Computers & Industrial Engineering 57 (2009) 1472–1483

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Survey

The vehicle routing problem: A taxonomic review

Burak Eksioglu [a,*], Arif Volkan Vural [b], Arnold Reisman [c]

[a] Department of Industrial and Systems Engineering, Mississippi State University, P.O. Box 9542, MS 39762, USA
[b] US Airways, 7206 McKnight Road, Pittsburg, PA 15237, USA
[c] Reisman and Associates, 18428 Darkland Drive, Shaker Heights, OH 44122, USA

ARTICLE INFO

Article history:
Received 11 November 2008
Received in revised form 11 May 2009
Accepted 12 May 2009
Available online 25 May 2009

Keywords:
Routing
Vehicle routing
VRP
Taxonomy
Classification

ABSTRACT

This paper presents a methodology for classifying the literature of the Vehicle Routing Problem (VRP). VRP as a field of study and practice is defined quite broadly. It is considered to encompass all of the managerial, physical, geographical, and informational considerations as well as the theoretic disciplines impacting this ever emerging-field. Over its lifespan the VRP literature has become quite disjointed and disparate. Keeping track of its development has become difficult because its subject matter transcends several academic disciplines and professions that range from algorithm design to traffic management. Consequently, this paper defines VRP's domain in its entirety, accomplishes an all-encompassing taxonomy for the VRP literature, and delineates all of VRP's facets in a parsimonious and discriminating manner. Sample articles chosen for their disparity are classified to illustrate the descriptive power and parsimony of the taxonomy. Moreover, all previously published VRP taxonomies are shown to be relatively myopic; that is, they are subsumed by what is herein presented. Because the VRP literature encompasses esoteric and highly theoretical articles at one extremum and descriptions of actual applications at the other, the article sampling includes the entire range of the VRP literature.

1. Introduction

The primary objective of this paper is to present a taxonomic framework for defining and integrating the domain of the extant VRP literature in terms that are operationally meaningful. Such a framework will enable the classification of all VRP papers, which in turn will enable, among other things, systematic identification of voids in the literature and thus lead to potential topics for research. During the last three decades advances in computational capability, together with computer accessibility, have spawned major advances in algorithm development. These developments have enabled major advances in addressing the VRP. The need to improve vehicle routing was, in turn, spurred on by explosive developments in theory and applications of supply chain management. So, it should come as no surprise that the VRP literature has grown exponentially as a result of the above.

The literature of history and philosophy of science is replete with admonitions that, as important as it is to publish knowledge gained from good research in a given subject area, it is even more important to periodically reflect and assess where the field has been, where it is heading, and what, if anything, should be done to change that field's course. This indicates the need for some form of meta-research (Abbott, 1988; Cooper, 1984, 1988, 1989, 1998).

> In primary (social science) research, data are collected by asking people questions or observing their behaviour. In research synthesis, data are collected by conducting a search of reports describing past studies relevant to the topic of interest – (Cooper, 1998).

Meta-research often serves other very important objectives as well. One of these is consolidating the knowledge in a given discipline; another is expanding the discipline's scope. Consolidation and expansion are not mutually exclusive; in fact, they are complimentary.

1.1. A review of some previous classification efforts and taxonomies

As discussed in Reisman (1992), there are at least two efficient and effective ways of consolidating knowledge. One of these is to create a taxonomy and the other is to create a generalized framework (a general model or theory) that subsumes all existing models, facts, or theories within that field. A taxonomy displays the subject's domain in terms that are easy to understand, communicate, teach, learn, and work with. It enables efficient and effective classification of any and all contributions/publications. In turn, this enables efficient and effective storage, recall, sorting, and/or statistical analyses. Because such classification results are meaningfully machine readable, they enable further meta-research which includes, but is not limited to, identification of voids in the literature

* Corresponding author. Tel.: +1 662 325 7625; fax: +1 662 325 7618.
E-mail address: beksioglu@ise.msstate.edu (B. Eksioglu).

0360-8352/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cie.2009.05.009

and, therefore, directions/specifications for research to be performed. As shown in Vogel and Weterbe (1984) and Reisman (1992), there are many other uses for such a classification scheme. Bibliometric analysis is one of the more important of these for graduate OR/MS and Decision Science education.

Some taxonomical efforts about VRPs have appeared in the literature. Bodin (1975), first to introduce a taxonomical structure, focused on routing and scheduling problems with static requirements. Bodin provided a taxonomy with the aim of offering solution methods for each subcategory identified. Bodin and Golden (1981) extended Bodin's work by including a hierarchical model that encompasses very simple vehicle scheduling problems to complex scheduling-routing problems. These two studies were later used by Min, Jayaraman, and Srivastava (1998) to provide a taxonomy with a perspective in location-allocation-routing problems. The authors, however, focused on static problems and justified this limited scope by the scarcity of dynamic problems. They introduced a taxonomy model for solution methods. However, their taxonomy failed to provide any insight into meta-heuristics. Desrochers, Lenstra, and Savelsbergh (1990) introduced a three-level classification scheme that is simple, yet elaborate and robust enough to represent the contemporary literature at the time of its publication. At the first level of this classification, the problems are studied based on "*addresses*" (the network's node characteristics), "*vehicles*" (characteristics of the vehicles and their routes), "*problem characteristics*" (the underlying network, service strategy, and constraints on relations between addresses and vehicles), and "*objectives*" (the objective function's characteristics). The Desrochers et al. (1990) model was applied to different problems within the literature. However, their taxonomy lacks the ability to incorporate current stochastic and dynamic VRPs as well as other static routing problems with uncommon constraints. Their work is practical and represents a good model for an academic standard in taxonomy. In a later study Desrochers, Jones, Lenstra, Savelsbergh, and Stougie (1999) developed a model and algorithm management system for vehicle routing, as well as for scheduling problems. It provided support in modeling situations and algorithms that might be applicable to emerging problems. The management system proposed by Desrochers et al. (1999) is most helpful in handling real-world problems, from observation to formulation, algorithm selection, and ultimately to implementation. Current and Marsh (1993) provided a classification for the multiobjective design of transportation networks within three hierarchical levels. The first level of the taxonomy partitions the multiobjective network problems into eight branches, one of which is the VRP. Each branch is divided into two sub-groups based on whether it incorporates a heuristic or exact algorithm. Although the taxonomy can handle many aspects, especially those related to the objective function, it provides hardly any information about constraints, network properties, or other physical attributes of problems. Powell and Shapiro (1999) provided a more detailed classification and representational structure. Their focus was on "dynamic resource transformation problems." This wide class further divides into "dynamic resource allocation problems," "dynamic resource scheduling problems," and "dynamic resource management problems." The study comprised, but was not limited to, vehicle routing, scheduling, and dispatching problems. They listed a number of problem types available in the literature and sorted them according to increasing levels of complexity and introduced a representational template with three major fields: *information, process,* and *controls*. However, with its level of detail, the paper fails to address many versions and configurations of the VRP. Actually, the authors did not attempt further development of their template into a single robust taxonomic structure. One important review and taxonomical study was provided by Psaraftis (1995). After identifying currently available dynamic transportation models, he provided a non-exhaustive classification of distribution problems under 10 configurations occurring in real world environments. Psaraftis clearly defined dynamic problems and isolated them from the static ones. Since a dynamic nature comes with input data characteristics, he provided a taxonomy useful in characterizing input information attributes. After defining twelve major factors that distinguish between static and dynamic transportation models, Psaraftis suggested some future research directions.

In addition to the taxonomy-based studies summarized above, two reviews need to be mentioned. After identifying what makes VRPs stochastic, Gendreau, Laporte, and Seguin (1996a) discussed solution concepts. The study further delineated stochastic VRP groups and discussed their configuration by citing implemented solution methods found in the literature. Returning to the original routing problems, Laporte and Osman (1995) provided a bibliography of 500 studies. They group the problems into four major categories based on configuration: the traveling salesman problem (TSP), the VRP, the Chinese postman problem, and the rural postman problem. Their study provided further detail for these problem types and provided characteristics reported in the literature. Laporte and Osman's study is one of a kind in the number of bibliographical entities provided on the vehicle routing literature.

1.2. A brief history of the VRP literature

The paper by Dantzig, Fulkerson, and Johnson (1954), the first record in the VRP literature, studied a relatively large scale TSP and proposed a solution method. That study was followed by a great volume of other TSP papers. TSP can be shown to be a specific case of VRP. Clarke and Wright (1964) first incorporated more than one vehicle in the problem formulation. Consequently, this study may be considered as being first in the VRP literature as we know it.

