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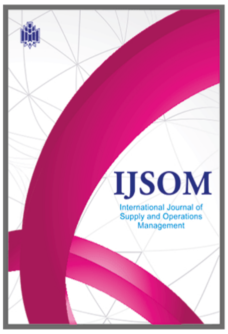

Multiple-Criteria Decision-Making Combined with VRP: A Categorized Bibliographic Study

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Abstract

In this research, author reviews references related to the topic of multi-criterion (goal programming, multiple objective linear and nonlinear programming, bi-criterion programming, Multi-Attribute Decision-Making, Compromise Programming, Surrogate Worth Trade-off Method) and various versions of vehicle routing problem (VRP), Multi-Depot VRP (MDVRP), VRP with time windows (VRPWTW), Stochastic VRP (SVRP), Capacitated VRP (CVRP), Fuzzy VRP (FVRP), Location VRP (LVRP), Backhauling VRP(BHVRP), Facility Location VRP (FLVRP), and Inventory control VRP (ICVRP). Although VRP is a research area with rich research works and powerful researchers, only 81 articles are found that relate various vehicle routing type problems with various multiple objectives techniques. This author found that there is no research done in some areas of VRP (i.e., FVRP, ICVRP, LRP and CVRP). It is interesting to see that this research area was completely unattractive to master students (with zero research reported) and somewhat attractive to doctoral students (with 6 researches reported). Among the many multi-criterion programming techniques available, only three of them (goal programming, bi-criterion programming, linear and nonlinear multi-objective programming) are being employed to solve the problem.

Keywords: Vehicle Routing Problem; Goal Programming; Bicriterion Programming; Multiple objective programming; Multi-Attribute Decision-Making; Heuristics; Meta-heuristic; Decision-Making.

1. Introduction

Vehicle Routing Problem (VRP) is a challenging logistics management problem with variations that range from school bus routing to the dispatching of delivery trucks for customer goods. Regardless of the variations, the basic components of the problem are a fleet of vehicles with fixed capacities and a set of demands for transporting passengers or certain objects (customer goods) between specified depots and delivery points. The problem is complicated because managers must also take into consideration a variety of constraints such as fixed vehicle capacity and the duration of the route. The prospective and prospects on VRP is discussed by Magnanti (1981). The concept of VRP has been addressed within the framework of other management science techniques. For instance, Federgruen (1984) discusses a combined knowledge of VRP and inventory problem and Ball (1983) discusses planning for truck fleet size in the presence of common-carrier option. Zare Mehrjerdi and Nadizadeh (2013) discuss the modeling of the problem within the location routing problem and in fuzzy environment. The purpose of this article is to review works published on the VRP combined with the Multi-Criteria Decision-Making. This review provides all types of researches published on this attractive combinatorial field,

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Including the Ph.D. dissertations, Master Thesis, Conference articles, Journal articles, and technical reports.
To provide a meaningful survey, the following criteria are considered in this paper:

1. Only works published in OR/MS literature.
2. Work done in the United States as well as abroad
3. Application areas as well as theoretical works related to the subject
4. Special articles thought to be important to the field of VRP.

A total of 81 published references on Multi-Criteria Decision-Making (MCDM) combined with Vehicle Routing Problem have been compiled in this research.
For those articles that were on the border line, this author decided to use the following characteristics for determining the paper whether it is eligible or not:

1. The title contains both VRP and multi-criteria decision-making language
2. The abstract relies on the concepts of VRP and MCDM
3. The paper addresses both topics theoretically, practically, or in the form of a case study
4. The list of references used in the article directs us to this reality that MCDM and VRP are dominating the content of the whole article.

To make the foregoing criteria operational, a survey was made using the following sources:

- www.Sciencedirect.com
- Web Directory such as Yahoo and Google
- This author personal knowledge on the topic.

Before digging truly into the topic of this article, I was wondering why there are not too many publications on the multi-criteria decision-making and VRP. Once I completed my research I came to this conclusion that there are people there who are interested on the topic and working hard to make the VRP more operational and manageable. Knowing that VRP is a subset of the combinatorial and an NP-hard type problem, we will appreciate the level of efforts that one needs to implement in model development and programming in a way that is manageable and suitable to an organization's profit-making.

2. Research Background

2.1 Travelling Salesman Problem

Some of the problems classified under the generic name are the traveling salesman problem (TSP) and its variants Multiple TSP and Time Constrained (MTSPT); Single depot, Multiple Vehicle Node Routing (SMVNR), Multiple depot, multiple Vehicle Node Routing (MVMNR); and single depot, Multiple Vehicle Node routing problem (SMVNR) with stochastic demands. These problems are of discrete type with combinatorial structure and hence are known as "combinatorial Optimization". The TSP, a combinatorial optimization problem with some real life applications, is the substructure of all VRP problems (1995) and has been studied extensively in the literature. Dantzig and Ramser (1959) described the TSP as follows: "Find the shortest route (tour) for a salesman, starting from a given city, visiting each of a specified group of cities, and returning to the original point of departure". Mathematically, this problem can be formulated as:

Minimize $$\sum_{i=1}^{N}\sum_{j=1}^{N} C_{ij} X_{ij} \qquad (1)$$

S.t.

$$\sum_{i=1}^{N} X_{ij} = 1 \qquad j \in S = \{1,\ldots,N\} \qquad (2)$$

$$\sum_{j=1}^{N} X_{ij} = 1 \qquad i \in S \qquad (3)$$

$$X_{ij} = \begin{cases} 0 \\ 1 \end{cases} \qquad i.j \in S \qquad (4)$$

$$X_{ij} = \{\text{form a tour}\} \qquad (5)$$

where C_{ij} is the cost of traveling from node I to node j, $C_{ij} = \infty$, where i=1,2,…,N. Constraint (5) can thus be written in the form of

$$Z_i - Z_j + NX_{ij} \le N - 1 \qquad 2 \le i \ne j \le N \qquad (6)$$

And for some nonnegative real numbers Z_i.

2.2 Vehicle Routing Problem

Since 1959 when Dantzig and Ramser (1959) first introduced the VRP and proposed a linear programming-based heuristic for its solution, the heuristic method has been widely researched. Christofieds and Eilon (1972, 1979) indicated that the largest VRP of any complexity solved to date by exact methods and reported in the open literature contains only 31 demand points. Before considering model development for this research, a formulation of the VRP problem as a 0-1 integer program is given below. The problem that is known as "pure delivery" can be formulated as (2006):

P3: Minimize $$\sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{\substack{k=1\\ i\neq j}}^{NV} d_{ij} X_{ijk} \qquad (7)$$

S.t.

S= {

$$\sum_{i=1}^{N}\sum_{k=1}^{NV} X_{ijk} = 0 \qquad j=2, 3,\ldots,N \qquad (8)$$

$$\sum_{i=1}^{N} x_{ipk} \sum_{\substack{j=1\\ i\neq j}}^{N} X_{pjk} = 0 \qquad k=1,2,\ldots,NV,\ \ p=1,2,\ldots,N \qquad (9)$$

$$\sum_{j=2}^{N} X_{ijk} \leq 1 \qquad k=1,2,\ldots,NV \qquad (10)$$

$$Z_i - Z_j + N\sum_{k=1}^{NV} X_{ijk} \leq N-1 \qquad i \neq j = 1,2,\ldots,N \qquad (11)$$

}

$$\sum_{i=1}^{N} d_i \left(\sum_{\substack{j=1\\ i\neq j}}^{N} X_{ijk}\right) \leq Q_k \qquad k=1, 2,\ldots,NV \qquad (12)$$

$$\sum_{i=1}^{N} t_{ijk} \sum_{\substack{j=1\\ i\neq j}}^{N} X_{ijk} + \sum_{i=1}^{N}\sum_{\substack{j=1\\ i\neq j}}^{N} t_{ijk} X_{ijk} \leq T_k \qquad k=1, 2,\ldots NV \qquad (13)$$

$$X_{ijk} = \begin{cases} 0 \\ 1 \end{cases} \qquad i,\ j,\ k \text{ and } i \neq j \qquad (14)$$

Where;

N= Number of nodes

NV= Number of Vehicles

Q_k =Capacity of Vehicle k

T_k = Maximum time allowed for vehicle k on a route

d_i = Demand at node i (assuming that d_1=0)

t_{ik} = Time required for vehicle k to deliver or collect at node $i (t_{1k} = 0)$

t_{ijk} = Travel time for vehicle k from node i to node j

d_{ij} = Distance from node i to j

$$X_{ijk} = \begin{cases} 1 \text{ if arc (i, j) is traversed by vehicle k} \\ 0 \text{ Otherwise} \end{cases}$$

Z_i = Arbitrary real numbers, i=1, 2,…,N.

