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A Review of Time Dependent Vehicle Routing Problem with Time Windows

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Abstract— The technological advances of the last few years give rise to a renewed interest on dynamic vehicle routing problem, namely time dependent vehicle routing problem with time windows (TDVRPTW), where finding optimal route for a vehicle depends on the time of the day the travel starts from its originating node. The optimization method consists in finding solutions that minimizes the number of tours and the total travel time. The trend is towards developing some intelligent algorithms that can solve the problem with high quality solutions within in a reasonable time. This paper presents a survey of the advanced heuristics used to solve the problem. Moreover, to the best knowledge of the authors, this is the first and the foremost survey paper which summarizes the extensive work done in the field of the TDVRPTW. The effort is not only to provide overview of methods but to classify the work done on basis of various attributes.

Keywords- *Dynamic vehicle routing problem, Time dependent vehicle routing problem with time window (TDVRPTW), heuristics.*

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I. INTRODUCTION *(HEADING 1)*

Vehicle Routing Problem (VRP) is one of the most complex combinatorial problem and it has been at the core of operation studies. It was first introduced by Danting and Ramesher as the generalization of travelling salesman problem. VRP consists of fleet of homogenous vehicles with limited capacity that has to be routed in order to visit a set of customers with minimum tour length. The VRP is generally defined on the graph $G=\{V,E, C\}$ where V is the set of vertices $\{v_0, v_1, \ldots v_n\}$ representing the customers$(v_1,..v_n)$ including depot (v_0) and E is the set of edges $\{(v_i, v_j): v_i, v_j \in V, i \neq j\}$ with C as the cost matrix that contains the travelling cost from one customer to another. The goal of VRP is to find the route length with minimum travel cost so that all customers are visited once and only once with identical vehicles.

With the advancement of communication and information technologies many variants of VRP are proposed. Broadly they are classified as static and dynamic problem as shown in Figure 1.1. In static problem all inputs are known prior and paths of vehicles does not changes once they are in execution. On the other hand in case of dynamic problem some inputs are known a-prior and some route changes with the progress of day. Moreover static problems are easier to solve as compared to dynamic problem. Table 1.1 summarizes the difference between static and dynamic problems. Classical problems like Capacitated Vehicle Routing Problem (CVRP), Vehicle Routing Problem with Time Windows (VRPTW), and Vehicle Routing Problem with Backhauls (VRPB) are some of the examples of static problems. Time Dependent Vehicle Routing with Time Windows like ambulance routing, online customer request belongs to the category of dynamic problems. Although DVRP differs from SVRP in various parameters but every dynamic problem can be consequently modelled as a sequence of SVRP. In particular each static VRP will contain all information known at that time, but yet not modelled. In this survey paper time dependent variant of VRPTW is addressed in which travel time is not fixed as in case of Solomon instances and it depends on the environmental conditions likes congestion, road accidents, traffic lights etc. The main contribution of this survey is to provide the latest advances in the field of TDVRPTW and to collaborate the dispersed knowledge under one roof. Beyond this solution approaches used by researchers in literature are compared from different parameters. The remainder of this document is summarized as follows. In section 2 formal description of the problem is presented. Section 3 reviews the application in which TDVRPTW is applicable. Section 4 address the challenges in this scenario. Section 5 highlights the work done by the researchers in this field. Finally Section 6 concludes the survey and gives the future directions.