The first paper bearing the phrase "vehicle routing" in its title is attributed to Golden, Magnanti, and Nguyan (1972). Other versions of VRP emerged in the early 1970s; e.g. fleet routing (Levin, 1971), dial-a-bus systems (Wilson & Sussman, 1971), transportation network design (O'Connor & De Wald, 1970), routing of public service vehicles (Marks & Stricker, 1970), distribution management (Eilon, Watson-Gandy, & Christofides, 1971), and solid waste collection (Liebman, 1970). Probabilistic content was introduced to the VRP by Golden and Stewart (1978). Solomon (1983) added time-window constraints to the classical VRP and introduced a set of well known benchmark problems now known as "Solomon Instances." During the 1980s, VRP research generated different static configurations of the original problem. Due to computational complexity and scarcity of microcomputers, stochastic, dynamic, and fuzzy versions of the VRP were not much studied. For a further inquiry into major problem types, formulations and solution methods of this era, one may refer to the works of Laporte and Nobert (1987), Assad (1988) and Laporte (1992).

VRP research accelerated during the 1990s. Primarily due to microcomputer capability and availability, researchers could develop and implement more complex search algorithms. During this era the term *meta-heuristics* was introduced to name a number of search algorithms for solving these VRPs as well as other combinatorial optimization problems. Gendreau et al. (1998) studied VRP applications with meta-heuristics such as: (1) simulated annealing, (2) deterministic annealing, (3) Tabu search, (4) genetic algorithms, (5) ant systems, and (6) neural networks. For further information one may refer to works of Wasserman (1989), Osman and Kelly (1996), Osman and Laporte (1996), Dorigo, Maniezzo, and Coloni (1996), Aarts and Lenstra (1997), Glover and Laguna (1997) and Cordeau, Gendreau, Laporte, Potvin, and Semet (2002).

In the database we compiled, the first stochastic VRP (SVRP) dates back to Cook and Russell (1978) – a simulation study.

Although a few papers appeared in the 1980s on SVRP, the pace quickened in this field during the 1990s. More powerful computers and enhanced coding capability helped researchers model and solve SVRPs easily. For a review of SVRP, see Gendreau, Laporte, and Seguin (1996b) and Yaohuang, Binglei, and Qiang (2002); for solution algorithms see Roberts and Hadjiconstantinou (1998) and Park and Hong (2003). The first dynamic VRP study dates back to Powell (1986). Together with the enhanced computational capability in the 1990s and the enhancements in vehicle tracking, data storage, and exchange media, dynamic VRPs (DVRP) became more frequent in the literature when the second half of the 1990s began. For a deeper inquiry in DVRP one may refer to studies by Psaraftis (1995), Gendreau and Potvinm (1998), Savelsbergh and Sol (1998), Larsen (2000), Larsen, Madsen, and Solomon (2002) and Fleischmann, Gnutzmann, and Sandvoss (2004). Note that some of the DVRP papers may also fall under the SVRP category. However, there are some DVRP papers that utilize fuzzy sets theory such as studies by Teodorovic and Pavkovic (1996), Tan and Tang (2001), Gomez and Zuben (2003), He and Xu (2005) and Saez, Cortes, and Nunez (2008). In our taxonomy, dynamic and fuzzy VRP papers will be grouped under the "unknown" category as indicated at the bottom of Fig. 6.

1.3. VRP definition and background

The VRP can be represented as the following graph-theoretic problem. Let $G = (V, A)$ be a complete graph where $V = \{0, 1, \ldots, n\}$ is the vertex set and A is the arc set. Vertices $j = 1, \ldots, n$ correspond to the customers, each with a known non-negative demand, d_j, whereas vertex 0 corresponds to the depot. A non-negative cost, c_{ij}, is associated with each arc $(i, j) \in A$ and represents the cost of traveling from vertex i to vertex j. If the cost values satisfy $c_{ij} = c_{ji}$ for all $i, j \in V$, then the problem is said to be a symmetric VRP; otherwise, it is called an asymmetric VRP. In several practical cases the cost matrix satisfies the triangle inequality, such that $c_{ik} + c_{kj} \geqslant c_{ij}$ for any $i, j, k \in V$ (Toth & Vigo, 1998).

The VRP consists of finding a collection of k simple circuits, each corresponding to a vehicle route with minimum cost, defined as the sum of the costs of the circuits' arcs such that:

i. each circuit visits vertex 0, i.e., the depot;
ii. each vertex $j \in V \setminus \{0\}$ is visited by exactly one circuit; and
iii. the sum of the vertices' demand visited by a circuit does not exceed the vehicle capacity, C.

In their taxonomy, Current and Marsh (1993) proposed a very high level framework that lists VRPs together with seven other multiobjective transportation network problems. Fig. 1 depicts the first level of that taxonomy, which is constructed based on the underlying mathematical structure and/or the purpose of the formulation. This figure is meaningful in the sense that it presented a family of problems encompassing the VRP and provided a sense of borders that isolate the VRP from all else. Such an effort was needed since researchers need to know what constitutes the VRP and what is considered to be inside, as well as outside of it. Thus, the Current and Marsh (1993) taxonomy dealt with a universe larger than its VRP constellation.

A high level classification scheme for the general dynamic transportation models was introduced by Psaraftis (1995). Although dynamic configurations are addressed, elimination of the word "dynamic" makes the proposed classification hold for the non-dynamic models as well. Psaraftis (1995) offers the following six categories under transportation models: (1) vehicle routing, (2) shortest path, (3) traffic assignment, (4) fleet management, (5) air-traffic control, and (6) facility location models. This classification fails to identify different versions of routing problems, but names all of them under vehicle routing.

Bodin, Golden, Assad, and Bull (1983) classified the VRP in seven categories: (1) simple TSP, (2) multi-travel salesman problem, (3) single-service station with multi-vehicle routing problems, (4) multi-service station with multi-vehicle routing problems, (5) single-service station with random demand multi-vehicle routing problems, (6) Chinese postman problem, and finally, (7) Chinese postman problem with load constraints. However, this classification is not coherent, i.e. it does not describe each category with identical level of detail. The model above may briefly be summarized under three categories: TSP, VRP, and the Chinese postman problem, providing further detail as sub-categories.

We propose a detailed but not exhaustive list of subcategories for the generalized routing problem as (1) shortest path problem, (2) Chinese postman problem, (3) rural postman problem, (4) dial-a-ride service route problem, (5) arc routing problem, (6) TSP, and (7) VRP. This classification clearly bounds and isolates the vehicle routing problem from the rest of the routing problem

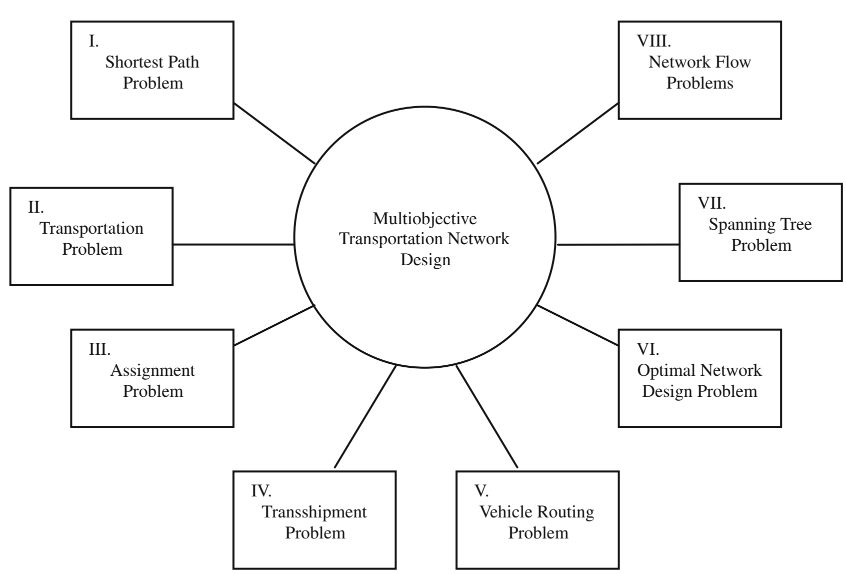

Fig. 1. Multiobjective transportation network and its basic instances (source: Current & Marsh, 1993).

types which differ by the routing scenario, constraints implied, and thus the imposed mathematical modeling requirements.

