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EFFICIENT VEHICLE ROUTING IN CONGESTED REGIONS

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ABSTRACT

Optimization methods could optimize costs and determine the optimal resources needed for supply chain management (SCM). The vehicle route selection problem in congested regions is a main challenge in SCM. The problem is to determine the daily shortest optimal route among several routes in congested regions. Unfortunately, optimization techniques could only find static fixed routes. However, finding dynamic routes, suitable for congested regions, is still challenging. In this paper we will propose a model for solving vehicle routing problem in congested regions. The proposed model combines both optimization techniques with live traffic information to determine daily optimal routes. Also, the paper will discuss the challenges of using both static and dynamic methods in solving vehicle routing problems in congested regions. The addressed problem has many applications in different fields especially in supply chain management, crowd management, fleet management, and congested cities.

Keywords: *Global Optimization Methods, Live Google Maps, Supply Chain Management, Fleet Management, Travelling Salesperson Problem, Artificial Intelligence, Vehicle Routing Problem***.**

1. INTRODUCTION

In the globalization world, organizations aim to decrease costs and optimize their resources. Supply chains consume many resources and presents additional costs. Most of the costs are related to manufacturing, production, operation, shipment, and transportation. However, scheduling and optimization of supply chains are one of the most challenging tasks that face many firms and enterprises. However, resources scheduling is not a simple task because many factors should be considered during the scheduling process. Fortunately, artificial intelligence techniques can provide efficient solutions to the scheduling problems by using optimization techniques.

Fleet management is an important task belonging to supply chain management. Many organizations want to optimize product delivery through effective fleet management operations especially in crowded and congested regions [1]. One problem related to fleet management is to decrease the total trip time needed to deliver people, products, or services to their destinations. Optimization techniques can balance the conflicts of the different entities. The vehicle routing problem results in additional costs and delivery delays in scheduled daily trips. So, in congested regions, the total trip time is increased hugely. Congestion causes accidents, psychological effects, costs, and work delays [1], [2]. So, there is a great need for efficient daily trips scheduling. However, identifying crowd congestion is a challenging problem [3]. Without crowd management, many disasters may occur [4].

Suppose an enterprise wants to deliver its workers through its fleet at 9:00 AM. In non-crowded city, there is no problem to selection a fixed daily route passing through all passengers. This fixed route is often depending on driver experience. So, the vehicle starts moving from a pre-determined initial starting location (may be the driver home or a workplace). Then, the vehicle passes through all authorized passenger until all passengers are picked up. Then, they are all moving to their destination. We called this problem as a static route selection (SRS). SRS could be solved by using different optimization techniques. SRS only considers the distances between different locations involved in the trip. The main drawback of SRS is that it does not consider the traffic status in the visited locations. So, SRS is suitable for non-congested regions. As the speed in these regions approximately constant. So, the daily total trip time is

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approximately the same. In this case choosing a daily fixed route, depending on the distances only between locations, may be inappropriate.

However, in congested cities, the total trip time is very critical. If the optimal route is not selected, then significant delay occurs to the trip. The result is a late arrival of passengers. So, their work will be affected by this delay. Additionally, waiting in congested regions causes more consumption of fuel. This increases the total cost of the trip and makes additional operating overheads. So, selection of a daily fixed route is not optimal in this case as the traffic information is changed continually [5].
Obviously, from the previous discussion, choosing optimal routes should not only depend on distances between any two locations, but also should depend on the traffic information between these two locations. The traffic information determines the speed of the vehicle that should be considered. So, the overall cost function should include both distances and road speed. We called this new modeling of the problem as a dynamic route selection (DRS) problem. Although solving SRS is straightforward through optimization methods, however, solving DRS is more difficult as it includes more information to be optimized. That is, solving DRS should consider both optimization algorithms and live traffic maps.