The objective function (7) represents minimization of total distance traveled by NV vehicles. Alternatively, costs could be minimized by replacing d_{ij} with C_{ij}, depending on the vehicle type. Equation (8) ensures that each demand node is served by exactly one vehicle; equation (9) ensures that if a vehicle enters a demand node it must exit from that node; and (10) guarantees that vehicle availability is not exceeded; equation (11) prohibits sub-tours generation, equation (12) is vehicle capacity constraint, and finally, (13) is the total elapsed route time constraint. Decision variables X_{ijk} that is of 0 and 1 type is represented by equation 14.

The set of constraints (8), (9), (10), and (11) produce a space that we will refer to as S in the remainder of this article. All feasible decision variables of the problem belong to this space. For having any decision variable from set S as an acceptable solution of the problem it must satisfy constraints (12), (13), and (14) as well.

Golden and Stewart (1977) formulated the single depot SVRP via the concept of CCP. The verbal nature of their formulation is as shown below:

Minimize {Expected total cost}

S.t.

{

1. A fixed set of routes
2. Satisfaction of customers
3. Vehicle capacity is obeyed
4. P (total demand $\geq$ truck capacity } >= (1-α)

}

where $0 \leq \alpha \leq 1$.

Tillman (1969, 1972) is credited for realizing the probabilistic nature of the customer demand in the scheduling of the multi-depot delivery and collection problems. This is a valuable problem and has been adapted by many industries dealing with the distribution and/or collection of products from one/many location(s) into many/one locations. Bodin (1979) used a survey by Kearney (1980) to show that about 16 percent of the sales value of an item is based upon the physical distribution costs of that item, and about one-fourth of that is due to the downstream distribution of the final product from distribution centers to customers. Turner and Vu (1979) further reported that in 1974 about 10 percent of the average community budget was spent on refusal collection and disposal, a total of 7.8 billion dollars in USA alone. Factors such as these attracted a great deal of attention to the VRP and SVRP.

Three excellent volumes have been published on the subject of the traveling salesman problem (Lawler et al., 1985), on routing and scheduling (Bodin et al., 1983) and on vehicle routing problem (Golden and Assad 1984). Each publication offers hundreds of references to the subject of routing and scheduling. Vehicle routing with stochastic elements has received attention as well. Stewart, and Golden (1984), Stewart (1981), Golden and Yee (1979), Dror and Trudeau (1986), Laporte and Louveau (1992) have employed stochastic optimization techniques to solve small size problems.

Park (1984) proposed a multiple objective analysis of the deterministic vehicle routing problem. Interactive VRP is studied by Waters (1984), while computational modifications of the savings method for VRP are studied by Yellow (1970). In 2004, Bianchi et al(2004) have studied vehicle routing problem with stochastic demand using meta-Heuristic approaches. In 2006, Bianchi et al (2006) have considered five meta-heuristics of Simulated Annealing; Tabu Search; Iterated Local Search; Ant Colony Optimization and Evolutionary Algorithms to study VRP with stochastic demand. In 2005, Haugland, Ho and Laporte (2005) studied the delivery districts for the VRP with stochastic demands. A two-stage hybrid algorithm for pickup and delivery vehicle routing problems with time windows and multiple vehicles is studied by Bent et al (2006). In the first stage, a simple simulated annealing algorithm is used for decreasing the number of routes while the second stage uses large neighborhood search for decreasing total travel cost. Zheng and Liu (2006) studied the vehicle routing problem in which the travel times are assumed to be fuzzy variables. Many other researchers have conducted studies on VRP to find an exact or approximate solution of the problem: Bertsimas et al. (1990), Golden et al. (1977), Holmes and Parker (1976), Magnanti (1981), Nagy and Salhi (2007), Salhi and Rand (1987), Stacy (1983), and Wassan and Osman (2002).

A brief discussion on MCDM problem is given in section 2. That is followed by the discussion on various types of VRP that is outlined in section 3. A brief review of solution methodologies for MCDM combined with VRP is given in section 4. Next, a discussion on Meta-heuristics Techniques and VRP is given in section 5. Data classification is the topic of section 6. The analysis of data and tables are given in section 7. The discussion on tables is given in section 8. Section 9 indicates the future research areas for VRP and author's conclusion on this topic.

3. Multiple-Criteria Methodologies

Perhaps the single most important decision faced by management when dealing with multiple objectives is the selection of an appropriate solution, which optimizes the proposed criteria simultaneously. Therefore, it is hardly surprising that much of the literature in operations research focuses on the Multiple Objective Programming Problems. Today, there are many multi-criteria solution techniques available that can be used to model this problem of vehicle routing problem. Some of the techniques that are most suitable for addressing the problem are: multiple objective linear programming, goal programming, surrogate worth trade-off method, the step method, bi-criterion programming, and multi-attribute decision-making. The review of 81 articles presented in this research with regard to MCDM indicates that the main tools used for solving various classes of VRP are those listed below: (1) Goal Programming; (2) Interactive Goal Programming; (3) Bi-criterion Programming; and (4) Multiple Objective Programming.

Goal programming was originally introduced by Charnes and Cooper in early 1961 for a linear model. It has been extended into many areas including the facility location analysis (Current et al., 1990), public project selection (Colin, 1985), government planning and budgeting (Joiner and Drakke), office management (Bres et al. 1980), insurance industry (Gleason, 1977), and stochastic vehicle routing programming (Zare Mehrjerdi, 1986), transportation network and location (Current et al., 1984), transportation network and routing (Current et al., 1993), transportation location (Current, et al., 1984) VRP with time windows (Calvete et al., 2007), to mention a few. Goal programming is a useful tool for planning because many planning criteria can be expressed in terms of goals. A goal programming model can be solved using one of the many techniques available in the literature as are listed below (Flavell 1976; Ijiri 1965; Lee 1972; Romero 1991; SchneiderJans 1995; Zare Mehrjerdi 1995; Zeleny 1982; Tamiz 1998; Ateuer 1999): (1) Archimedean Goal Programming; (2) Preemptive (Lexicographical) Goal Programming; (3) Partitioning Goal Programming; (4) Multiple Criterion Function Goal Programming; (5) Iterative Goal Programming; (6) Dual Simplex method for Goal Programming; and (7) Revised Simplex method of Goal Programming.

Additionally, one can solve a GP model either regularly or interactively. To solve a GP model interactively, one needs to develop a computer program that can allowthe decision-maker as a part of the solution process. Goal programming and interactive goal programming are chosen to solve multi-criterion vehicle routing problem for the following primary reasons: (1) Computationally efficient (Park 1984) and ease of modeling; (2) Concepts can be easily communicated with the decision-makers (Park 1984); and (3) It is flexible enough to address problems in a MCDM format.