Partyka and Hall (2000) provide a non-exhaustive list of vehicle routing applications picked from the industry. Some of these are beverage delivery to bars and restaurants, currency delivery and scheduling at ATM machines, dynamic sourcing and transport of fuels, grease pickup from restaurants, home appliance repair service and delivery, internet-based home grocery delivery, milk pickup and inventory management, pickup of charitable donations from homes, portable toilet delivery, pickup and service, prisoner transportation between jails and courthouses, transport of urine samples from medical offices to laboratories, trash pickup and trans-shipments, wholesale distribution from warehouses to retailers, and postal delivery truck routing.

Besides the problems listed above, more instances exist in the literature. Our study's aim and scope is confined to identifying configuration characteristics and basic design parameters of the VRPs. Our focus area is contained and isolated from other routing problems given above in our categorization. Our taxonomy lists and accommodates the design specifications we have encountered so far in the literature, however while compiling those, some characteristics observed at other routing problems transferable to VRP are also included. As the literature reports more disparate problems, our taxonomy will make it easy to identify the similarities and the differences as well as accommodate new attributes in its structure.

2. Epistemology of the VRP literature

2.1. Literature search process

At the outset, a wide set of academic studies, databases such as *EBSCO Inspec, Ei Compendex,* and *ISI Web of Science*, and the bibliographical list provided by Larsen (2003) were utilized to compile information on the VRP. The databases were searched using "vehicle routing" as the search phrase. This exact phrase was searched in "Subject/Title/Abstract" field options. This constraint reduced the number of hits irrelevant to this study and eliminated those hits where VRP was tangential, or referred to, but was not studied as the main topic. Additionally, bibliographical entries that refer to studies in languages other than English were eliminated.

2.2. Statistical findings

The 1494 bibliographical entities, which included journal articles, books, book chapters, technical reports, and articles from various conference proceedings, were kept for initial review. Table 1 provides a breakdown of the compiled bibliography.

Although we have full access to most of the above 1021 journal articles, some of them are either not accessible or only the abstract is accessible. The main reasons for this inaccessibility are geographical because access to regional journals is blocked and publisher databases such as Springer and EBSCO provide only limited access. Among all the journal articles, we have full access to 686 and limited access is available for 314. Only bibliographical information can be accessed in the remaining 21 articles. Those 21 journal articles appeared in journals that are mostly old, discontinued, or local to a scientific association. For instance, "Operations Research Quarterly" is the most frequent source in this group of 21 journal articles. The six articles that are appeared in "Operations Research Quarterly" have been published between 1969 and 1976.

Table 1
Listing of different types of studies in the VRP literature.

Entity type	Count
Journal article	1021
Proceeding	381
Technical report	61
Book	5
Book chapter	26
Total	1494

2.3. Literature growth

As indicated above, introduction of microcomputers has enabled researchers to solve VRP type combinatorial optimization problems more efficiently. As the computing power has increased, researchers and practitioners were able to solve ever larger VRP problems. As a result of this, the number of articles published in this area during the 1980s and mostly in the 1990s has increased significantly. During the 1990s, computational methods to obtain quality solutions led to the development of new fields such as meta-heuristics and fast, real-time heuristics, which require high programming skills. Tabu search, evolutionary algorithms, and other search algorithms emerged and have been widely applied on the VRP during the last decade. Fig. 2 shows the number of VRP articles published since the early 1950s. As can be seen, there is a rising trend in the number of articles published in this field.

The names of the most frequently appearing researchers within the VRP field are Gilbert Laporte (66 times), Michel Gendreau (42 times), Jean-Yves Potvin (41 times), Bruce L. Golden (34 times), Marius M. Solomon (22 times), and Christos D. Tarantilis (19 times). According to Ei Compendex database search results, some of the most frequent keywords that appear along with the phrase "vehicle routing" are *heuristic methods, algorithms, problem solving, optimization, transportation routes, mathematical models,* and *scheduling*. Most frequent classification codes given by the same database for studies on VRP are *applied mathematics, optimization techniques, highway transportation, management, computer software data handling and applications, operations research, artificial intelligence, numerical methods,* and *combinatorial mathematics*.

Due to enhanced data collection, tracking capabilities, and computational availabilities, trends in the VRP literature have shifted from static to more dynamic and fuzzy cases that incorporate real-time data. Since most of the characteristics of dynamic and fuzzy problems are also common to the static case, this paper provides a taxonomy of all VRP publications. Fig. 3 shows the accumulation of VRP refereed articles on semi-logarithmic coordinates. If one eliminates the first 2 years of data, i.e. the gestation period, as well as the year 2006 the result is almost a straight line time-trend described by

$$\textit{Number of publications} = ce^{0.0609t}$$

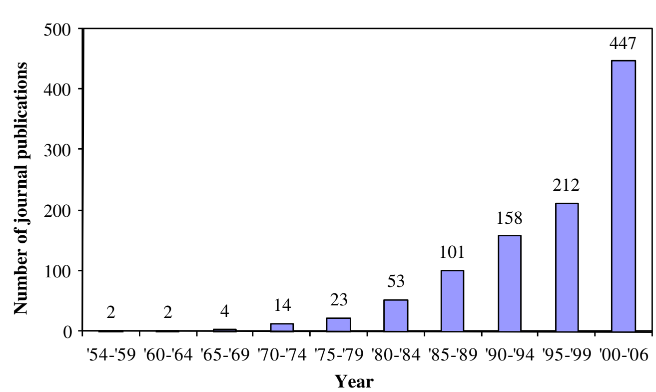

Fig. 2. Number of VRP articles published in refereed journals from 1954 to 2006.

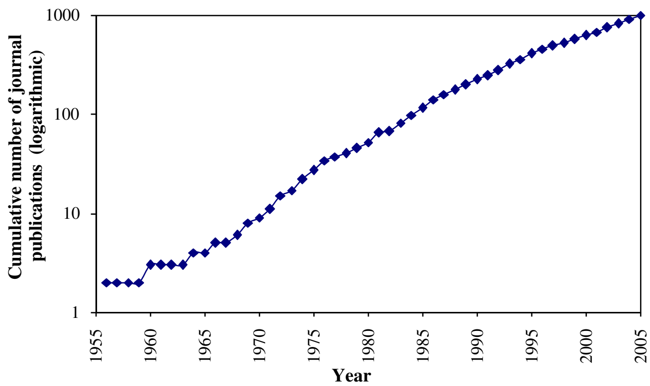

Fig. 3. Cumulative number of VRP articles for the period 1956–2005.

In other words, the literature growth is almost perfectly exponential with a 6.09% annual growth rate. This fact alone demonstrates VRP's vitality. However, it is not as rapid when compared to other contemporaneous OR/MS growth disciplines, e.g. Data Envelopment Analysis (DEA) having a rate of 25.5%, Flowshop Scheduling with 15.1%, Cell Manufacturing at 10.6% (Gattoufi, Oral, Kumar, & Reisman, 2004) and Mass Customization with 10.6% (Kumar et al., 2006). The slower rate of increase may be explained in several ways: perhaps solutions of VRP problems require much more sophistication than do the others. This is certainly the case with DEA and Mass Customization.

2.4. Major article producers and the journals of choice

In Table 2, the journals are arrayed in descending order of the total number of VRP articles published. From this it can be seen that *EJOR* and *Transportation Science* are by far the journals of preference for VRP authors. *EJOR* and *Transportation Science* together account for 20% of all VRP articles published in refereed journals. It can further be seen that the top five journals in Table 2 account for 41% of the literature, the top 10 journals for almost 52%, and finally 28 journals constitute 72% of all the journal entities. All other journals have no more than five hits each. Moreover with the exception of the seven articles which appeared in the *Journal of Food Engineering* the publications are dominated by what might be considered the "hard core" of OR/MS literature. If such is indeed the case then this fact alone may not bode well for the field as will be discussed later.

Among the articles published in refereed proceedings, 55 of them appeared in lecture notes in computer science, 24 of them in transportation research record, and 10 of them in lecture notes in artificial intelligence. The total figure of these articles is 89 and it constitutes 23% of the 379 proceeding entries we identified. These articles are not counted with the journal articles since they were classified as proceedings in the databases where we performed our search.