So, in this paper we will propose a model for solving DRS by combining traffic information with optimization techniques. The rest of this paper is organized as follows; section 2 presents the necessary background. Section 3 presents the static route selection methods. Section 4 presents the proposed DRS model. Section 5 shows the model clarification. Section 6 discusses the possible challenges of DRS. Finally, the paper is concluded in section 7.

2. BACKGROUND

SRS could be modeled directly by using the traveling salesperson problem (TSP) modeling. TSP is a traditional problem in optimization [6]. In this problem, a salesperson wants to visit some cities starting from a specified city. The destination is known. The transition from one city to another is based on a cost function. The salesperson wants to minimize the total distance of the trip. The overall objective is to determine the optimal route and the sequence of cities having the minimum cost.
Suppose n is the total number of cities to be visited by the salesperson. The problem can be graphically illustrated by a graph where the nodes represent cities, and edges represent the cost of transition from one node to another.

Let $V = \{ v_1 ,......, v_n\}$ is the set of cities to be visited by the salesperson. Consider the edge set $A= \{(r,s) : r, s \in V\}$ which connecting two nodes r and s. Let $d_{rs} = d_{sr}$ where d is the cost function between r and s. So, in this problem $d_{rs} = d_{sr}$ because the cost function is only the distance between the two cities. The optimal shortest distance route could be determined by using one of the optimization algorithms. This analysis is illustrated in the following example.

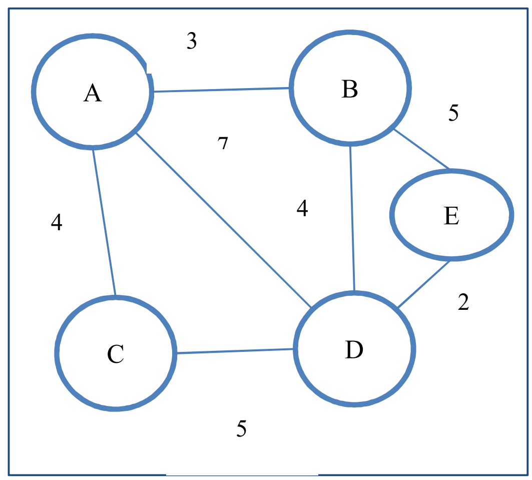

Fig. 1 : SRS problem illustration

Example: suppose a person wants to visit five locations *A*, *B*, *C*, *D*, and *E*. These locations are shown in Figure 1 by a graph. The driver wants to start his trip from location *A* for example. The driver wants to visit all other locations in the graph reaching his destination *C* for example. So, *C* is the final location to be visited. The distances between these locations are illustrated on the links connecting the locations. By using TSP, the cost function is simply the distance between these locations. In this case, the optimal route selected is the route having the least total distances. So, the optimal route selected may be *A-B-E-D-C* with a total distance is 3 + 5 + 2 + 5 = 15. Other routes have longer total distances.

SRS could be modeled as TSP. So, SRS could be solved by using optimization algorithms [7].

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Different optimization algorithms are existed in the literature. The global optimization algorithms try avoiding the problem of local minimum. Examples of optimization algorithms are Tabu Search, genetic algorithms, and swarm intelligence algorithms [8]. However, the performances of these algorithms are different.

However, in congested regions, another factor should be considered which is the traffic information. That is, traffic information determines vehicles speed. So, we called this new problem modeling as the dynamic routing problem (DRS). DRS is more appropriate for modeling congested areas. In DRS, both distance and speed information are considered as cost function when solving TSP. It could be solved by using both optimization algorithms and traffic maps.

3. STATIC ROUTE SELECTION (SRS)

SRS uses only distance information to be optimized for decreasing the total time of the trip [9]. This problem can appear in optimal vehicles routes designs when serving group of customers [10]. Solving this problem can optimize resources and reduces costs. The research in this area is also classified in [11] which shows a lot of research in this area [11]. As stated before, the straightforward solution to this problem is through using optimization algorithms. In [12], the authors present a new measure for solving crowd management. This new measure uses direct counting of entities in roads.