In many cases it is necessary to have the decision-maker as a part of the solution process to obtain an end result that is consistent with his/her needs. The fact that any analytic tool is comprised of many iterations therefore having DM as a part of solution process and feeding his/her feedbacks into the process in a straight manner is of primary concern. The original works done in the area of VRP by Park (1984) and Zare Mehrjerdi (1986, 1993, 2013, 2014) are of interactive goal programming type.

As indicated by Jones et al. (2002), the recent decades have seen an increase in the awareness of multiple objectives and the design of multi-objective programming techniques to handle situations where it also is true about the vehicle routing problem. A multi-objective programming problem can be formulated as:

Maximize $f_1(x_j) = \sum_{j=1}^{n} C_{1j} X_j$

Maximize $f_m(x_j) = \sum_{j=1}^{n} C_{mj} X_j$

S.t.

$X \in S$

In multiple objective programming, we solve the problem and identify a set of non-dominated solutions and then represent those to the decision-maker for final decisions to be made. A good review of multiple objective programming is presented in (Cohon 1979; Deb, 2001, Zeleny 1974). There are few methods available for generating the set of non-dominated solutions in multi-objective programming area. These methods are: (1) Weighting method; (2) ε - constrained method; (3) Phillip's linear multi objective method; and (4) Zeleny's linear multi-objective method. The areas of VRP combined with multi-objectives are studied by Min (1991), Fonseca. (1995), Keller (1985), Lacomme (2003), Daskin(1985), Hall (1994), Kim (2006), Lin(2006), Josefowiez (2007), Baran (2003), Boffey (1995), Bowerman (1995), Corberan(2002), Ehrgott (2000), El-Sherbeng (2001), Josefoweiz (2004, 2005), and Ribeiro (2001) as are listed in the references.

As it was discussed above, there are many other Multi-Criterion solution techniques that can be used to solve a version of a VRP. What is important in problem solving is the result that can be obtained at the end and the level of the effort that must be put into that in order to reach the final solution. A method known as surrogate worth trade-off can also be used to solve a VRP combined with MCDM. Compromise programming (Romero 1998, Yu 1973) which has a common mathematical root with goal programming Zeleny (1974, 1982) can also be used for solving multi-objective VRP.

4. Vehicle Routing Problem by Types

The problem of VRP can be classified into ten categories of: (1) deterministic Vehicle Routing Problem (DVRP), (2) Multi-depot VRP (MDVRP), (3) VRP with time windows (VRPWTW), (4) Stochastic VRP (SVRP), (5) Capacitated VRP (CVRP), (6) Fuzzy VRP (FVRP), (7) Location VRP (LVRP), (8) Facility Location VRP (FLVRP), (9) Backhauling VRP (BHVRP), and (10) Inventory Control VRP (ICVRP). In the sections that follow each of these subcategories are very briefly discussed.

4.1. Deterministic VRP

The basic components of the VRP are a fleet of vehicles with fixed capacities and a set of demands for transporting passengers or certain objects (customer goods, etc.) between specified depot and delivery points. The problem is complicated because managers must also take into consideration a variety of constraints such as fixed vehicle capacity and the duration of the route. The prospective and prospects on VRP are discussed by Magnanti (1981). The concept of VRP has been addressed within the framework of other management science techniques. For instance, Federgruen (1984) discusses a combined knowledge of VRP and inventory problem and Ball et al (1983) discusses planning for truck fleet size in the presence of common-carrier option.

4.2. Vehicle Routing Problems with Time Windows

Vehicle routing problem with time windows are divided into two categories of VRP with hard time windows (VRPHTW) and VRP with soft time windows (VRPSTW). The goal of VRPHTW is to determine the optimal set of routes and the optimal sequence of customers visited by each vehicle, taking into account vehicle capacities, service times and time windows. These time windows are hard constraints when a route is not feasible if the service of any customer does not start within the limits established by the time window. These are Vehicle Routing Problems with Hard Time Windows (VRPHTW) (Calvete, 2007). Comprehensive reviews of these problems are presented in (Tan et al. 2003; Tan et al. 2006; Tan el al., 2003; Van Landeghem 1988). There are cases that both lower and upper bounds of the time window can be violated at a price, for a penalty. These are Vehicle Routing Problems with Soft Time Windows (VRPSTW) (Calvete, 2007). The number of references in VRPSTW is relatively small. Sexton and Choi (Sexton et al. 1986) consider a single-vehicle pickup-and-delivery routing problem where each load has its own origin and its own destination.

4.3. Stochastic VRP

Stochastic Vehicle Routing Problems (SVRP) can be classified into four categories as listed below:

1. Stochastic Customers (Jaillet and Odoni 1988; Jaillet 1987),
2. Stochastic Demands (Bianchi et al. 2004; Bianchi et al. 2006; Dror et al. 1993; Golden and Stewart 1977; Golden and Yee 1979; Haugland 2005; Tan 2007; Tillmand 1969; Tillman et al, 1972; Yee and Golden 1980; Zare Mehrjerdi 1986),
3. Stochastic travel and unload times (Zare Mehrjerdi 1993; Zare Mehrjerdi 1986),
4. Stochastic demands and stochastic travel and unload times (Zare Mehrjerdi, 1986, 2013, and 2014).

In 2004, Bianchi et al (2004) studied vehicle routing problem with stochastic demand using meta-heuristic approaches. In 2006, Bianchi et al (2006) have considered five meta-heuristics of Simulated Annealing; Tabu Search; Iterated Local Search; Ant Colony Optimization and Evolutionary Algorithms to study VRP with stochastic demand. In 2005, Haugland, Ho, and Laporte (2005) studied the delivery districts for the VRP with stochastic demands. Demands are assumed to be uncertain at the time when districts are made, and these are revealed only after the districting decisions are determined.

4.4. The VRP with Backhauls

The VRP with backhauls is an extension of the VRP that includes both a set of customer to whom they should deliver goods and a set of vendors from whom they need to pick up the goods for transporting back to the distribution center. In addition to that, on each route all deliveries have to be made before any goods can be picked to avoid rearranging of the loads on the truck. This is a problem of some concerns to some distribution centers that need to be studied clearly and timely (Jacobs Blecha, 1998).

4.5. Multi Depot VRP

In the MDVRP, each customer may be serviced by a vehicle originating at any of the available depots. Tillman (1969 and 1972) is credited for realizing the probabilistic nature of the customer demand in the scheduling of the multi-depot delivery and collection problems. This is a valuable problem and has been adapted by many industries dealing with the distribution and/or collection of products from one/many location(s) into many/one locations.

4.6. Location Routing Problem

Location routing problem (Negi and Salhi, 2007) is a new research area that has gained the attention of some researchers recently. The LRP is comprised of a research area in the framework of the local analysis while having deep and specific looks at the vehicle routing problem. There are few works done in this area and none is related to the combined topics of location routing problem and multi-objective programming. To obtain a better understanding of the topic one may consult the work of Balakrishnan (1993), Laporte (1992), Berman (1995), and Min (1991).

4.7. Capacitated VRP

Capacitated Vehicle Routing Problem (CVRP) is another subset of the VRP that has attracted the attention of many researchers. In this problem, one has to deliver goods to a set of customers with known demands on minimum cost vehicle routes originating and terminating at a depot. The vehicles are assumed to be homogeneous and having a certain capacity. In some versions of the CVRP, one also has to obey a route duration constraint that limits the lengths of the feasible routes (Tavakkoli-Moghaddam et al.2006 and Tavakkoli Moghaddam et al. 2007).