Over the years, three mainstream journals, *EJOR*, *Transportation Science* and *JORS*, dominated the VRP literature. These journals combine to create a 'footprint' rate (percentage of VRP articles published in these journals as compared to the total VRP publications) of 35% from 1983 to 1985. Although this rate fell down to 16% in 1986, the figure peaked at 47% and 45% consecutively in 1988 and 1989. The average of the succeeding years through 2005 is around 29% which is only one more point than the overall footprint rate of these three journals, 28%, among all the VRP literature we have collected. The highest number of VRP articles published in a single year in *EJOR* was 15 in 2004. The highest for *JORS* was 14 in 2002, and *Transportation Science* had 12 in 2004. Although explaining these trends is not easy, studying the preferences of VRP researchers as well as types of studies submitted to particular journals could explain their motivations. One thing is certain: editorial boards and policies play a key role in defining the "*coloration*," the mix of articles each journal publishes. Fig. 4 gives the cumulative distribution of percentage of articles published with respect to the percentage of all journals we discovered in our search.

Table 2
Listing of articles with respect to academic journals.

Journal title	Count
European Journal of Operational Research	117
Transportation Science	89
Journal of the Operational Research Society	77
Computers and Operations Research	70
Operations Research	61
Networks	35
Annals of Operations Research	31
Transportation Research Part B: Methodological	19
Interfaces	18
Journal of Heuristics	17
Computers and Industrial Engineering	16
Omega	14
Discrete Applied Mathematics	13
Management Science	13
Mathematical Programming	13
Operations Research Letters	13
ORSA Journal on Computing	13
Asia-Pacific Journal of Operational Research	12
INFORMS Journal on Computing	12
International Transactions in Operational Research	12
OR Spectrum	10
American Journal of Mathematical and Management Sciences	9
INFOR	9
Transportation Research Part A: Policy and Practice	9
Journal of Food Engineering	7
Decision Support Systems	6
Transportation Planning and Technology	6
Transportation Research Part E Logistics and Transportation Review	6
First 5 total	414
First 10 total	534
Total of first 28	727
Others	294
Total	1021

3. Need for a VRP taxonomy

The size and growth rate of the VRP literature demands a systematic way to classify the various contributions in a manner that will vividly provide a panoramic view of what exists and will also clearly identify any existing gaps in the state of the art as suggested by Reisman (1992) and Reisman (1993). Hence VRP literature needs a taxonomy which:

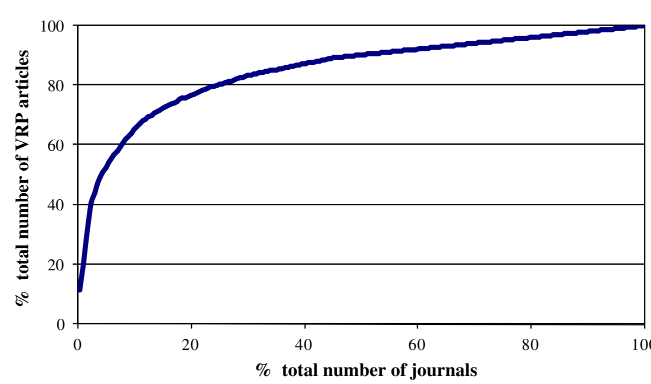

Fig. 4. Cumulative percentage of articles per journal.

Graphically, symbolically or both, will vividly display the similarities and the differences among the various contributions, thus demonstrating the relationship of all contributions and the practical applications of each to other. It will provide a framework by which all of the existing knowledge can be systematically filed and therefore recalled efficiently and effectively. By providing what amounts to an aerial view – a picture of the territory – it will identify the voids in the literature... Knowledge consolidation is a means to various ends, and it is also an end to itself. It is a means toward the end of more efficient and more effective teaching and learning of new or existing knowledge. It is a means toward the end of more efficient storage and more effective recall and/or retention of knowledge. It is a means toward a more efficient and more effective processes of research leading to the yet unknown, to the design of the yet unavailable, and it is a means toward more efficient problem solving – (Reisman, 1992).

Moreover,

The key to taxonomy effectiveness rests on criteria of comprehensiveness, parsimony and usefulness. Obviously, to be effective, a taxonomy must represent the full spectrum of the research chosen for categorization. Thus, comprehensiveness is a necessary condition for effectiveness. It is, however, not sufficient. To further be effective, a taxonomy should be parsimonious. It should not include unnecessary categories. Finally, to be considered effective, the taxonomy should be robust and generally useful. The categories should be reasonably if not mutually exclusive, i.e., non-overlapping, reasonably distinct, meaningful, commonplace, and descriptive to allow utilization by a wide variety of interested persons – (Vogel & Weterbe, 1984).

A taxonomy is not only a tool for systematic storage, efficient and effective teaching/learning, and recall for usage of knowledge, but it is also a neat way of pointing to knowledge expansion and building. It identifies voids, potential theoretical increments or developments, and potential applications for the existing theory. Basic motivations and uses for taxonomy may be listed as follows:

1. It defines or delimits the boundaries of a subject domain and that is, in itself, useful information.
2. It vividly, efficiently, and effectively shows/displays all of that domain's attributes/dimensions.
3. It vividly, efficiently, and effectively shows/displays that any one of the possible combinations of these attributes/dimensions defines or delimits the boundaries of a subject sub-domain.
4. It allows one to have a panoramic view of the entire "forest" while examining and classifying a given "tree."
5. It allows one to unify disjointed and disparate subfields or subdisciplines into a meaningful whole.
6. It allows one to organize his or her knowledge about the domain, and this has major implications for teaching, learning, storing, and recalling information.
7. It allows one to identify voids and well explored territories in the extant literature base which is very important for researchers, funding agencies and other decision makers.

Clearly, as is the case in one of the greatest and best-known taxonomies of all time, the periodic table of elements (Mendeleyev, 1889), what is presented here is open for incremental evolutions. A taxonomy is very much dependent on the definition of the boundaries of the universe it classifies. Hence, the classification developed in this study is open to expansion as the scope of the VRP enlarges. With the Periodic Table of Elements (PTE) as a role model, one can discuss the usage of a taxonomy to knowledge building. The PTE has always indicated cells which described with great efficiency elements yet to be discovered. Thus if and when the taxonomy classifies all extant VRP articles, the cells remaining empty will vividly show the voids in the literature. To be sure some of those void "cells" have a greater research potential than others. However, the empty cells will all create a full set of specifications for the researchers to pursue as amply demonstrated by Reisman (1992) while the already filled cells provide guidance and methodological aid for the inquirers in this field. Professionals and researchers may easily identify which study covers what aspect of the very original problem they have. If on the other hand, only a sample of the extant papers is classified then the probability that a void is identified truly so increases with the sample's richness and representativeness.

VRP has already generated a large enough literature to allow it to be considered as a separate and distinct field of knowledge. The increasing interest in VRP makes a systematic elaboration of this field more crucial in helping current researchers as well as in attracting potential newcomers to the field.

The current attempt to define a taxonomy for the VRP literature may have its own disadvantages but it does not suffer from ambiguity as was the case for classifications by Desrochers et al. (1990) and Desrochers et al. (1999). In fact, this taxonomy may be too detailed. This makes applications cumbersome, but also increases its descriptive powers. However, aggregating sub-classifications and/or pruning outer branches is easier then the inverse. Having to disaggregate classifications already made typically requires a great deal of effort. The taxonomy proceeds in an arborescent way (Reisman, 1992) as illustrated in Fig. 5. The cells that do not have any sub-branches in Fig. 5 are referred to as end-nodes and will be used to classify a set of selected papers.

4. VRP taxonomy

In this section we present our taxonomy and introduce the main features we considered while building it. We provide definitions as well as justifications for those main features and provide identification of some terms within the content of the taxonomy.

Our taxonomy is built in an arborescent way. The branching levels from top to bottom are, at most, three in order to provide coherence and parsimony, yet sacrifice nothing in terms of comprehensiveness.

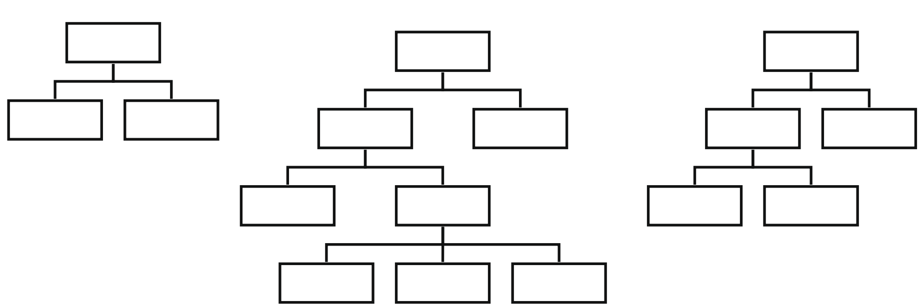

Fig. 5. Attribute vector description based taxonomy.