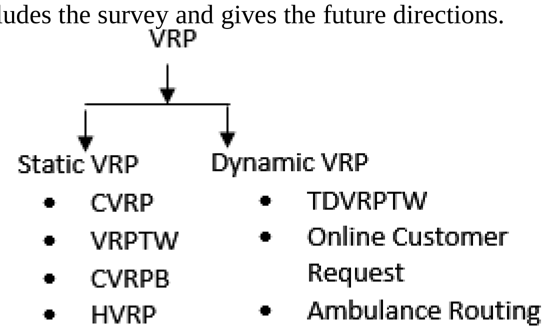

Figure 1.1 Classification of VRP

II. PROBLEM DESCRIPTION

The static vehicle routing problem with time window constraint is described as follows: a set of homogenous vehicles are scheduled to visit a given set of N customers, each customer c_i is characterized by a quantity q_i of goods, a time window (e_i,l_i), a service time s_i, a route originating and ending at a depot. Each delivery can be done no later than the latest closing time of the customer window and if the arrival time is before the opening time e_i, the delivery has to wait until the beginning of time window. The service time s_i must have elapsed before it is possible to leave the location for the next delivery. Other assumptions are: (1) each customer must be visited once and only once. (2) each tour must begin and end at depot. (3) Demand of customer q_i should be less than the capacity of the vehicle. (4) the quantity requested by the customer is to be delivered in a single issue and in full.

The problem can be modelled in mathematical terms through a directed graph *G (V, E)*, where *V* is the set of customers including depot and E is the set of edge representing the roads between two customers. The goal is to find a feasible set of tours with minimum travel cost i.e minimum travel distance with minimum number of vehicles.

With the advancement of communication and information technologies it is possible to obtain and to quickly process the data in real time [5, 6]. Therefor dynamic vehicle routing problem was extensively studied. Time Dependent VRPTW (TDVRPTW) is motivated by the fact that in urban areas variable traffic conditions play an essential role and cannot be ignored. Urban routes that ignore these significant variations can lead to unfeasible and suboptimal solutions, this unfeasibility increases as traffic conditions are varied. This survey paper address the TDVRPTW model. In this problem the goal is to minimize the total travel time instead of total travel distance. To better understand TDVRPTW consider Figure 2.1.Suppose the initial route plan is (1, 2, 3, 4, 5) as in Figure 2.1 (a). Now suppose at time t_1 due to congestion link fails between 2 and 3 as shown in figure 2.1 (b) and the initial route is adjusted to fulfill them.

Finally at time t_f the route plan is (1, 3, 4, 2, 5) as shown in Figure 2.1 (c). This example shows how the routes are dynamically adjusted which requires the technical support between depot and vehicles.

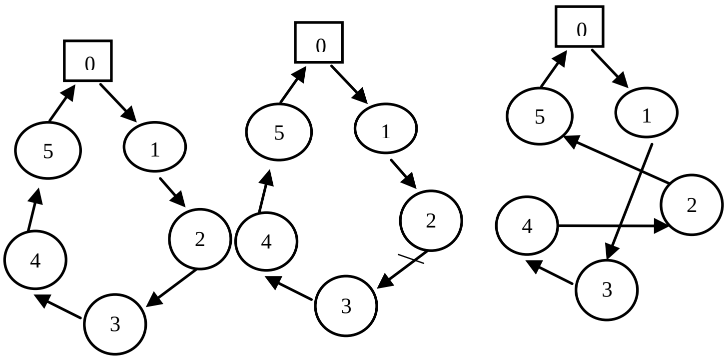

Figure 2.1(a) Initial Route Figure 2.1(b) Link Failure Figure 2.1(c) Executed Plan

Table 1.1 Static vs Dynamic VRP

Parameters	Static VRP	Dynamic VRP
Nature	Deterministic/ Stochastic	Deterministic/ Stochastic
Inputs	Known Beforehand	Changes over time
Route Changes	No	Yes
Technological Support	Needed	Not Needed
Complexity	Less	More
Knowledge of Vehicle Position	Needed	Not Needed
Decisions Taken	Offline	Online
Objective Function	Fixed	Differs
Example	CVRP,VRPTW,VRPB	TDVRPTW, Ambulance Routing

III. APPLICATIONS

Recent advances in technology has made TDVRPTW applicable in many practical situations. Some of the areas are:

- Transportation: It involves the transportations of goods and people. Many applications involves transportation of people from their work place to home or vice versa. In [4] a DARP with changing travel speeds and traffic congestion is studied.
- Emergency Services: To decide among a number of emergency calls, the severity of the cases are evaluated and a vehicle route is planned accordingly. Having an efficient dispatching system reduces the response time, thus improving the service level for the society.
- E-commerce Services: To select among an arbitrary number of customers requesting a product on a website, the customer choses a time frame for the delivery of products at his home. The goal is to maximize the total expected revenue in minimal time by deciding whether or not to accept a customer request that can be serviced within a time window.
- Maintenance Services: A common application can be found in the area of maintenance operation where customers are committed by the maintenance companies for periodical and planned visits at their locations. Therefore, the technician needs to follow the best possible route for providing the service to its customer on time.
- Atmospheric Disturbance Resolution: Considering a network of road segments when affected by a moving storm, routes of the vehicles are updated accordingly so that it can serve a large number of customers within a time window.
- Courier Services: Taking into account not only the known request, delivery locations and time windows but also considering traffic conditions and varying travel times, couriers are dispatched to customer locations to collect packages and either deliver them to their destinations with the goal of improving service quality and response time.

IV. LITERATURE REVIEW

Unlike widely studied version of the VRP, few research was conducted on TDVRPTW. The TDVRPTW is first formulated by Malandraki and Daskin in [16]. A mixed integer linear programming approach and a nearest neighbor, branch and cut algorithm is used to solve the problem without time windows.

This model does not follows a FIFO property which guarantees that if a vehicle leaves customer i to go to customer j at time t, any identical vehicle with the same destination leaving i at time t+ Δ t, will arrive later. This principle is important for maintaining the consistency among the vehicles. Furthermore it allows to keep linear the time required to check for the feasibility of local search moves, as in the constant speed models.

Ichoua et al [17] proposed a tabu search approach to solve TDVRPTW, where customers are characterized by soft time windows. The model presented satisfies the FIFO property. In this model the objective function was to minimize the sum of total travel time plus penalties associated with time window violations. Moreover they tested their method using Solomon problem set, soft time windows, three time periods, and three types of time dependent arcs.

Another approach include the work of Donati et al. [6] used multi ant colony and local search improvement approach to update the slack or the feasible time delays. They defined slack time as the time by which the delivery can be delayed so that none of the time windows of the following customers will be missed. These slack times are calculated backward. Moreover, the travel times are solved by discretizing the time space thus satisfying the FIFO property. Application of the model to the real case is presented. Hard time window are considered. However, the results cannot be compared with previous approaches because of different speed functions.

Recent work by S.R Balserio [9] uses ant colony hybridized with insertion heuristic to solve hard time window TDVRP. They used the same parameters as that of [6] to solve the problem. Both single route and multi route local search operators are used to improve the results of ant colony solution. However the computation efforts are more.

In [2] both hard and soft time windows are considered. Two algorithms namely route construction and route improvement are used to solve the problem. Furthermore it uses service time improvement algorithm to improve the service time. Deterministic approaches were used so that less randomization is involved. Furthermore replicable test cases were proposed and showed that the time complexity is O (n^2).

Figliozziet at. [1] proposes an algorithm to quantify the impacts of congestion on time dependent real world urban freight distribution networks. This study utilizes (a) the real world network data to estimate travel distance and time matrices (b) land us and customer data to estimate origin and destination patterns (c) congestion data from an extensive archive of freeway and street traffic sensor data to estimate travel time and (d) a state of the art time dependent vehicle routing solution method to design routes. Novel algorithms are developed to integrate real world road network and travel data to TDVRP solution methods.

Xin Zhao et al [8] presents a genetic approach to time dependent VRP. Degree of dynamism (dod) is defined. The used approach follows the FIFO property. In their objective routing travel time and lateness for customer is given preference. The proposed algorithm seems to be robust as the degree of dependency increases results are improved. However starting solutions produced by the genetic algorithm quickly bring the local search to a local minimum.

In [9] a hybrid evolutionary algorithm consisting of fuzzy and genetic is used to address the problem. Furthermore a real case study is considered to prove the results. The used method seems to be robust, flexible and efficient.

Ali Haghani [10] uses genetic algorithm with vehicle merging operators to tackle the problem. In this case soft time windows are considered. Heterogeneous vehicles and real time service request were considered. Continuous functions for travel time is used so that FIFO property can be guaranteed. However the used algorithm lacks in simplicity because of use of too many parameters.

Hvattam et al [15] uses a heuristic approach to solve the problem. This method divides the planning horizon into time intervals. At the beginning of the interval the method revises the routing by assigning a subset of promising request to the vehicles.