4.8. Inventory Control/Periodic VRP

The inventory routing problem arises when inventory replenishment considerations are added to the vehicle routing problem. Considering this problem, the timing of deliveries to customers must be determined based on their inventory positions, the replenishment policy, and the routing costs. In problems such as delivery of liquids, gases or fuels to distributors, it is necessary to consider a planning horizon of, say, one week, and then plan to visit that place, for instance, 3 times per week (Sunday, Tuesday and Thursday or Monday, Wednesday, and Friday). This problem is called assignment routing problem or period routing problem. Algorithms for solving the Period Routing problem are suggested by Russell and Igo (1979), and Tan and Beasley (1984).

4.9. Fuzzy VRP

A fuzzy vehicle routing problem is assumed to have the following characteristics (Zhenyu et al. 2003):

1. Each vehicle has a container with a physical capacity limitation and the total loading of each vehicle cannot exceed its capacity;
2. A vehicle will be assigned for only one route on which there may be more than one customer;
3. A customer will be visited by only and only one vehicle.
4. Each route begins and ends at the company site (depot);
5. Each customer specifies its time window within which the delivery is permitted or preferred to start;
6. Travel times between customers are assumed to be fuzzy variables.

Zheng and Liu (2006) studied vehicle routing problem in which the travel times are assumed to be fuzzy variables.

4.10. Facility Location VRP

Due to budget limitation and growths of population and demand, developing countries usually face the determination of cost effective public facilities taking people most important requirements into consideration. In most of these countries, distance is the most influential factor. This means that distance and transporting mean play an important role in this type of problem development. Taking at least two criteria into consideration, we need to design, develop, and solve a multi-objective facility location vehicle routing problem into consideration. A simple example of this case is the development of a healthcare center in a city or urban area. Doerner (2006) has proposed such a problem for a mobile center using multi-objective routing problem.

5. Solution Methodologies for Combined MCDM and VRP

Solution techniques for the VRP fall into two categories: those which solve the problem heuristically and those which solve the problem optimally. Basically, heuristics techniques have proved to be an attractive alternative to exact methods because they are easy to understand, readily accepted by managers, easy to program and maintain for computerized planning, and effective in solving a wide range of practical problems which provide solutions that are usually accepted as "reasonable".

The VRP formulation as an integer program is actually the one presented originally by Golden et al. (1997). Balinski and Quandt (1964) formulated the VRP as integer program where it is a representative of a cluster-first, route-second approach to the VRP in which demand points are first assigned to the vehicle clusters and then each vehicle is routed over the demand points assigned to it to determine a delivery sequence. Foster and Ryan (1976) proposed an integer programming formulation of the VRP which is solved using the revised SIMPLEX Method. This method is strictly primal in that both feasibility and integrality are withheld at all stages. An integer programming formulation of the VRP with a planning horizon of more than one day is extended to incorporate the linear constraints.

The solution process for VRP can be divided into (1) one-phase method; and (2) two-phase method. In one-phase method which is usually used in exact solution techniques one can solve the problem by a general mathematical programming model. The model proposed by Dantzig and Ramser (1959) are of this type. Other methodologies belonging to this category involve the use of branch and bound methods (Bard 2002), column generation (Mourgaya et al. 2007; Skitt 1985; and Talliard 1999), and Lagrangian relaxation (Kohl 1997; and Stewart and Golden 1984). For larger problems, researchers usually focus on heuristic and meta-heuristic (tabu search, genetic algorithms, simulated annealing) methods to derive a solution of an acceptable quality in a reasonable computation time (Gendreau 1994; Greistorfer 2003; Hertz 2000; Pacheco 2006; Taillard 1997; Wassan 2002; Tavakkoli-Moghaddam ----; Park 2001; Potvin 1996; Rahoual 2001; and Zhou 2003)

In two-phase method, customers are first assigned to vehicles without specifying the sequence in which customers are visited. In the second phase, routes are obtained for each vehicle using a TSP heuristic. The procedures introduced by Gillett and Miller (1974) and Christofieds and Eilon (1979) are two-phase methods that use a modified Lin-Kernighan heuristic in phase-two. The two-phase method is comprised of two stages of (1) the route construction stage and (2) the route improvement stage as are discussed below. The solution methodology proposed in (Zare Mehrjerdi 1986) for solving the stochastic vehicle routing problem is also of a two-phase method.

5.1. The Route Construction Stage

The RCS of the VRP consists of the problem of partitioning a set of stations into feasible sets of vehicle routes. To deal with the NP-hard type problems and solving those in a manner acceptable to managers only heuristic methods are considered. The RCS of the VRP consists of following steps:

1. Problem formulation in which objective functions and constraints are identified.
2. Transformation of the defined problem into an equivalent deterministic form when demand or time constraints are of probabilistic type, and
3. Partitioning of a set of stations into feasible subsets using an appropriate heuristic approach.

5.2. The Route Improvement Stage

When the arrangement of stations on one route does not exactly or even partially meet the decision maker's needs, then the route improvement technique needs to be taken into consideration. This stage of the problem is required for sequencing stations on each route for the purpose of meeting customer's requirements and decision maker's obligations. Stations on each route are sequenced using an appropriate management science technique. Prior to the utilization of this technique, decision-maker should acknowledge the following information from the route construction stage of the problem.

- Construction routes

- Total demand of each route
- Total expected cost, time or distance for whole delivery system
- Unload and travel times for each route, and
- Number of required vehicles.

6. Meta-heuristics Techniques and VRP

Meta-heuristics have become prominent approaches in tackling complex and multi-objective problems (Jones et al. 2002). Recent examples include a bus driver scheduling problem (Lourenco 2001) and a resource-constrained project scheduling problem (Viana et al. 2000). What are known as meta-heuristics techniques are tabu search, simulated annealing, genetic algorithm, evolutionary algorithm, and Ant Colony Optimization. In the sections that follow, each of these techniques are discussed briefly.

6.1 Tabu search

Tabu Search is a direct searching algorithm for optimizing very complicate problems. This method that is based upon the human memory process generates a list of the latest points that are being investigated. The purpose of this list preparation is the prevention of transformation to the points that have been investigated previously. The tabu search implementations of Taillard (1999) has obtained the best known results to benchmark VRPs. Similar results were reported by various authors using tabu search (Gendreau 1994; Greistorfer 2003; Hertz 2000; Pacheco 2006; Taillard et al. 1997; Wassan 2002), or simulated annealing (Tavakkoli-Moghaddam 2006). Taillard et al. (1997) recognized possible savings allowing multiple uses of vehicles in VR modeling and scheduling. These researchers applied tabu search in a 3-step procedure to design routes with multiple vehicle uses to minimize the total cost of routes. Golden et al (1997) reported on the use of a tabu search based upon the “adaptive memory procedure” for solving a VRP with a Minmax objective.

6.2 Simulated Annealing

A methodology known as simulated annealing has its origin in statistical mechanics (Tavokkoli Moghaddam 2006 and 2007) which draws its concept from the annealing process of solids. The annealing process can be described as heating a solid to high temperature and then cooling that gradually to lower it to crystallize. The process of heating allows the atoms to move randomly. A rapid cooling process gives atoms sufficient time to align themselves to reach a minimum energy state known as “equilibrium” or “stability”. As described in (Czyzak et al. 1998, Tavakkoli Moghaddam 2006 and 2007), this methodology can be used in combinatorial optimizations in which the state of solid corresponds to feasible solution and the energy at each state corresponds to an improvement in the objective function and the minimum energy state will be the optimal solution. Simulated annealing was applied to improve the solution.

6.3 Genetic Algorithms (GA)

Genetic Algorithm is a new optimization technique used mostly for solving nonlinear and very complicated programming problems. This method is based upon the evolution process which has an evolutionary path as a biological path would own. In a simple term, this method by generating various generations (solution sets) of feasible solutions try to move toward the optimal solution point of the problem. Among the modern meta-heuristics, GA is used wide with several applications reported in the area of VRP (Park 2001; Potvin 1996; Rahoual 2001; Zhou 2003) . GA is used for solving the VRP with backhauls, multi-depot routing problem (Tillman 1969, 1972), and school bus driving (Bowerman 1995; Corberan 2002). Baker and Ayechew (2003) put forward a conceptually straightforward genetic algorithm for the basic VRP, which is competitive with other modern heuristics in terms of computing time and solution quality.