The classifications and sub-classifications at the first and second levels are not strictly distinguishing in the sense that a paper might address many different subcategories of the same category. The first partitioning is built so that each paper may be classified by five different aspects within a single level (see Fig. 6). This first level of branching is composed of: (1) type of study, (2) scenario characteristics, (3) problem physical characteristics, (4) information characteristics, and (5) data characteristics. Within the first characteristic set, type of study, a paper is distinguished based on its content and whether it fits one of the four sub-categories presented. After identifying the type of the study, for those papers that comprise a problem, we introduce the rest of the categories. In the second category, scenario characteristics, those factors that are not a part of the constraints embedded into the solution, but part of the problem scenario, are listed. The third category, problem physical characteristics, comprises those factors that directly affect the solution. This category is an extended version of the works of Bodin (1975) and Bodin and Golden (1981). The fourth category, called information characteristics, deals with the solution of the VRP presented by qualifying the nature, accessibility, and processing of the information. This category is taken from the work of Psaraftis (1995), which actually aims to classify dynamic VRPs. However, we believe that the same structure may be used to study the information characteristics of all dynamic, fuzzy, static, and stochastic VRPs. Although the last category, Data Characteristics, possesses a similar name to the previous category, it introduces a distinctive purpose: to classify the type of data based on its origin.

5. Testing the taxonomy with disparate VRP articles

By using a group of articles that represent rather different approaches and that address different issues of the VRP, we tested the taxonomy of Fig. 6 for its robustness and its ability to discriminate in a parsimonious manner. The articles used for that purpose are identified in Figs. 7 and 8. Note that in applying the above taxonomy to classify a specific document, some cells may remain empty. This means that the paper does not address or involve that cell's attributes. The domains or attributes corresponding to end-nodes are marked with 'X'. Shaded columns represent domains or classes which branch, so that shading suggests why these columns are not marked. This representation scheme enables us to assign more designations in a confined space.

As can be seen, Figs. 7 and 8 have many blank cells. However, these classifications for the papers that test the taxonomy leave

1. Type of Study
   1.1. Theory
   1.2. Applied methods
      1.2.1. Exact methods
      1.2.2. Heuristics
      1.2.3. Simulation
      1.2.4. Real time solution methods
   1.3. Implementation documented
   1.4. Survey, review or meta-research
2. Scenario Characteristics
   2.1. Number of stops on route
      2.1.1. Known (deterministic)
      2.1.2. Partially known, partially probabilistic
   2.2. Load splitting constraint
      2.2.1. Splitting allowed
      2.2.2. Splitting not allowed
   2.3. Customer service demand quantity
      2.3.1. Deterministic
      2.3.2. Stochastic
      2.3.3. Unknown[1]
   2.4. Request times of new customers
      2.4.1. Deterministic
      2.4.2. Stochastic
      2.4.3. Unknown
   2.5. On site service/waiting times
      2.5.1. Deterministic
      2.5.2. Time dependent
      2.5.3. Vehicle type dependent
      2.5.4. Stochastic
      2.5.5. Unknown
   2.6. Time window structure
      2.6.1. Soft time windows
      2.6.2. Strict time windows
      2.6.3. Mix of both
   2.7. Time horizon
      2.7.1. Single period
      2.7.2. Multi period
   2.8. Backhauls
      2.8.1. Nodes request simultaneous pick ups and deliveries
      2.8.2. Nodes request either linehaul or backhaul service, but not both
   2.9. Node/Arc covering constraints
      2.9.1. Precedence and coupling constraints
      2.9.2. Subset covering constraints
      2.9.3. Recourse allowed
3. Problem Physical Characteristics
   3.1. Transportation network design
      3.1.1. Directed network
      3.1.2. Undirected network
   3.2. Location of addresses (customers)
      3.2.1. Customers on nodes
      3.2.2. Arc routing instances
   3.3. Geographical location of customers
      3.3.1. Urban (scattered with a pattern)
      3.3.2. Rural (randomly scattered)
      3.3.3. Mixed
   3.4. Number of points of origin
      3.4.1. Single origin
      3.4.2. Multiple origins
   3.5. Number of points of loading/unloading facilities (depot)
      3.5.1. Single depot
      3.5.2. Multiple depots
   3.6. Time window type
      3.6.1. Restriction on customers
      3.6.2. Restriction on roads
      3.6.3. Restriction on depot/hubs
      3.6.4. Restriction on drivers/vehicle
   3.7. Number of vehicles
      3.7.1. Exactly n vehicles (*TSP in this segment*)
      3.7.2. Up to n vehicles
      3.7.3. Unlimited number of vehicles
   3.8. Capacity consideration
      3.8.1. Capacitated vehicles
      3.8.2. Uncapacitated vehicles
   3.9. Vehicle homogeneity (Capacity)
      3.9.1. Similar vehicles
      3.9.2. Load-specific vehicles[2]
      3.9.3. Heterogeneous vehicles
      3.9.4. Customer-specific vehicles[3]
   3.10. Travel time
      3.10.1. Deterministic
      3.10.2. Function dependent (a function of current time)
      3.10.3. Stochastic
      3.10.4. Unknown
   3.11. Transportation cost
      3.11.1. Travel time dependent
      3.11.2. Distance dependent
      3.11.3. Vehicle dependent[4]
      3.11.4. Operation dependent
      3.11.5. Function of lateness
      3.11.6. Implied hazard/risk related
4. Information Characteristics
   4.1. Evolution of information
      4.1.1. Static
      4.1.2. Partially dynamic
   4.2. Quality of information
      4.2.1. Known (Deterministic)
      4.2.2. Stochastic
      4.2.3. Forecast
      4.2.4. Unknown (Real-time)
   4.3. Availability of information
      4.3.1. Local
      4.3.2. Global
   4.4. Processing of information
      4.4.1. Centralized
      4.4.2. Decentralized
5. Data Characteristics
   5.1. Data Used
      5.1.1. Real world data
      5.1.2. Synthetic data
      5.1.3. Both real and synthetic data
   5.2. No data used

[1] Unknown refers to the case in which information is revealed in real-time (i.e., dynamic and fuzzy studies fall under this category)

[2] Each vehicle can be used to handle specific types of loads

[3] A customer must be visited by a specific type of vehicle

[4] Cost of operating a vehicle is not negligible

Fig. 6. Taxnomoy of the VRP literature.

