	-5,831259	4
12	Quartier Marjane	35,745838	-5,849469	3
13	Quartier Achakar	35,737182	-5,885006	1
14	Quartier Boukhalef	35,736764	-5,878639	1
15	Quartier Doha Marjane	35,749527	-5,847284	3
16	Quartier Drissia	35,757445	-5,805427	5
17	Quartier Girari	35,746414	-5,807998	3
19	Quartier Gzenaya	35,708051	-5,907357	3
20	Quartier Mghougha	35,759335	-5,790931	2
21	McDonald Marjane	35,744725	-5,843763	7
22	Quartier Mesnana	35,756984	-5,852997	2
23	Quartier place de ville	35,775301	-5,810942	3
24	Quartier Souani	35,770353	-5,825248	4
25	Quartier Sidi Driss	35,742331	-5,831769	1
26	Quartier Tanger Balia	35,772204	-5,770773	6
27	Quartier Val Fleuri	35,765797	-5,834518	1
28	Quartier Zemmouri	35,741341	-5,86805	4
29	Quartier Kharba	35,752539	-5,84642	2

According to Bing map, this is the distribution of pickup points and destination (company's address) in the map:

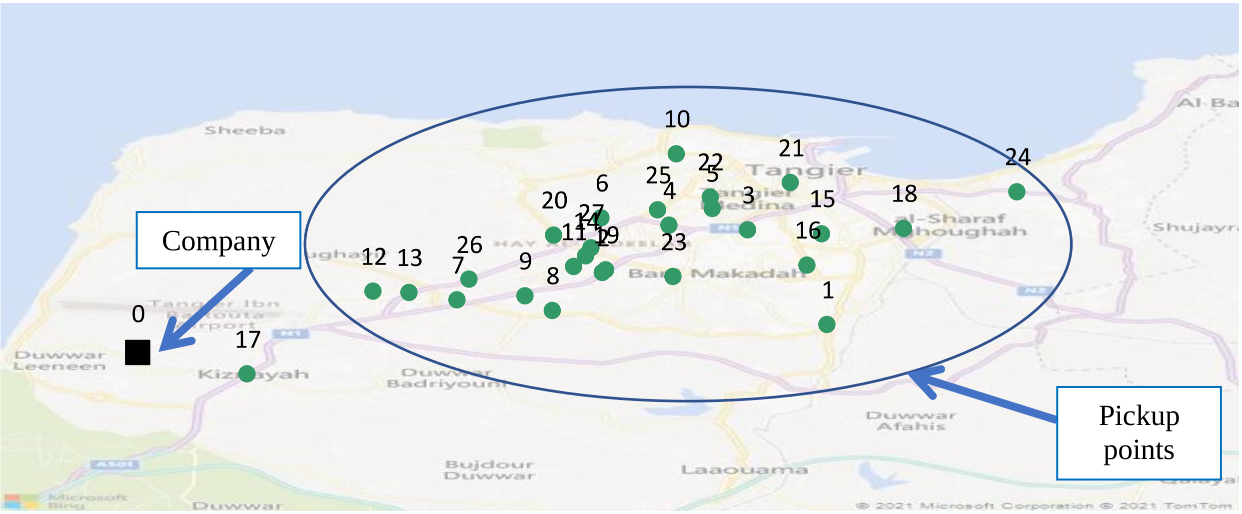

Figure 2: The distribution of pickup and delivery points

3.2. Computational results: COVRPTW with 100% capacity:

After 6800 iterations we obtain the results bellow:

Table 4: Summary of computational results: 100% capacity

Vehicle	Number of stops	Distance travelled	Driving time	Arrival time (company)	Working time	Load of the vehicle	Objective function
V1	2	7,85 km	16 min	7:16 AM	16 min	6	-130 MAD
V2	9	18,01 km	45 min	7:47 AM	47 min	19	0 MAD
V3	6	17,14 km	43 min	7:44 AM	44 min	19	0 MAD
V4	5	23,30 km	43 min	7:44 AM	44 min	18	-10 MAD
V5	5	15,89 km	43 min	7:44 AM	44 min	18	-10 MAD
V6	-	-	-	-	-	-	-
V7	-	-	-	-	-	-	-
V8	-	-	-	-	-	-	-

We need only 5 vehicles of 8 in the fleet. We obtain results that satisfy our constraints, and with a minimum load of 31% and maximum 100%, the mean value is acceptable: 84% this means that for each travel, on average 84% of costs are amortized. Knowing that for 4 travels of 5, we amortize 97% of transport costs. The driving time does not exceed 45 min adding maximum 5 minutes of service, based on the duration and distance issued from BING map, all vehicles arrive before 8h00 which is the stating working hour for administration staff. The map bellow shows the itinerary of each vehicle from the furthest pick up zone, up to the company:

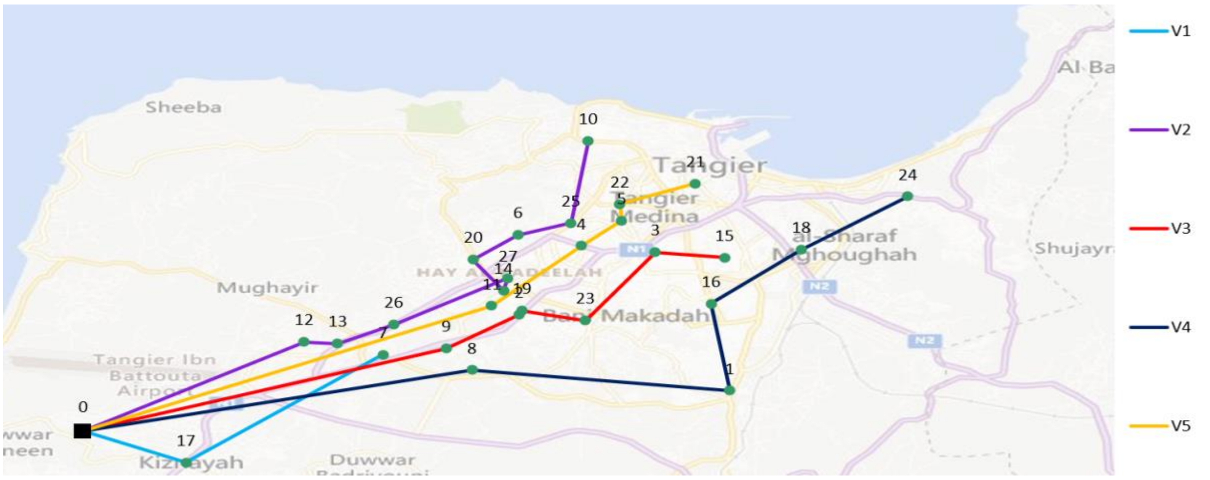

Figure 3: Routes in the case of 100% capacity

3.3. Computational results: COVRPTW with 75% capacity:

After 6089 iterations we obtain the results bellow:

Table 5: Summary of computational results: 75% capacity

Vehicle	Number of stops	Distance travelled	Driving time	Arrival time (company)	Working time	Load of the vehicle	Objective function
V1	4	20,06 km	44 min	7:45 AM	45 min	14	-50 MAD
V2	4	10,58 km	23 min	7:24 AM	24 min	10	-90 MAD
V3	4	20,19 km	40 min	7:40 AM	41 min	14	-50 MAD
V4	7	16,19 km	39 min	7:40 AM	40 min	14	-50 MAD
V5	4	13,46 km	36 min	7:27 AM	37 min	14	-50 MAD
V6	4	13,04 km	26 min	7:27 AM	27 min	14	-50 MAD
V7	-	-	-	-	-	-	-
V8	-	-	-	-	-	-	-

For 75% of capacity restriction equivalent to 14 seats, we need an additional vehicle, the number becomes 6 vehicles of 8 in the fleet (increase of transport budget of 20%). We obtain results that satisfy our constraints, and with a minimum load of 71% and maximum 100%, the mean value is acceptable: 95%. Although using only 75% of capacity, we pay full cost trip. The driving time does not exceed 45 min adding maximum 5 minutes of service, based on the duration and distance issued from BING map. All vehicles arrive before 8h00 which is the stating working hour for administration staff. The map bellow shows the itinerary of each vehicle from the furthest pick up zone, up to the company