6.4 Evolutionary Algorithms

Under the most frequent classification, Evolutionary Algorithms, together with Fuzzy Logic and Neural Networks, is part of the so-called Soft Computing. Evolutionary Algorithms is comprised of Genetic Algorithms, Evolutionary Programming, Evolutionary Strategies and Genetic Programming and some similar techniques. Evolutionary Algorithm may have the following structure (Coello Coello 2002; Tan et al. 2003; Tan el al. 2006; Tan el al. 2007 and Tan and Cheong 2007):

- Search space – space of all possible solutions.
- Population – set of actual candidates for solution; elements of population are called individuals or items, or search nodes, or points in search space.
- String space – space that contains string representations of individuals in population.
- Functions for conversion between points in search space and points in string space (coding and decoding).
- Set of genetic operators for generating new strings (and new individuals).

- Fitness function – it evaluates fitness (degree of adaptation) for each individual in population.
- Stochastic control of genetic operators.

Basic steps in Evolutionary Algorithms are:

1. Initialization (using random sampling to generate initial population).
2. Evaluation (to calculate fitness for all individuals in population).
3. Selection (to choose surviving individuals in population in accordance with the values of fitness function).
4. Recombination (includes crossover and mutation) – to change individual's representation.
5. Repeating steps 1 to 4 until fulfilling finishing criteria.

In multi-objective vehicle routing problems, the Pareto concept is frequently used within an evolutionary framework. Many authors (Coello Coello 2002; Deb 1999; Deb et al. 2002; Jaszkiewicz 2003; Jozefowiez 2004; Lacomme 2003; Li 2005; Murata 2005; Paqurte 2003; Sarker 2002; Tan 2003; Tan et al. 2003; Tan and Cheong and Goh 2007; Tan and Chew and Lee 2006; Tan, Lee, Chew and Lee 2003; Tan, Chew and Lee 2006; Van Veldhuizen 1998; Zhenyu 2003; Zitzler 2000; and Deb 2001) have used evolutionary algorithms methods to solve multi-objective routing problems. Some have used evolutionary algorithms with Pareto methods (Li, 2005; and Skitt 1985) to solve the MOVRP as well. Others have employed hybrids based on evolutionary algorithms and local searches, heuristics, and/or exact methods for the considered problem (Bodin 1983; Doerner et al. 2006; Ehrgott 2000; Jozefowiez et al. 2005; Jozefowiez et al. 2006; Lacomme 2003; Sessomboon et al. 1998; Tan et al. 2003). Pareto dominance has also been used by El-Sherbeny (El-sherbeny 2001) in a simulated annealing technique called Multi-Objective Simulated Annealing (MOSA) while Paquete et al. (2003, and 2004) have called upon Pareto Local Search techniques. These techniques are based on the principle that the next current solution is chosen from the non-dominated solutions of the neighborhood.

6.5 Ant Colony Optimization

There are some researches that report the application of Ant Colony (AC) in the combinatorial optimization (Bell and McMullen 2004; Baran 2003; Chitty et al. 2004; Donati 2007; Gambardella et al. 1999; and Martinezet al. 2007)

These published works have reported successful applications. Baker and Ayechew (2003) pointed that with a 2-opt heuristic applied to improve individual routes produced by artificial ants this approach provided results which are only slightly inferior to those from tabu search. Baràn and Schaerer (2003) do not use a standard multi-objective approach for solving multi-objective VRP. They had considered the reality of dealing with the problem of multiple objective nature using appropriate mechanisms in the ant colony system being proposed. Chitty and Hernandez (2004) reported an ant colony system adapting bi-objective situation considering total mean transit time and the variance in the transit time. Pareto Ant Colony Optimization (PACO) is a multi-objective meta-heuristic approach used by Doerner et al (2006) for solving the location-routing problem with several objective functions.

6.6. Hybrid Algorithm

A techniques that is known as hybrid algorithm combines one or more of meta-heuristics techniques along with an optimization or heuristic technique that can solve the problem accurate, fast and easy. A two-stage hybrid algorithm for pickup and delivery vehicle routing problems with time windows and multiple vehicles is studied by Bent et al (2006). In the first stage, a simple simulated annealing algorithm is used for decreasing the number of routes while the second stage uses large neighborhood search for decreasing total travel cost. Studies on VRP and LRP (Bres et al. 1980) suggests that building hybrid meta-heuristics, like tabu search and simulated annealing, helps to combine their best features to gain the best results possible. A hybrid approach to vehicle routing using neural networks and GA has also been reported (Potvin 1996). A hybrid heuristic which incorporates neighborhood search into GA is also considered.

7. Data Classification and Analysis

In the following sections we will classify the data into nine tables as listed below:

Table 1- Presents the list of works published on the VRP combined with MCDM methodology by solution methodologies

Table 2- Presents the list of works published on the VRP combined with MCDM methodology by solution methodologies

Table 3- Presents the list of works published on the VRP combined with MCDM methodology by VRP classifications

Table 4- Presents the list of works published on the VRP combined with MCDM methodology for important

cases
Table 5- Presents sample objective functions used in VRP areas by researchers
Table 6- Presents the sample objective functions used by practitioners
Table 7- Presents publications classifications by type of research
Table 8- Presents publications classifications by publications Journal
Table 9- Presents publications classifications by MCDM.

Table 1 presents the list of 81 articles by the names of authors and the years of publications starting from 1984. This class of researches was started by the work of Park (1984) in the department of Industrial Engineering and Management at Oklahoma State University and then followed by the work of Keller (1985 and 1988), Current (1985), Daskin (1985), Zare Mehrjerdi (1986, 1993, 2013 2014) and Park and Keolling (1986 and 1989) . Most of these researchers started their works with the interactive goal programming as a tool for solving VRP with more than one objective functions. For the first time, a VRP with more than one objective functions was solved by Zare Mehrjerdi where demand, travel time and unload time were assumed to be random variable with known distribution functions.

Table 2 shows the list of works published on the VRP combined with the MCDM methods and by solution methodologies. Generally speaking, multiple objective vehicle routing problems are solved using one or more of the techniques of tabu search, genetic algorithm, simulated annealing, evolutionary algorithm, heuristic methods, Pareto method, meta-heuristics, and hybrid heuristics. Table 3 shows the list of works published by the names of the authors combined with the MCDM methodologies and by VRP classified into ten categories of VRP, SVRP, FVRP, VRPWTW, CVRP, LRP, FLVRP, BHVRP, MDVRP, and ICVRP.

Table 4 shows the list of works published on the VRP combined with the MCDM methodologies for important cases such as Library Distribution System, Control Engineering Problem, Truck and Trailer VRP, School Bus routing problem, Bus Driver Scheduling Problem, Waste Collection VRP with Time Windows, Location Routing Problem, Transit Vehicle Scheduling, Traffic Light Network, Urban School Bus Routing, Rural School Bus Routing, Mobile Health Care Facility Tour Planning, and Belgian Transportation Company as reported in the literature of Operations Research and VRP. Tables 5 and 6 list the most important objective functions taken into consideration in the problem formulation of the multiple objective vehicle routing problems.

According to table 7, of 81 articles researched, only 6 are Ph.D. dissertations, 11 are conference articles, 13 are published as a chapter of a book and 50 are published as research articles in scientific journals. Table 8 shows the publications classification by publications Journals. This author has found that about 29 percent of these research articles are published by the European Journal of Operational Research, 5 percent by the Computers and Operations Research Journal and 4 percent by the Transportation Science Part A journal. Table 9 shows that in most of the published articles, heuristics and genetic algorithms have been chosen for solving multi-criterion problems of VRP types. The same table also shows the distribution of published works by multi-criteria tools.