Article title	Toth and Vigo (1999)	Bent and van Hentenryck (2001)	Laporte et al. (1999)	Rego and Roucairol (1995)	Ichoua et al. (2000)	Savelsbergh and Sol (1998)	Gendreau et al. (1996a)	Nagy and Salhi (2005)	Nanry and Barnes (2000)	Fleischmann et al. (2004)	Meng et al. (2005)	Jaw et al. (1986)	Letchford and Eglese (1998)	Eglese (1994)	Lee and Ueng (1999)	Brandao and Mercer (1997)	Angelelli and Speranza (2002)	Cordeau and Laporte (2001)	Archetti et al. (2005)	Fu (2002)	Chuah and Yingling (2005)	Frizzell and Giffin (1995)	Zagrafos and Androutsopoulos (2004)	Kim et al. (2005)	Trudeau and Dror (1992)	Malandraki and Daskin (1992)	Sural and Bookbinder (2003)	Bard et al. (1998)	Ahn and Shin (1991)	Jaillet (1988)
1.																														
1.1.													×						×	×				×						×
1.2.																														
1.2.1.											×		×								×		×			×	×	×		
1.2.2.	×	×	×	×			×	×	×			×		×	×	×	×	×		×	×	×			×	×		×	×	
1.2.3.					×	×																		×	×					
1.2.4.					×	×				×														×						
1.3.										×																				
1.4.			×					×																		×				
2.																														
2.1.																														
2.1.1.	×	×	×					×	×		×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	
2.1.2.				×	×	×	×			×																				×
2.2.																														
2.2.1.			×						×										×			×						×		
2.2.2.	×	×		×	×	×	×	×		×	×		×		×	×	×	×		×	×		×		×	×	×			
2.3.																														
2.3.1.	×	×	×					×	×	×					×	×	×	×	×	×			×			×	×	×		
2.3.2.				×			×															×			×					
2.3.3.						×															×									
2.4.																														
2.4.1.	×							×	×			×	×		×	×	×	×	×	×		×	×	×		×	×	×	×	×
2.4.2.				×	×	×																			×					
2.4.3.										×											×									
2.5.																														
2.5.1.									×		×		×		×	×		×					×			×		×	×	
2.5.2.											×																			
2.5.3.																														
2.5.4.																						×			×					
2.5.5.										×																				
2.6.																														
2.6.1.					×					×														×	×	×				
2.6.2.				×							×	×	×	×		×				×			×						×	
2.6.3.		×				×			×									×			×	×								
2.7.																														
2.7.1.											×	×		×	×	×		×	×	×			×	×		×	×	×	×	×
2.7.2.													×				×				×	×			×					
2.8.																														
2.8.1.								×																						
2.8.2.	×							×				×											×				×	×		
2.8.3.																				×										
2.9.																														
2.9.1.	×			×		×			×	×	×	×								×										
2.9.2.																	×								×		×			×
2.9.3.													×				×					×			×			×		
3.																														
3.1.																														
3.1.1.										×							×							×		×				
3.1.2.	×	×	×	×	×	×	×	×	×		×	×	×	×	×	×		×	×	×	×	×	×		×		×	×	×	×
3.2.																														
3.2.1.	×	×	×	×	×	×	×	×	×	×		×			×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
3.2.2.													×	×																
3.3.																														
3.3.1.					×					×				×						×		×			×	×				
3.3.2.	×				×	×	×					×					×						×							
3.3.3.				×	×																							×		

Fig. 7. Summary of the illustrative classifications (attributes 1 through 3.3). (See above-mentioned references for further information.)

only a small percentage, 1.23%, of the end-nodes in each tree empty. For the total number of columns, nodes marked only once constitute 4.94%. This value becomes 12.34% for nodes marked twice and 6.17% for nodes marked thrice. These percentages clearly attest to the fact that the taxonomy of Fig. 6 is robust enough to succinctly classify the large diversity of the VRP literature. Of the end-node classifications, the only empty column denotes 'vehicle type dependent service/waiting times' which was not addressed

Article title	3.4.	3.4.1.	3.4.2.	3.5.	3.5.1.	3.5.2.	3.6.	3.6.1.	3.6.2.	3.6.3.	3.6.4.	3.7.	3.7.1.	3.7.2.	3.7.3.	3.8.	3.8.1.	3.8.2.	3.9.	3.9.1.	3.9.2.	3.9.3.	3.9.4.
Toth and Vigo (1999)		X			X										X		X			X			
Bent and van Hentenryck (2001)		X			X			X							X		X			X			
Laporte et al. (1999)		X			X								X				X			X			
Rego and Roucairol (1995)			X			X		X			X				X		X					X	
Ichoua et al. (2000)		X			X				X				X										
Savelsbergh and Sol (1998)			X			X		X						X			X				X	X	
Gendreau et al. (1996a)		X			X								X				X			X			
Nagy and Salhi (2005)		X	X		X									X			X			X			
Nanry and Barnes (2000)		X			X								X				X			X			
Fleischmann et al. (2004)			X			X		X						X			X			X			
Meng et al. (2005)		X				X		X	X				X										
Jaw et al. (1986)			X			X		X						X			X					X	
Letchford and Eglese (1998)		X			X			X					X					X					
Eglese (1994)			X		X				X						X		X			X			
Lee and Ueng (1999)		X			X									X			X					X	
Brandao and Mercer (1997)		X			X			X			X				X		X					X	X
Angelelli and Speranza (2002)		X				X					X		X				X			X			
Cordeau and Laporte (2001)		X			X			X		X			X				X					X	X
Archetti et al. (2005)		X			X										X		X					X	
Fu (2002)		X			X			X							X		X					X	
Chuah and Yingling (2005)		X			X			X		X	X		X				X			X			
Frizzell and Giffin (1995)		X			X			X		X					X		X			X			
Zagrafos and Androutsopulos (2004)		X			X			X		X	X				X		X			X			
Kim et al. (2005)								X															
Trudeau and Dror (1992)		X			X			X		X			X				X			X			
Malandraki and Daskin (1992)		X			X			X					X				X			X			
Sural and Bookbinder (2003)		X			X								X				X						
Bard et al. (1998)		X				X					X			X			X			X			
Ahn and Shin (1991)		X			X			X		X													
Jaillet (1988)		X			X								X					X					

Article title	3.10.	3.10.1.	3.10.2.	3.10.3.	3.10.4.	3.11.	3.11.1.	3.11.2.	3.11.3.	3.11.4.	3.11.5.	3.11.6	4.	4.1.	4.1.1.	4.1.2.	4.2.	4.2.1.	4.2.2.	4.2.3.	4.2.4.	4.3.	4.3.1.	4.3.2.	4.4.	4.4.1.	4.4.2.	5.	5.1.	5.1.1.	5.1.2.	5.1.3.	5.2.
Toth and Vigo (1999)		X						X							X			X								X					X		
Bent and van Hentenryck (2001)		X						X							X			X						X		X					X		
Laporte et al. (1999)		X						X							X			X														X	
Rego and Roucairol (1995)		X					X	X	X							X			X					X		X						X	
Ichoua et al. (2000)		X						X			X					X			X					X		X					X		
Savelsbergh and Sol (1998)		X						X	X	X						X					X		X			X	X				X		
Gendreau et al. (1996a)		X						X								X					X		X			X	X				X		
Nagy and Salhi (2005)		X						X							X			X						X		X					X		
Nanry and Barnes (2000)		X					X				X				X			X						X		X					X		
Fleischmann et al. (2004)					X		X				X					X				X	X			X		X				X			
Meng et al. (2005)			X				X	X							X			X						X		X						X	
Jaw et al. (1986)		X					X				X				X			X						X		X					X		
Letchford and Eglese (1998)		X								X					X			X						X		X					X		
Eglese (1994)			X					X	X						X			X						X		X						X	
Lee and Ueng (1999)		X					X								X			X						X		X					X		
Brandao and Mercer (1997)		X					X	X	X						X			X						X		X				X			
Angelelli and Speranza (2002)		X						X							X			X						X		X					X		
Cordeau and Laporte (2001)		X					X								X			X						X		X					X		
Archetti et al. (2005)		X						X	X						X			X					X			X							X
Fu (2002)			X	X			X		X		X				X				X					X		X					X		
Chuah and Yingling (2005)		X						X		X					X			X						X		X						X	
Frizzell and Giffin (1995)		X					X		X	X					X			X	X					X		X					X		
Zagrafos and Androutsopulos (2004)		X						X				X			X			X						X		X					X		
Kim et al. (2005)					X		X		X		X					X			X	X	X			X		X						X	
Trudeau and Dror (1992)		X						X		X	X					X		X	X					X		X				X			
Malandraki and Daskin (1992)			X					X							X			X	X					X		X					X		
Sural and Bookbinder (2003)		X						X		X					X			X						X		X					X		
Bard et al. (1998)		X						X							X			X						X		X					X		
Ahn and Shin (1991)			X	X			X								X			X	X					X		X					X		
Jaillet (1988)		X						X							X				X					X		X							X

Fig. 8. Summary of the illustrative classifications (attributes 3.4 through 5.2). (See above-mentioned references for further information.)

in any paper tested. By checking the rest of the bibliographic list, it may be concluded that this attribute represents work not previously attempted by anyone, rather than a superfluous node within the current paradigm of VRP's scope.

Attributes which are marked less than thrice in the figure are: 2.3.3, 2.4.3, 2.5.2, 2.5.4, 2.5.5, 2.8.1, 3.2.2, 3.8.2, 3.9.2, 3.9.4, 3.10.3, 3.10.4, 3.11.6, 4.2.3, 4.4.2, and 5.2. Among these attributes, 2.3.3, 2.4.3, 2.5.5, and 3.10.4 denote unknown data observed in real-time. These VRPs with dynamic content have been relatively less studied or reported in archival journals thus far.