The problem is also studied in Hajj by the authors in [13] as millions of pilgrims arrive in a small area in Hajj. They use the game theory model to solve the problem. The authors in [3] present a method to identify congestion in videos that may be collected through cameras [3]. This may be useful in traffic management when the images and videos of roads are analyzed. Also, the authors in [4] use internet of things (IoT) to solve crowding in Mecca during Hajj by identifying the possible routes and paths while maximizing safety.

Regarding optimization algorithms, the authors in [14] propose an adaptive ants colony optimization (ACO) algorithm to solve the convergence non-maturity problem. Their results indicate that the adaptive algorithm can solve the traveling salesperson problem efficiently [14]. The authors in [7] develop an improved ACO algorithm to solve TSP. The algorithm has a fast convergence time. Their algorithm avoids the local minima problem that is known in optimization problems [7].

The swarm intelligence algorithms are also global optimization algorithms that could solve SRS. One example of these algorithms includes the chicken swarm optimization (CSO). The bat algorithm (BA) is another global optimization algorithm. BA mimics the behavior of micro bats [15]. Also, the authors in [16], propose a novel multi-objective binary bat algorithm for feature selection of keystroke dynamics. Their results indicate that BA performs well in feature selection. Also, the authors in [17], propose a particle swarm optimization algorithm to optimize solar system performance.

The genetic algorithm (GA) is a well-known global optimization method that simulates biological inheritance. The authors in [18] develop an Android mobile application for using Google maps efficiently. The application enables different manipulations on Google maps such as addition and updating of different locations [18]. The authors in [19] develop a new location-based service called (LoCo). By using this service, persons can locate other persons with the same interests [19]. In [20], the authors extract congestion and traffic information from Google maps by using an open-source tool. The estimated arrival time could also be estimated by using this tool [20].

From the previous discussion the vehicle route selection problem is very important problem in logistics and supply chain management. The problem could be modeled as travelling salesperson problem which is an optimization problem.

However, the existing optimization techniques can only solve the static version of the problem that is called (SRS). However, the problem in the congested regions is another story. This problem cannot be modeled as an ordinary SRS. Alternatively, it should be modeled as a dynamic route selection (DRS). Unfortunately, optimization algorithms cannot individually solve DRS.

Alternatively, they should be combined with other techniques such as traffic information techniques to solve the problem of DRS. In fact, DRS has many applications than the traditional

SRS. So, in the following section we will discuss the dynamic route selection (DRS) and its possible solutions. However, solving DRS is not straightforward. It needs additional computation.

4. THE DYNAMIC ROUTE SELECTION MODEL

In this section, we will address the dynamic travelling salesperson problem that aims to find dynamic routes for vehicles in repetitive scheduled trips. The main objective is to decrease the total time of the repetitive trips. Decreasing the total time of the trip is very important to save fuel, trip time, and decreases pollution especially in congested cities such as Jeddah located in Kingdom of Saudi Arabia (KSA). Congested areas could be efficiently discovered by using timely traffic maps such as Google maps.

It is clear from the previous section that, modeling of the problem as a static route selection (SRS) is inappropriate [21], [22]. That is, the main drawback of SRS is that it provides only a static fixed route based on the minimal distances between the visited locations. There is no other traffic and congestion information is considered in this case. However, in congested areas, there are some different considerations from the traditional SRS. First, the addressed problem has two predetermined locations: the starting location of the vehicle that the driver starts with, and the vehicle destination which often may be the enterprise location.

The second difference is that the addressed problem should consider traffic information including congestion and road speed not only the distances between these locations. Third, the traffic maps change instantaneously. So, modeling the addressed problem as SRS is inappropriate. Alternatively, a dynamic route selection (DRS) is required for each daily trip individually. So, the global optimization algorithms individually cannot solve the dynamic route selection problem. So, a possible DRS solution should combine both global optimization algorithms with traffic maps that include congestion information and vehicle speed to solve DRS.