Table 1. List of works published on the VRP combined with MCDM methodology

Year	Author	Characteristics of the Problem
1984	Park, Y.B.	VRP, single depot, deterministic, interactive goal programming.
1985	Keller, C.P.	VRP with time window, Multiple objective programming.
1985	Current, J.R., et al.	General Transportation, Network, Multiple Criteria programming.
1985	Daskin, M.	VRP, multiple Objective, Stochastic, Multiple Modes.
1986	Zare Mehrjerdi, Y.	SVRP review, single depot, stochastic programming, goal programming.
1986	Park, Y.B. and Keolling, C.P.	VRP, single depot, deterministic, interactive goal programming.
1987	Solommon	VRP with time windows
1988	Van-Landeghen	VRP with time windows, Bicriterion programming.
1988	Ronen, D.	VRP, Truck Routing and Scheduling, Multiple Objective Programming, Genetic Algorithm, Software design.
1988	Keller, C.P.	TSP, Lexicographical Method, Heuristics.
1989	Park, Y.B., et al.	VRP with Time Windows, single depot, deterministic, interactive goal programming
1990	Sutchiffe and Board	VRP, Bicriterion programming.
1991	Min, H.	VRPTW, deterministic, goal programming, a case study of Library distribution system in Franklin County Ohio.
1992	None	None
1993	Zare Mehrjerdi	SVRP, single depot, stochastic demand, stochastic load and unload times, Multiple Objective goal programming, chance constraint programming
1994	None	None
1995	Fonseca, C.M.	VRP, Multiple Objective Programming, Control Engineering Problem.
1995	Fonseca, C.M.	VRP, Multiple Objective Programming, Control Engineering Problem.
1995	Bowerman, R.	Rural Schoold Bus Touting, Multiple Objectives, Aggregation, Heuristics.

1995	Boffey, B.	VRP, Multiple objective programming.
1995	Ulungu…	VRP, Combinatorial Optimizations, Bicriterion programming, Two phase methods.
1996	Shang, J.S., Cuff,C.	VRP, Multiple Objective programming, minimizing Vehicle expenses, Minimizing Tardiness and travel times.
1997	Golden, B., et al.	VRP, Minmax Objectives, Capacitated VRP, Tabu Search.
1998	Sessomboon, W.,	VRP with time windows, Pareto Approach, Bicriterion programming.
1998	Czyzak, P.	VRP, multiple objective programming, Simulated Annealing
1998	Van-Veldhuizen	VRP, Multiple objective programming, Evolutionary Algorithm.
1998	Gainnikor, …	Location Routing Problem, Goal Programming, Hazardous Management.
1998	Lee and Ueng…	VRP, Aggregation, Minimize the traveled distance.
1999	(Hong, S.C.)	VRP with time windows, Bicriterion Programming
2000	Viana, A.	VRP, Multiple objective programming, metaheuristics
2000	Talbi, E.G.	VRP, Multiple objective, Sample problems.
2000	Ehrgott,…	VRP, Approximation Algorithms, Multiple objectives.
2001	Rahoual, M.	VRP with time windows, Multi-Criterion Genetic Algorithm
2001	Lourenco,	VRP, Bus driver scheduling problems, multiple objective Metaheuristics
2001	Jaszkiewicz)	VRP, Multiple objective and Genetic Algorithm.
2001	El-Sherbeny,	VRP, Simulated Annealing, Pareto Approach, Multiple objective Programming.
2001	Geiger…	VRP with time windows, Multiple Objective Programming, Pareto Approach.
2001	Ribeiro,	VRP, Multi-Period VRP, Aggregation, Multiple Objective Programming.
2002	Corberan, A.	VRP, School bus scheduling, Multiple objective programming, Heuristic
2002	Sarker, R.	VRP, Multiple objective programming, Evolutionary algorithm.
2002	Borges, P.C.	TSP, Multiple Objectives.
2002	Corberan,	Rural School Bus routing, Multiple Objectives, ε - Constraint approach.
2002	Jaszkiewicz	VRP with route Balancing, Goal programming, Tabu Search.
2002	Jozefowies,	VRP, parallel modeling, Hybrid modeling, Multiple objectives.
2003	Lacomme, P.	VRP, Multiple objective programming
2003	Tan, K.C.,	Truck and Trailer VRP, hybrid multiple objective evolutionary algorithms
2003	Tan, K.C.	VRP with time window, deterministic, Multiple Objective Evolutionary Algorithm.
		VRP with Time Windows, Tabu Search, Multiple Objectives, Heuristics.
2003	Lau, H.C., et al.	Shortest path with time windows, Traffic Light, bi-criterion.
2003	Chen, Y., et al.	VRP, Allocation, Genetic Algorithms, Bi-Criterion.
2003	Zhuo, G., et al.	VRP with time windows, Ant Colony Systems, Multiple Objectives.
2003	Baran, B.	VRP, Genetic Algorithm, Goal programming.
2003	Geiger…	TSP, Aggregation, Multiple Objective Programming.
2003	Paquete…	TSP, Genetic Algorithms, Pareto Approach, Multiple Objective Programming.
2003	Zhenyu,…	
2004	Angel E. et al	TSP, Multiple Objective Programming, Local Search.
2004	Jozefowiez ..	VRP modeling, Evolutionary Algorithms, Multiple Objective.
2004	Zografos,	VRP with time windows, Heuristics, Aggregation, Multiple Objective Programming.
		VRP, dynamic VRP, Ant Colony optimization, bi-objective modeling.
2004	Chitty, et al	VRP, Multiple Period, Heuristics, Multiple objectives.
2004	Mourgaya	VRP, evolutionary algorithms, Applications, Multiple objectives.
2004	Jozefowiez …	TSP, Pareto Local Optimum, Bicriterion programming.
2004	Paquete	
2005	Jozefowiez .	VRP, tour balancing, Applications demonstrations.
2005	Li, …	TSP, Heuristics, Bicriterion programming.
2005	Murata,	VRP, Genetic Algorithms, Multiple Objective Programming, Pareto Search.
2005	Riera-Ledesma ,	TSP, Aggregation
2006	Lacomme, P.	VRP with time windows, bicriterion Genetic algorithms.
2006	Kim, B., et al.	VRP with time windows, Waste Collection, Capacitated VRP, Multiple Objective, Arc routing, Clustering.
2006	Lin, C.K.Y., et al.	VRP, Logistics, Multiple Objectives, Metaheuristics.
2006	Doerner,	Mobile health care facilities tour planning, Multiple objectives Programming, Ant Colony Optimization.
2006	Jozefowiez .	VRP, route balancing, Pareto search.
2006	Ombuki,	VRP with time windows, Genetic Algorithms, Multiple objective programming, Weighted sum.
		Rural School Bus routing, ε — constrained Method, Multiple Objectives Programming.
2006	Pacheco,	VRP, Capacitated VRP, Genetic Algorithms, Multiple Objectives.
2006	La Commet et al	
2007	Herminia, I.	VRP with soft time windows, Goal programming
2007	Zare Mehrjerdi	VRP, Chance Constrained Programming, goal programming,
2007	Zare Mehrjerdi	VRP, Chance Constrained Programming, goal programming, theory and developments for approximations
2007	Calvete, H.I., et al.	VRP with soft time windows, Multiple Objective, Goal programming, Logistics.
		VRP, Bi-criteria, Exact Methods, Metaheuristics, Combinatorial Optimization.
2007	DaSilva, C.G., et al	TSP, Ant Colony, multiple Objective Optimization, Evolutionary Algorithms.
2007	Martinez, C.G., et al	VRP, Multi-objective, Ant Colony System , Hierarchical objectives.
2007	Donati, A.V., et al.	VRP, Multiple Objective programming.
2007	Josefowiez, N., et al	VRP, Combinatorial Optimization, Bi-Objectives.
2007	Mourgaya, M., et al	VRP, Genetic Algorithms, Multiple Objective Programming, Pareto Search.
2007	Murata,	