In the VRP literature, on-site service/waiting times mostly appear to be uniformly distributed quantities. Thus, they rarely reveal time-varying or time-dependent attributes (2.5.2). Using stochastic variables for on-site service/waiting times (2.5.4) and travel times (3.10.3) constitute a relatively smaller percentage of the overall VRP literature. However, stochastic VRP instances are studied in greater depth than the dynamic VRPs.

Other less frequently observed attributes are: 2.8.1, 3.2.2, 3.8.2, and 3.11.6. These are not very common in the VRP literature or in the path selection problems studied. Routing with simultaneous backhauls (2.8.1) is a fairly new field. Since our search is confined to VRPs rather than to arc-routing, studies that involve arc-routing (3.2.2) are mostly omitted. Routing with uncapacitated vehicles (3.8.2) is a very common problem configuration that is observed in the literature, especially until early 1990s. However, after introduction of faster heuristics, more complex and realistic problems with capacitated vehicles became more common. The conventional TSP, Chinese postman, and rural postman problems are some instances resulting from no capacity constraints on the vehicles. Transportation cost calculations based on implied hazards to the environment (3.11.6) are studied in many hazardous material (hazmat) transportation problems (Erkut, Verter, & Tjandra, 2005). Since most of the hazmat literature on routing focuses on the shortest path selection rather than on forming complete tours, implied hazard assessment problems within the VRP literature are relatively rare. For a recent and elaborate review on hazmat transportation one may refer to Luedtke and White (2002) and Erkut et al. (2005).

Employing load-specific (3.9.2) or customer-specific (3.9.4) vehicles are very rarely observed in the VRP literature. Traveling repairmen problems are mostly customer-specific (3.9.4) instances, while distribution of multi-commodity loads are load-specific (3.9.2) types of problems. These two problems suggest some open fields to be studied in the future.

Usage of raw forecast data (4.2.3) is quite rare. However, fitting collected data into some stochastic distribution functions and embedding these functions into problems is a more common approach. Thus, stochastic problems are more frequently observed than problems utilizing forecast data.

Information is processed and routes are generated mostly at a central location. However, with today's technology, distributed and parallel systems are easier to construct and maintain. Although decentralized processing of information (4.4.2) is a rare solution for most of the studies, with the increasing number of real-time solution instances, need for shorter response times will lead to more parallel processing algorithms and may even lead to each truck establishing its own path as real-time data is observed at customer nodes.

Review papers or theoretical studies usually need no data samples or sets, and they constitute a smaller percentage of the overall VRP literature. When Figs. 7 and 8 were constructed, papers were selected to reflect very different attributes that are not common in the literature. Because of this emphasis on distinctive problem instances, review papers or theoretical papers without data usage are mostly omitted. The review papers we included in Figs. 7 and 8 contain problem instances and solution algorithms (e.g. Laporte, Gendreau, Potvin, & Semet, 1999; Malandraki & Daskin, 1992; Nagy & Salhi, 2005). Thus, real or synthetic data are included in this study, and taxonomical papers are not incorporated into Figs. 7 and 8. The only papers without data usage are those which are theoretical, and thus, frequency of papers without data usage (5.2) seems relatively low.

6. Concluding remarks

Because of the subjectivity inherent in selecting illustrative papers, we tried to select papers that represent different periods, different journals, differing paths of VRP analysis and differing research strategies. The respective authors emanate from different countries, indeed from different continents.

The taxonomy presented has been demonstrated to be robust enough to subsume a diverse set of VRP articles, as well as all previously published taxonomies in this field. It is currently being used to classify all 1021 VRP papers published in refereed journals circa 2008. This exercise, when completed, will provide rather detailed specifications of research to be done – a road map for future workers – as was demonstrated for another subject domain in Reisman, Cem, and Oral (in press). At this time, test results of a well-selected subset of thirty very dissimilar and diverse papers are presented.

However, based on a less systematic review of the 686 full papers and 314 abstracts of additional VRP papers, the following can be said:

1. To date, the literature has not arrived at a consensus on how to define the VRP. Moreover, given any one definition, there is no unanimity as to how to address it.
2. Forming strategies to improve the performance of solution methods for the VRP appears to be lacking.
3. Most papers studied the VRP in a static manner, and dynamic treatments of the VRP are relatively recent because they started to emerge as of 1986.
4. No previous study has ever proposed a taxonomy as detailed or as comprehensive as the one presented in this paper.
5. No epistemological studies were performed on the VRP literature.
6. No previous study ever reported counts of published papers by year, by journal, and by solution methods used (see Reisman et al., in press).
7. No other article investigated the most cited or the most influential author(s), paper(s), or journal(s). However, the journal with the most publications in any given field or the journal considered the most prestigious does not necessarily publish the paper with the greatest influence on subsequent research (Reisman & Oral, 2005).
8. To date, no paper reported the kind of content analysis for VRP that was done for DEA in Gattoufi, Oral, and Reisman (2004), Gattoufi, Oral, Kumar, et al. (2004).

The taxonomy provided can be used in many other ways than those already mentioned. Using it in the teaching of VRP subject matter is one important way. The taxonomy defines the VRP domain very globally, yet very minutely. Moreover, it does so without taking much class time, as discussed in Reisman (2004).

The taxonomy in Fig. 6 may well be too detailed than is necessary for common usage. If so, this violates the principle of parsimony. However, experience shows that aggregating data in hand is easier than not to have collected it in sufficient detail in the first place (Reisman, 1992). Lastly, no taxonomy should be considered fixed for all time. It should evolve as the field it addresses evolves. Indeed, the above taxonomy can be meaningfully enhanced by redefining the subject. For example, as the number of dynamic and fuzzy studies increase the "unknown" category in our taxonomy can be renamed to reflect this increase. Over time, even the Periodic Table of Chemical Elements has been and remains in the constant state of evolution.

References

Aarts, E., & Lenstra, J. K. (Eds.). (1997). *Local search in combinatorial optimization*. Chichester, England: Wiley.

Abbott, A. (1988). *The system of professions: An essay on the expert division of labor*. Chicago, IL: University of Chicago Press.

Ahn, B.-H., & Shin, J.-Y. (1991). Vehicle routing with time windows and time-varying congestion. *Journal of the Operational Research Society, 42*(5), 393–400.

Angelelli, E., & Speranza, M. G. (2002). The vehicle routing problem with intermediate facilities. *European Journal of Operational Research, 137*, 233–247.

Archetti, C., Mansini, R., & Speranza, M. G. (2005). Complexity and reducibility of the skip delivery problem. *Transportation Science, 39*(2), 182–187.

Assad, A. A. (1988). Modelling and implementation issues in vehicle routing. In B. Golden, A. A. Assad (Eds.), *Vehicle routing: Methods and studies, North-Holland, Amsterdam* (pp. 7–45).

Bard, J. F., Huang, L., Dror, M., & Jaillet, P. (1998). A branch and cut algorithm for the VRP with satellite facilities. *IIE Transactions, 30*(9), 821–834.

Bent, R., & van Hentenryck, P. (2001). A two stage hybrid local search for the vehicle routing problem with time windows. Technical report, Department of Computer Science, Brown University, CS-01-06.

Bodin, L. (1975). A taxonomic structure for vehicle routing and scheduling problems. *Computers and Urban Society, 1*, 11–29.

Bodin, L., & Golden, B. (1981). Classification in vehicle routing and scheduling. *Networks, 11*, 97–108.

Bodin, L., Golden, B., Assad, A., & Bull, D. (1983). Routing and scheduling of vehicles and crews: The state of the art. *Computers and Operation Research, 10*, 63–111.

Brandao, J., & Mercer, A. (1997). A Tabu search algorithm for the multi-trip vehicle routing and scheduling problem. *European Journal of Operational Research, 100*, 180–192.

Chuah, K. H., & Yingling, J. C. (2005). Routing for a just-in-time supply pick up and delivery system. *Transportation Science, 39*(3), 328–339.

Clarke, G., & Wright, J. W. (1964). Scheduling of vehicles from a depot to a number of delivery points. *Operations Research, 12*, 568–581.

Cooper, C. M. (1984). *The integrative research review: A systematic approach*. Beverly Hills, CA: Sage Publications.

Cooper, C. M. (1988). Organizing knowledge syntheses: A taxonomy of literature reviews. *Knowledge in Society, 1*, 104–126.

Cooper, C. M. (1989). Meta-analysis and the integrative research review. A paper presented at the meeting of the Operations Research Society of America/The Institute of Management Sciences, New York.