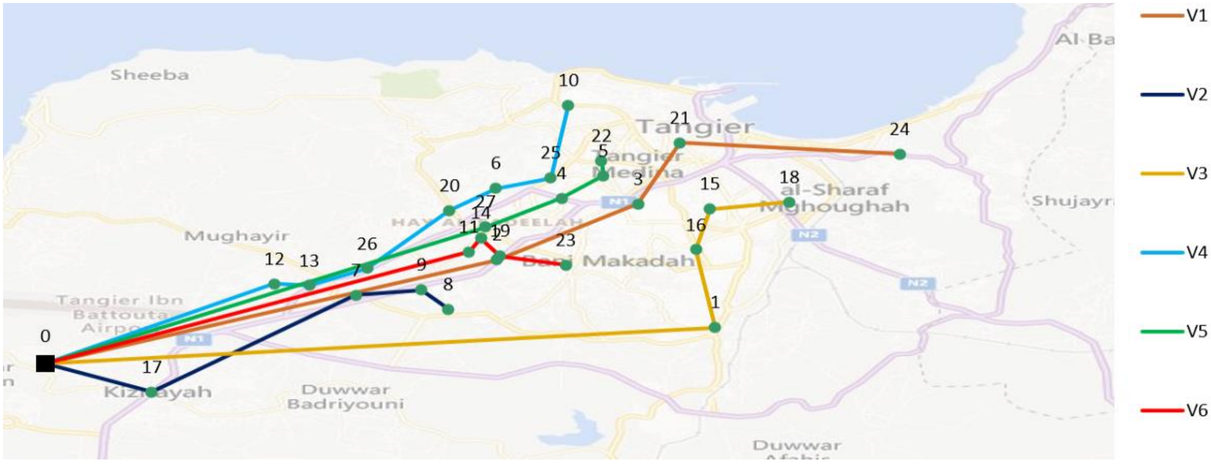

Figure 4: Routes in the case of 75% capacity

3.4. Computational results: COVRPTW with 50% capacity:

After 5992 iterations we obtain the results bellow:

Table 6: Summary of computational results: 50% capacity

Vehicle	Number of stops	Distance travelled	Driving time	Arrival time (company)	Working time	Load of the vehicle	Objective function
V1	2	10,11 km	19 min	7 :19 AM	19 min	8	-110 MAD
V2	3	10,82 km	21 min	7 :21 AM	21 min	9	-100 MAD
V3	2	17,18 km	29 min	7 :29 AM	29 min	9	-100 MAD
V4	3	16,47 km	40 min	7 :40 AM	40 min	9	-100 MAD
V5	3	15,81 km	36 min	7 :27 AM	36 min	9	-100 MAD
V6	4	17,16 km	38 min	7 :39 AM	39 min	9	-100 MAD
V7	3	10,15 km	21 min	7 :21 AM	21 min	9	-100 MAD
V8	4	12,61 km	29 min	7 :30 AM	30 min	9	-100 MAD
V9	3	19,28 km	39 min	7 :39 AM	39 min	9	-100 MAD

For 50% of capacity restriction equivalent to 9 seats only, we need four additional vehicles, the number becomes 9 vehicles versus 8 in the fleet (increase of transport budget of 80%). We obtain results that satisfy our constraints with a minimum load of 89% and a maximum of 100%, the mean value is acceptable: 99%. Although using only 50% of capacity, we pay full cost trip. The driving time does not exceed 45 min adding maximum 5 minutes of service, based on the duration and distance issued from BING map. All vehicles arrive before 8h00. The map bellow shows the itinerary of each vehicle from the furthest pick up zone, up to the company:

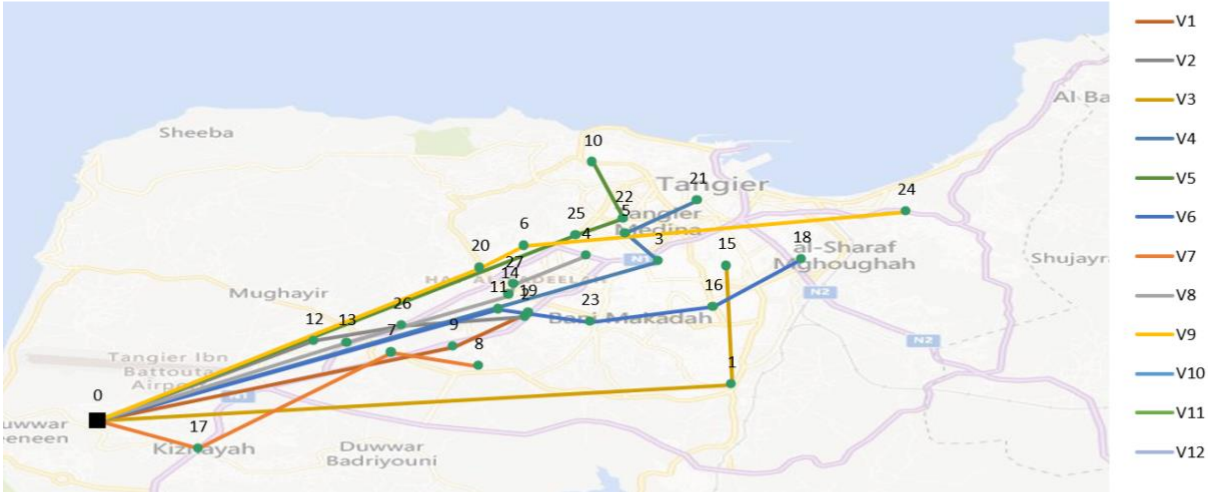

Figure 5: Routes in the case of 50% capacity

4. Discussion and Synthesis

After obtaining the simulation data of the two scenarios. The tables below summarize the results obtained with full capacity, then 75% capacity and finally 50%, and the impact of each capacity restriction on transport budget. it is necessary to mention that without this tool, the company couldn't supervise the transport cost and the daily routes before Covid19 (100% of capacity), and couldn't quantify the impacts of Post covid19 (75% and 50% capacity restriction) compared to normal situation:

Table 7: Synthesis of Results: Objective Function

Vehicle	Objective function			% Cost not amortized		
	Scenario 100%	Scenario 75%	Scenario 50%	Scenario 100%	Scenario 75%	Scenario 50%
V1	-130 MAD	-50 MAD	-110 MAD	68%	26%	58%
V2	0 MAD	-90 MAD	-100 MAD	0%	47%	53%
V3	0 MAD	-50 MAD	-100 MAD	0%	26%	53%
V4	-10 MAD	-50 MAD	-100 MAD	5%	26%	53%
V5	-10 MAD	-50 MAD	-100 MAD	5%	26%	53%
V6	-	-50 MAD	-100 MAD	-	26%	53%
V7	-	-	-100 MAD	-	-	53%
V8	-	-	-100 MAD	-	-	53%
V9	-	-	-100 MAD	-	-	53%

Table 8: Synthesis of results: Budget impact

Vehicle	% Load based on current authorized load			% Load based on total capacity		Budget Impact %	
	Scenario 100%	Scenario 75%	Scenario 50%	Scenario 75%	Scenario 50%	Scenario 75%	Scenario 50%
V1	32%	100%	89%	74%	42%		
V2	100%	71%	100%	53%	47%		
V3	100%	100%	100%	74%	47%		
V4	95%	100%	100%	74%	47%		
V5	95%	100%	100%	74%	47%	+20%	+96%
V6	-	100%	100%	74%	47%		
V7	-	-	100%	-	47%		
V8	-	-	100%	-	47%		
V9	-	-	100%	-	47%		

• In the scenario of full capacity, the simulation gives good quality results, with only 16% of total costs that are not amortized, and a maximized load rate for four vehicles. The rest of employees were assigned to the last vehicle. This proves the strength of the model developed.

• In the scenario of 75% capacity restriction, the total costs not amortized becomes 30%, the load rate is maximized and balanced. The company must add one vehicle to ensures all routes, the financial impact of this decision compared to the initial budget (100% capacity) is 20% of increase.

• In the scenario of 50% capacity restriction, the total costs not amortized becomes 53%, the load rate is maximized and balanced because for the model developed the capacity constraint was slightly relaxed. The company must add four vehicles to ensure all routes, the financial impact of this decision compared to full capacity budget is almost doubled the budget, about 96% of increase.

The model developed allowed to optimize the daily routes by, first, regrouping employees into clusters to reduce the pickup points. Then by creating routes under an objective function which tend to amortize the cost paid by the company for transporting each employee from his home up to the company and vice versa. This could be identified through the results of simulation, except the last bus In the fleet, all bus have maximum load in the routes defined. Finally, by permitting the company to adjust the capacity of bus in order to abide by the restrictions set by the authorities in order to flatten the pandemic curve Function of restrictions, which changes frequently. The dynamism degree of the model in addition to the results obtained were very satisfying.

5. Conclusion and perspectives

The model developed is dynamic and will serve as a decision-making tool in strong term. It gives good results under all the constraints defined at the beginning, regarding the capacity restriction, total route time and total net profit maximization. All the constraints were satisfied, and initial specifications were respected. It is also relevant to highlight the computing rapidity which is required for such situation of instant decision imposed by the government. After the simulation considering the different capacity restrictions due to Covid19, the results show that the impact of the pandemic is obvious on transport, and particularly in the transport of employee, these restrictions have direct impact on allowed transport budget, and swings from 20% to 96% of increase in function of the pandemic situation of the country.

For further work of research, we aim to minimize the total net profit to give companies more agility to face such pandemic situations which we will probably face in the future. We will propose a new model including a preliminary clustering before assignment to minimize the number of pick-up points and thus, minimize the total route time. Even though these two goals seem contradictory.

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Contribution of Researchers

All researchers have contributed equally to writing this paper.

Conflicts of Interest

The authors declare no conflict of interest.

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