Finally Umman Mahiret al [11] address the VRPTW with both time dependent and independent cases. Soft time windows are considered. Ant Colony approach is used to minimize the total distance in independent case and then to minimize total tour time for dependent cases. Deterministic travel speed function is used to obtain the time dependency. Experimentation results shows that proposed approach obtain good quality results but with larger computation time.

Table 4.1 summarizes the solution approaches in terms of various attributes. On the horizontal side different approaches are compared and on the vertical size various attributes are taken for comparison. Objective function reveals the objective taken by author to solve the problem. Meta heuristic attribute tells about the methods used by the researches for problem solving. Parameters tells about the number of parameter used which in terns tells about the simplicity, flexibility of the algorithm .Finally the considered time window i.e Hard and Soft are taken.

Table 4.1 Comparison among different approaches

Attributes	Approaches						
	Ichoua et al[17]	Donati et al[5]	S.R Balserio[11]	M.A Filiozzi[3]	XinZaho et al[8]	Lai Wei Lup et al [4]	Ali Hanhani et al[10]
Objective Function	Total Travel time, Penalties	Fleet size , total route duration	No of vehicles , total time of all routes	No of routes , total time	Travel time and lateness for customers	Shortest Path , Shortest Time	Vehicles, routing cost, user inconvenience
Meta heuristic	Tabu	Multi ant colony + Local Search	ACO+Local search	Nil 3 Algorithms	Genetic	Fuzzy, Genetic, Graph Partitioning	Genetic
Parameters	Few	Few	Few	Few	-	Few	Many
Simplicity	Simple	Complex	Complex	Simple	Simple	Complex	Complex
Flexibility	YES	YES	YES	YES	YES	YES	NO
FIFO Property	YES	YES	YES	YES	YES	YES	YES
Replicable Results	NO	NO	NO	YES	NO	NO	NO
Comparison	NO	NO	NO	YES	NO	NO	NO
Time Windows	Soft	Hard	Hard	Hard and Soft	Soft	-	Soft

From the above table it is clear that the technique used by M.A Filiozzi is better in terms of replicable test cases. Moreover the results obtained can be compared with other results. Furthermore most literature uses ant colony heuristic and local search operators to further improve the results.

V. CHALLENGES

(i) NP Hardness: VRP is hard combinatorial problem. It belongs to the category of NP Hard problem. As TDVRPTW is the variant of VRPTW so it is also NP hard. These class of problems takes non polynomial time for the solution. Many methods like exact and heuristic are developed to solve the problem but fails for large instances, thus these are addressed by metaheuristics. Powerful meta heuristics should be developed so that problem can be solved within reasonable time.

(ii) Non Availability of benchmarks: In contrast to static problems where Solomon data set is available for the comparison of techniques dynamic problem requires the establishment of the data set. Some researchers proposed new replicable test problems that capture the typical speed variations of congested urban settings.

(iii) Objective Function: To date, there is no fixed objective function for TDVRPTW. Although, it is worth noting that some author carries their research by taking minimum travel time as their objective function, minimization of penalties are the core objective while in others user inconvenience is taken as objective function.

(iv) Performance Evaluation: Comparison are also problematic in TDVRPTW because objective function, routing constraints and the platforms are dissimilar. So new metrics to assess the performance of TDVRPTW should be introduced.

(v) Fine tuning of parameters: In TDVRPTW authors uses various parameters and manually tune them to get best results, creating a problem for comparison of results. In some papers few parameters are used while other uses many parameters to achieve the objective.

VI. CONCLUSION

The VRPTW is a well-known NP hard Problem occurring in several transportation and logistics problem. During the last decade a lot of research has been for the heuristics to solve VRPTW. Some of them were extended for addressing its variant TDVRPTW. Indeed, recent solution approaches obtains more accurate results still the literature is not collected under one roof. In this survey paper the authors had collected the various approaches under one domain. Furthermore applications, challenges of the problem are highlighted and a comparison of variety of technique is made in terms of various parameters. Moreover it is fair to say that most of the approaches are simple, flexible, robust while few scores well on replicable results.

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