Table 2. List of works published on the VRP combined with MCDM methodology by Solution Methodologies

Solution Methodologies	Authors
Goal Programming & VRP	Zare-Mehrjerdi,Y.(2007),Zare-Mehrjerdi,Y.(2007), Herminia (2007), Calvete, .I., et.al.(2007), Geiger (2003),Giannikor(1998), Jaszkiewicz(2002).
Interactive-Goal Programming & VRP	Park,Y.B. (1984), Park,Y.B. and Keolling(1985), Zare Mehrjerdi (1986).
Bi-Criterion Programming & VRP	Van-Landeghen (1988), Lacomme,P.(2006), Sessomboon,W.(1998), Chen,Y.,et. Al. (2003), Mourgaya,M., et al. (2007), Ulungu (1995), Sutcliffe et al.(1990), Hong,S.C. and Park,Y.B.(1999), Zhou, G.,et.al.(2003), DaSilva, C.G.,et.al.(2007), Josefoweiz (2007).
Multiple-Objective Programming	Min,H.(1991), Fonseca,C.M.(1995), Keller,C.P.(1985), Lacomme,P.(2003), Daskin,M.(1985), Hall,G.B. et.al. (1994), Kim,B., et.al.(2006), Lin,C.K.Y.,et.al(2006), Josefowiez, N.,et.al.(2007), Baran,B.(2003),Boffey,B.(1995), Bowerman,R.(1995), Corberan(2002), Ehrgott(2000), El-Sherbeng(2001), Josefoweiz (2004), Josefoweiz (2005), Ribeiro(2001).
Multiple Objective Programming (Simulated Annealing) &VRP	Czyzak,P.(1998), El-Sherbeny(2001).
Multiple Objective Programming (Evolutionary Algorithms) & VRP	Tan,K.C.(2003, Tan,K.C.(2006), Tan,K.C.(2006), Sarker, R(2002), Van-Veldhuizen(1998), Martinez, C.G., et.al.(2007), Josefoweiz (2004).
Multiple Objective Programming (Genetic Algorithms) &VR	Ombuki(2006), Lacomme, P.(2006), Jaszkiewicz(2001), Rahoual,M.(2001), Fonseca,V\C.M.(1995), Ronen,D. (1988), Zhou,G.et.al.(2003), geiger (2003),Murata(2005, 2007), Ombuki(2006), Seasomboon(1998), Zhenyu (2003), LaCommet et.al.(2006).
Multiple Objective Programming (Tabu Search)& VRP	Jaszkiewicz (2002), Golden, B. et.al.(1997), Lau,H.C., et.al.(2003), Pacheco(2006).
Multiple Objective Programming (Heuristics) &VRP	Park,Y.B. and Kelloing(1986), Zare Mehrjerdi (1993), Lau, H.C. et al.(2003), Zografos(2004), Mourgaya(2004), Corberan,A.(2002), Ronen,D.(1988), Min,H.(1989), Hall,G.B., et.al.(1994), Bowerman,R.(1995), Keller (1985), Keller(1988), Li(2005).
Multiple objective Programming (Hybrid Heuristics) &VRP	Josefoweiz (2002), Tan,K.C.(2003), Seasomboon(1988).
Multiple Objective Programming (Pareto) & VRP	Geiger(2001), Josefoweiz (2006), Murata(2005, 2007), Paquete(2004), Seasomboon(1987), La Commet, et.al(2006).
Multiple Objective Programming (Metaheuristics) & VRP	Lin,C.K.Y.(2006), Lourenco(2001), Viana,A.(2000), DaSilva,C.G.92007).
Other Multi-Criterion Techniques & VRP	Golden,B. et al.(1997), Donati,A.V.et.al.(2007)

Table 3. List of works published on the VRP combined with MCDM methodology by VRP Classifications

Solution Methodologies	Authors
MOP and deterministic VRP	Park, Y.B.(1984), Park, Y.B. and Keolling, P.C.(1986, 1989)
MOP and Stochastic Demand VRP	Zare Mehrjerdi (1986), Tan, K.C.(2007),
MOP and Stochastic Time and demand VRP	Zare Mehrjerdi (1986, 1993, 2007),
MOP and Multi-Period VRP	Mourgaya (2004)
MOP and Backhauling VRP	Min,H.(1989), Shange, J.et.al.(1996)
MOP and VRP with Time Window	Tan, K.C.(2003), Van-Landeghen(1988), Hong,S.C., and Park,Y.B. (1999), Sessomboon,W.(1998), Herminia, I. (2007), Rahoual, M.(2001), Lau,H.C. et.al.(2003), Kim,B. et.al.(2006), Calvete, H.I., et.al.(2007), Chen, Y., et.al. (2003), Baran,B.(2003), Geiger (2001, 2003), Ombuki (2006), Rahoual(2001), Solomon(1987),
MOP with Capacitated Vehicle Routing Problem	Golden, B. et.al.(1997), La Comment et.al.(2006), Kim,B. et.al.(2006)
MOP and Location VRP	Lin,C.K.Y.(1965), Giannikor (1998)
MOP and Facility Location VRP	Doerner (2006)
Others (MOP and Fuzzy VRP, MOP and Multi-depot VRP, and MOP and Inventory control VRP)	None

Table 4. List of works published on the VRP combined with MCDM methodology for important cases

Important Cases/ Problems Solved	Authors
Library Distribution System	Min, H.(19910
Control Engineering Problem	Fonseca, C.M.(1995)
Truck and Trailer VRP	Tan,K.C.(2003)
School Bus routing	Corberan, A.(2002)
Bus Driver Scheduling Problems	Lourenco(2001)
Waste Collection VRP with Time Windows	Kim, B. et.al(2006)
Location Routing Problem	Lin,C.K.Y.(2006)
Transit Vehicle Scheduling	Wanh,H.(2007)
Traffic Light Network	Chen,Y.et.al(2003)
Urban School Bus Routing	Bowerman R.(1995)
Rural School Bus Routing	Corberan (2002)
Mobile Health care Facility Tour Planning	Doerner(2006)
Belgian Transportation Company	El-sherbeny
Rural School Bus Roating	Pacheco (2006)

Table 5. Sample of objective functions used in VRP

Minimize the traveled distance	Maximize the realization of the urgent queries
Minimize the merchandise deterioration	Maximize the capacity utilization
Maximize the equalization of the vehicle travel times	Optimize the balance of the load
Maximize the customer satisfaction	Minimize the number of vehicles
Optimize the balancing (numbers of visited customers)	Minimize the total mean transit time
Minimize the total variance in transit time	Maximize profit
Minimize the total customer waiting times	Minimize the total travel times
Minimize the total deviations from the time windows violations	

Table 6. Sample of objective functions used by Practitioners

Minimize the total length	Minimize the student walking distance
Optimize the balance of the load	Minimize the total cost
Minimize the total perceived risk	Minimize the individual perceived risk
Minimize the individual disutility	Minimize the total time
Minimize the waiting times	Minimize the number of trucks
Minimize the number of covered trucks	Maximize the flexibility
Minimize the number of unused working hours	Optimize the regionalization (clustering) of the customers
Minimize the ineffectiveness of the personnel	Minimize the average distance for an inhabitant to walk
Maximize the size of the population covered	