For solving DRS, the current traffic information is extracted from live Google maps. Then, this information is fed into the global optimization algorithm to find the next suggested location to be visited. So, the proposed algorithm provides an enhanced dynamic route selection as it uses double information including both distance and velocity. So, the objective function of the proposed model will include both distance and velocity information. The current traffic information is extracted from live Google maps when the vehicle reaches one destination. Then, this information is fed into the global optimization algorithm to find the next suggested location to be visited. So, the decision is performed at each visited location to determine the next location to be visited. In fact, this is a new difference from SRS.

The velocity and distance information could be obtained from real time traffic maps services such as Google maps. Google maps can show current congestions and roads traffic status instantaneously. In this case, the time required to go from one location to another is not only dependent on the distance between these two locations, but also depends on the current traffic status. Once this information is obtained, the problem is transformed to DRS instead of SRS. The cost function of DRS includes a vector of information not a scalar. This information vector includes distance and velocity [23]. So, using this double information leads to compute the time between these two locations at the time of the trip. Also, the traffic information is considered when visiting the new location based on the traffic map.

There are many traffic maps that could be used in the proposed model. Google traffic maps [1] that can determine traffic delay at any region worldwide. So, the dynamic information could be obtained using Google Maps.
So, Google maps are one of the best maps because of the popularity of this maps and the availability of many tools and web services that could be integrated with theses maps. The performance of the proposed model could be tested using any real-time maps combined with any global optimization algorithms. The evaluation metrics may include convergence curves, objective function fitness curves, accuracy, and time performance curves [1].

To illustrate the idea of the vector information proposed in DRS, consider the graph shown in Figure 2. This graph is a modified version of the graph shown in figure 1. Again, the vehicle driver wants to start his trip from location *A* reaching to his destination at location *C*. The main difference between figure 1 and figure 2 is related to the used cost function located on the links connected various locations. For example, in figure 2, to travel from location *A* to location *B* we have a vector (3,4) that containing two pieces of information. The first information piece equals 3 which represents the distance between locations *A* and *B*. The second information piece represents the estimated time to move from location *A* to location *B*. Both the distance and the estimated time could be obtained from real time traffic maps such as Google maps.

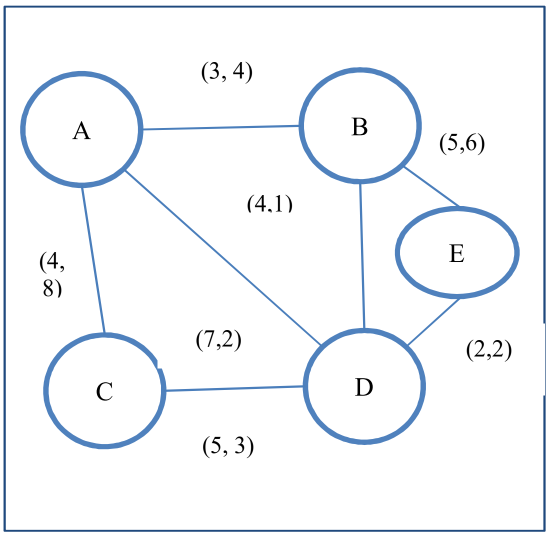

Fig. 2 : DRS problem illustration

Recall that, using SRS, the driver will decide to visit location *B* after visiting *A* based on the distance information. However, in the proposed DRS model, the model decides to visit *D* next instead of *B* because visiting *D* next needs only two seconds. However, visiting *B* next needs 4 seconds. In this case, the time parameter is important than the distance parameter which decreases the overall trip time. This is more appropriate to the crowded and congestion regions which leads to decrease the total time of the trip.

Interestingly, in the proposed model, the second part of the information vector located on the graph is updated continuously according to the traffic status. That is, after selecting *D* to be visited next, the proposed model decides which location to be visited next according to the traffic information in this instance of time. The traffic maps are checked again, and the cost vector on figure 2 is also updated. So, visiting the next location is not determined unless the cost function is updated. To illustrate this idea, after visiting *D*, if the traffic information is changed and there is another location that is not congested, then, this location is visited next before the other locations. The decision is continued at each visited location to determine the next visited one. So, in figure 3 the next visited location will be *E* instead of *B* because the speed to visiting E is larger than that of reaching *B*.

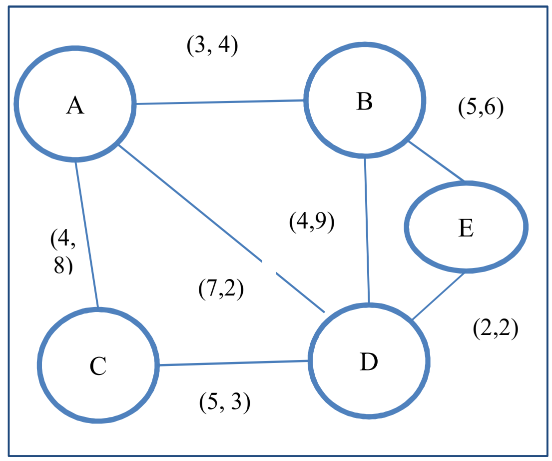

Fig. 3 : updated cost function according to the dynamic traffic information

So, the algorithm for determining the optimal dynamic route selection of the vehicle is explained here. The idea of the model is to determine the starting and ending locations in the beginning. Then, the dynamic graph is constructed. The dynamic graph includes information vector with two parties; distance between the different locations and the time needed to traverse between these locations. This information vector is fed to one of the global optimization techniques. The role of this optimization technique is to make a balance between the local and global information regarding the traversing speed.

Also, the optimization algorithms avoid entering in infinite loops. Optimization techniques also help in the dynamic part of the model. That is, when the traffic information between any two locations in the graph is changed, then the optimization techniques will decide the new

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location to be visited based on the global traffic information in the whole graph.

The overall result of this combination is to determine the daily optimal dynamic route of the vehicle. Certainly, this route is optimal regarding the total trip time. However, the time needed for obtaining this optimal route is depending on the optimization algorithm used. That is the convergence time of each algorithm is different from one optimization algorithm to another.

5. CLARIFICATION OF THE PROPOSED MODEL

In this section, we will introduce an example of using real time traffic maps in solving DRS. Google maps are used in this example. Ten random locations are chosen in a congested city in KSA which is Jeddah. We assume the vehicle driver wants to pick up passengers from the first location reaching to the destination representing one daily trip. These random locations are shown in the left side of figure 4. From figure 4, the total estimated trip time is one 1:58 hours. However, this estimation made by Google maps is not optimal. That is, this estimation is based on the order given by the vehicle driver. So, Google maps compute the total trip time as the summation of the time needed to traverse from the first location to the second location and so on to the destination.

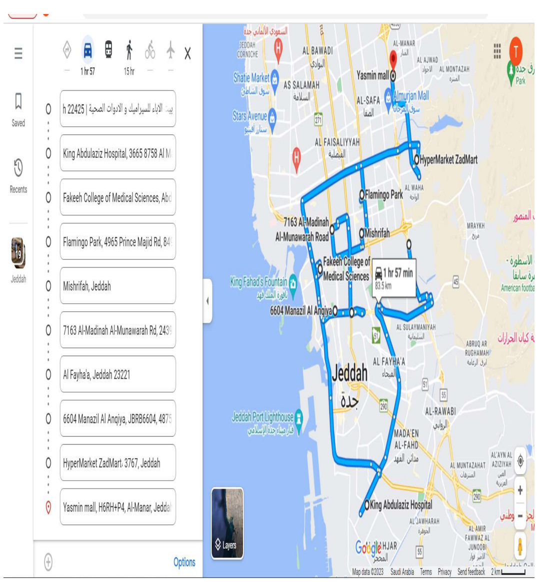

Fig. 4 : Using of Live Google Maps for determining dynamic distances

Consider L_1, L_2, …., L_n represent the locations to be visited. Let t_1, t_2, …, t_n represent the time needed to go from L_1, L_2, …., L_n respectively. Then, according to Google maps computation, the total trip time is:

$$T = \sum_{n}^{1} ti \quad (1)$$

However, this computation is not efficient. Because *ti* is not fixed all the time. They are varying according to the traffic information. In fact, this is the main disadvantage of the static fixed routes. Alternatively, in the dynamic route selection method, the total trip time may be computed as:

$$T = t1 + min\ (G(t_i, t_i+1)) \quad (2)$$

Where *G* is a cost function represents the instantaneous traversing time between two locations. Certainly, this total trip time is less than or equal to the total trip time introduced from Google maps in this case.

6. CHALLENGES OF THE DRS MODEL

Modeling of vehicle routing problem in congested regions is best modeled as DRS. The solution of DRS can satisfy many advantages related to decreasing the total trip time of daily trips. This achieves many benefits regarding saving operating costs, saving fuel, providing comfort to passengers, decrease overheads, decreasing traffic congestions, and enhance life quality.
However, despite these advantages, the dynamic route selection problem has many challenges to be considered a solved. In this section we will address these challenges.

The first challenge is related to the implementation of the model. The model is a combination of optimization algorithms with traffic maps. The model may be implemented as a mobile application and may be available on different application stores. Fortunately, different mobile platforms may help in this implementation. Additional requirement is to avail this application with an affordable price to be used widely among all public transport drivers.

The second challenge is related to the vehicle driver overhead. Although the fixed route selection has many disadvantages as explained before, however, the static route selection is

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easier to vehicle drivers. That is drivers easily remember these fixed routes. However, dynamic routes require drivers to use the application and determine the next location to be visited. This process may need some few seconds to be performed by the driver. The solution to this challenge is that the DRS application may be provided by additional capabilities such as voice capabilities that may help drivers to find the next location to be visited. Also, the drivers may be trained on this issue and the benefits of this model may be explained to them.

The third challenge is related to the selection of the traffic maps in this model. There are many traffic maps that could be used to prove the solution model. One of the well-known traffic maps is the Google maps. Fortunately, Google maps are provided by both websites and google application. Google maps have the capabilities of computing both distance and the time to reaching different locations. So, they can provide the vector information required for solving the dynamic problem. Also, the application may be integrated with these maps.

The fourth challenge is related to the optimization technique used. Although there are many optimization techniques that could be used to implement this model, the global optimization techniques prove superiority against other techniques. It is interesting to note that, the performance of these techniques is different. So, the chosen optimization should satisfy good performance metrics such as low convergence time, shortest trip time, least response time, and other good performance measures.

The final challenge is related to awareness. The benefits of the dynamic should be shared to all stakeholders related to the addressed problem. Stakeholders may include company owners, managers, drivers, and passengers. Passengers may be affected by reordering of the locations visited in each daily trips. Their appointments to ride vehicle may be negatively affected. However, the overall benefits of the solution model should be shared with them. So, knowledge management and knowledge sharing are very important in this aspect.

7. CONCLUSIONS

This paper presents the problem of route selection of vehicles in daily and repetitive trips. The target is to decrease the total trip time of the daily trips which achieves many advantages related to saving costs and efforts. We explain the existing solution of finding daily fixed routes. Also, we explain the related problems of SRS and optimization problems. So, we review the problems related to this fixed route. Also, we present the dynamic model for solving the problem by finding different dynamic vehicles routes.

The discussion shows that using dynamic routes is more realistic than choosing fixed routes especially in congested regions. Although the dynamic vehicle routing model achieves many advantages related to decreasing costs and efforts, however, some challenges are also discussed. Also, suggested solutions to these challenges are explained. However, adopting dynamic vehicle routing models still faced with some difficulties that should be considered. The advances in the upcoming computing technologies are expected to concentrate on the dynamic models soon.

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