Table 7. Publications Classifications by type of research

Journal or Type of Distribution	**Number of Works**	**% of Total**
Ph.D. Dissertation	6	7.4%
Master of Science Thesis	0	0
Conference Articles	13	16.0
Journal Articles	50	61.7
Technical Report – University level	1	1.2
Published as a Chapter of a Book	11	13.6
Total	81	100%

Table 8. Publications Classifications by publications Journal

Name of Journals carried such publications	**Number of Works**	**% of Total**
1) European Journal of Operational Research	23	28.4%
2) Computers and Operations Research	4	4.9
3) Transportation Science Part A	3	3.7
4) Operations Research Society	2	2.5
5) International Journal of Production Economics	2	2.5
6) Computers and Industrial Engineering	2	2.5
7) Transactions of the Japan Society of Mechanical Engineering	2	2.5
8) Theoretical Computer Science	1	1.2
9) TOP	1	1.2
10) Multi-Criteria Decision-Making	1	1.2
11) International Journal of Operations Research	1	1.2
12) Journal of Heuristics	1	1.2
13) Environmental and Planning B: Planning and Design	1	1.2
14) Socio-Economic Planning Science	1	1.2
15) Applied Intelligence	1	1.2
16) Engineering Costs and production Economics	1	1.2
17) Foundations of Computing and Decision Sciences	1	1.2
18) Journal of Industrial Engineering International	1	1.2
19) Discrete Optimization	1	1.2
20) Others	31	38.3
Total	81	100%

Table 9. Publications Classifications by Multi-Criterion Techniques

Rows	**Multi-Criteria Tools**	**Number of Works Published**
1	Bicriterion Programming	11
2	Goal Programming	7
3	Interactive Goal Programming	4
4	Multi-Objective Programming	18
5	Multi-Objective Heuristics	13
6	Multi-Objective Meta-heuristics	4
7	Multi-Objective & Genetic Algorithm	13
8	Multi-Objective and Tabu search	4
9	Multi-Objective & Simulated Annealing	2
10	Multi-Objective & Evolutionary Algorithm	7
11	Hybrid Multi Objective & Heuristic Algorithm	3
12	Multiple Objective and Pareto	6
13	Other Multiple objective methods	2

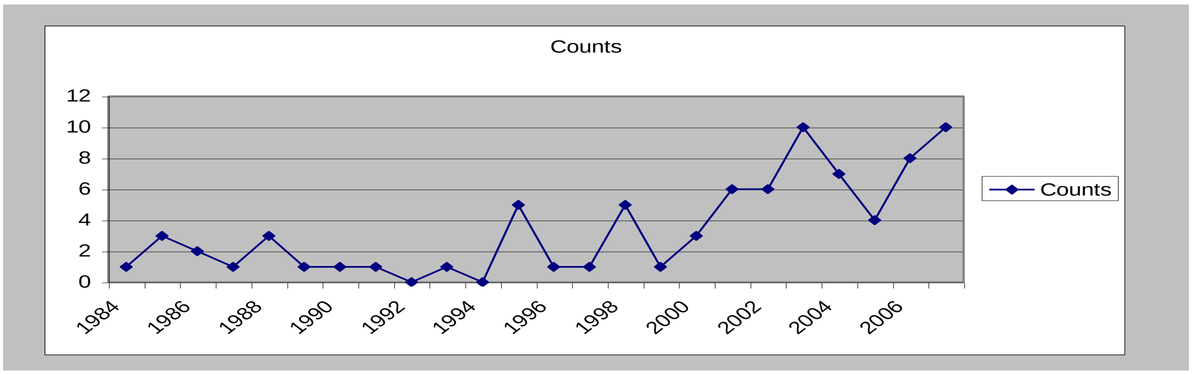

Figure 1. Distribution of publications by years of publications

8. Future Research and Conclusion

Figure 1 shows that although up to year 2000 there were not too many researches reported in the multiple objective VRP, since that time the trend is upward and hopefully it will continue likewise. The area that is relatively rich with research in multi-criterion technique is VRP with time windows. Another area that has received more attention is multi-objective programming VRP using genetic algorithms and heuristics to solve the problem. With the present research, I have come to this conclusion that there are many untapped areas in various subsets of VRP that require the attention of researchers. The most important areas that need more attention are:

1. Fuzzy vehicle routing problem
2. Location routing problem
3. Capacitated vehicle routing problem
4. Facility location vehicle routing problem
5. Multi-period vehicle routing problem
6. Backhauling vehicle routing problem
7. Stochastic vehicle routing problem

Each of these VRP subsets can be considered in the mathematical modeling of the problem and then by proposing an appropriate exact or heuristic solution technique the problem can be solved.

Due to the fact that we are looking at eleven different types of VRP and all multi-criterion decision-making tools, in this research we expect to see more than 77 cases that are of interest to us. These cases are shown in table 10. The cross sign of X is used to show where there exist untapped areas that need more attention from researchers. From table 10 it can be seen that of these 77 areas of research, only 17 areas are being fully or to some degree taken into consideration. Other areas are either untapped or barely touched by researchers.

Table 10. Problem Classification by VRP types and Multi-Criterion Techniques

Types of VRP Problems	Goal Program.	Interactive Goal Program.	Bi-Criterion Program.	Multi-Objective Program.	Compromise Program.	Surrogate Worth Trade-off Method	Other Multiple Objective Methods
VRP					*	*	*
SDVRP (1)			*		*	*	*
SDTVRP (2)			*		*	*	*
VRPWTW					*	*	*
FVRP	*	*	*	*	*	*	*
CVRP	*	*	*	*	*	*	*
LRP	*	*	*	*	*	*	*
FLVRP	*	*	*	*	*	*	*
BHVRP	*	*	*	*	*	*	*
MDVRP	*	*	*	*	*	*	*
ICVRP	*	*	*	*	*	*	*

(1) Stochastic Demand VRP (SDVRP)

(2) Stochastic Demand and Travel and unload times VRP (SDTVRP)

In this article author viewed all references related to the topics of multi-criterion (goal programming, multiple objective linear and nonlinear programming, bi-criterion programming, multi-attribute decision-making, compromise programming, etc.) and various branches of vehicle routing problem such as deterministic VRP (DVRP), MDVRP, VRPWTW, VRP with stochastic demand (SDVRP), VRP with stochastic travel and unload times (STVRP), CVRP, FVRP, LRP, FLVRP, and ICVRP. Although VRP is a research area with powerful researcher hands on, only 81 articles are found that relate various vehicle routing problems with various multiple objectives techniques. This author has found that no research was done in some of the areas of VRP such as FVRP, ICVRP, LRP, and CVRP. It was interesting to notice that this research area has not been able to attract one researcher at the Master of Science level to do a master thesis (zero research reported in the literature.) On the other hand, it was attractive to the Doctoral Students to some level only (6 researches reported in this case.) Among the many multi-criterion programming techniques available, only three of them (i.e., goal programming, bi-criterion programming, linear, and nonlinear multi-objective programming) are being employed to solve the problem.

In conclusion, with this research we will be able to dig into all untapped areas of VRP combined with MCDM that are of many values to both researchers and practitioners. This review indicates that VRP combined with MCDM is still a developing area of combinatorial optimization. We hope that the challenges posed here will arouse the interest of some researchers and readers and direct them in working on this challenging research area. In addition to all those discussed above a combination of Radio Frequency Identification technology (RFID) with various types of routing and inventory problems and supply chain management can be of the demand in the future. More on RFID topics can be seen from the work of Zare Mehrjerdi (2008; 2009; 2010; 2011a; 2011b; 2011c; 2012; 2013a, 2013b, 2013c, 2013d, 2013e, 2013f, 2014) and Ruta et al. (2010). Moubed and Zare Mehrjerdi (2015) have modeled a reverse supply chain problem as an inventory-routing problem.

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