Cooper, H. (1998). *Synthesizing research: A guide for literature reviews*. London: SAGE Publications.

Cordeau, J.-F., Gendreau, M., Laporte, G., Potvin, J.-Y., & Semet, F. (2002). A guide to vehicle routing heuristics. *Journal of the Operational Research Society, 53*(5), 512–522.

Cordeau, J.-F., & Laporte, G. (2001). A tabu search algorithm for the site dependent vehicle routing problem with time windows. *INFOR, 39*(3), 292–298.

Cook, T. M., & Russell, R. A. (1978). A simulation and statistical analysis of stochastic vehicle routing with timing constraints. *Decision Sciences, 9*(4), 673–687.

Current, J. R., & Marsh, M. (1993). Multiobjective transportation network design and routing problems: Taxonomy and annotation. *European Journal of Operational Research, 65*, 4–19.

Dantzig, G., Fulkerson, R., & Johnson, S. (1954). Solution of a large-scale travelling salesman problem. *Operations Research, 2*, 393–410.

Desrochers, M., Lenstra, J. K., & Savelsbergh, M. W. P. (1990). A classification scheme for vehicle routing and scheduling problems. *European Journal of Operational Research, 46*, 322–332.

Desrochers, M., Jones, C. V., Lenstra, J. K., Savelsbergh, M. W. P., & Stougie, L. (1999). Towards a model algorithm management system for vehicle routing and scheduling problems. *Decision Support Systems, 25*, 109–133.

Dorigo, M., Maniezzo, V., & Coloni, A. (1996). Ant system: Optimization by a colony of cooperating agents. *IEEE Transactions on Systems, Man, and Cybernetics – Part B, 26*, 29–41.

Eglese, R. W. (1994). Routing winter gritting vehicles. *Discrete Applied Mathematics, 48*(3), 231–244.

Eilon, S., Watson-Gandy, C. D. T., & Christofides, N. (1971). *Distribution management: Mathematical modelling and practical analysis*. NY: Hafner Publication Co.

Erkut, E., Verter, V., & Tjandra, S. (2005). Hazardous materials transportation. In G. Laporte, C. Barnhart (Eds.), *Handbooks in operations research and management science: Transportation, North-Holland, Amsterdam*.

Fleischmann, B., Gnutzmann, S., & Sandvoss, E. (2004). Dynamic vehicle routing based on online traffic information. *Transportation Science, 38*(4), 420–433.

Frizzell, P. W., & Giffin, J. W. (1995). The split delivery vehicle scheduling problem with time windows and grid network distances. *Computers and Operations Research, 22*(6), 655–667.

Fu, L. (2002). Scheduling dial-a-ride paratransit under time varying, stochastic congestion. *Transportation Research Part B, 36*(6), 485–506.

Gattoufi, S., Oral, M., & Reisman, A. (2004). A taxonomy for data envelopment analysis. *Socio-Economic Planning Sciences, 38*, 141–158.

Gattoufi, S., Oral, M., Kumar, A., & Reisman, A. (2004). Content analysis of data envelopment analysis literature and its comparison with that of OR/MS fields. *Journal of the Operational Research Society, 55*(9), 911–935.

Gendreau, M., Laporte, G., & Seguin, R. (1996a). A tabu search heuristic for the vehicle routing problem with stochastic demand and customers. *Operations Research, 44*(3), 469–477.

Gendreau, M., Laporte, G., & Seguin, R. (1996b). Stochastic vehicle routing. *European Journal of Operational Research, 88*, 3–12.

Gendreau, M., Laporte, G., Potvin, J.-Y. (1998). Metaheuristics for the vehicle routing problem, Technical report, Les Cahiers du GERAD, Montreal, Canada, G-98-52.

Gendreau, M., & Potvinm, J. Y. (1998). Dynamic vehicle routing and dispatching. In T. G. Crainic & G. Laporte (Eds.), *Fleet management and logistic* (pp. 115–226). Kluwer Academic Publishers.

Glover, F., & Laguna, M. (1997). *Tabu search*. Boston: Kluwer Academic Publishers.

Golden, B. L., Magnanti, T. L., & Nguyan, H. Q. (1972). Implementing vehicle routing algorithms. *Networks, 7*(2), 113–148.

Golden, B. L., & Stewart, Jr. W., 1978.Vehicle routing with probabilistic demands. In *Computer science and statistics, tenth annual symposium on the interface* (pp. 252–259).

Gomes, L., de, C. T., & Zuben, F. J. V. (2003). Multiple criteria optimization based on unsupervised learning and fuzzy inference applied to the vehicle routing problem. *Journal of Intelligent & Fuzzy Systems, 13*, 143–154.

He, Y., & Xu, J. (2005). A class of random fuzzy programming model and its application to vehicle routing problem. *World Journal of Modelling and Simulation, 1*, 3–11.

Ichoua, S., Gendreau, M., & Potvin, J.-Y. (2000). Diversion issues in real-time vehicle dispatching. *Transportation Science, 34*(4), 426–438.

Jaillet, P. (1988). A priori solution of a traveling salesman problem in which a random subset of customers are visited. *Operations Research, 36*(6), 929–936.

Jaw, J.-J., Odoni, A. R., Psaraftis, H. N., & Wilson, N. H. (1986). A heuristic algorithm for the vehicle advance request dial-a-ride problem with time windows. *Transportation Research Part B, 20*(3), 243–257.

Kim, S., Lewis, M. E., & White, C. C. (2005). Optimal vehicle routing with real-time traffic information. *IEEE Transactions on Intelligent Transportation Systems, 6*(2), 178–188.

Kumar, A., Gattoufi, S., & Reisman, A. (2006). MASS CUSTOMIZATION: An epistemological review of its literature and comparison with other fields of OR/MS. Working paper.

Laporte, G. (1992). The vehicle routing problem: An overview of exact and approximate algorithms. *European Journal of Operational Research, 59*, 345–358.

Laporte, G., Gendreau, M., Potvin, J.-Y., & Semet, F. (1999). Classical and modern heuristics for the vehicle routing problem. Technical report, Les Cahiers du Gerad, G-99-21.

Laporte, G., & Nobert, Y. (1987). Exact algorithms for the vehicle routing problem. *Annals of Discrete Mathematics, 31*, 147–184.

Laporte, G., & Osman, I. H. (1995). Routing problems: A bibliography. *Annals of Operations Research, 61*, 227–262.

Larsen, A. (2000). The dynamic vehicle routing problem. PhD Thesis, Department of Mathematical Modelling (IMM), Technical University of Denmark (DTU), Lyngby, Denmark.

Larsen, A. (2003). all_vrp_new.bib. <http://www2.imm.dtu.dk/~ala/all_vrp_new-bib.html>.

Larsen, A., Madsen, O. B. G., & Solomon, M. (2002). Partially dynamic vehicle routing – models and algorithms. *Journal of the Operational Research Society, 53*(6), 637–646.

Lee, T.-R., & Ueng, J.-H. (1999). A study of vehicle routing problems with load balancing constraints. *International Journal of Physical Distribution and Logistics, 29*(10), 646–658.

Letchford, A. N., & Eglese, R. W. (1998). The rural postman problem with deadline classes. *European Journal of Operational Research, 105*, 390–400.

Levin, A. (1971). Scheduling and fleet routing models for transportation systems. *Transportation Science, 5*(3), 232–256.

Liebman, J. C. (1970). Mathematical models for solid waste collection and disposal 38th national meeting of the Operations Research Society of America. *Bulletin of the Operations Research Society of America, 18*(2).

Luedtke, J., White, C. C. (2002). HAZMAT transportation and security: Survey and directions for future research. Research paper, Department of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta, Georgia, USA.

Malandraki, C., & Daskin, M. S. (1992). Time dependent vehicle routing problems: Formulations, properties, and heuristic algorithms. *Transportation Science, 26*(3), 185–200.

Marks, D. H., & Stricker, R. (1970). Routing for public service vehicles. *ASCE Journal of the Urban Planning and Development Division, 97*(UP2), 165–178.

Mendeleyev, D. I. (1889). The periodic law of chemical elements (Faraday lectures). *Journal of the Chemical Society, 55*, 643–656.

Meng, Q., Lee, D.-H., & Cheu, R. L. (2005). Multiobjective vehicle routing and scheduling problem with time window constraints in hazardous material transportation. *Journal of Transportation Engineering, 131*(9), 699–707.

Min, H., Jayaraman, V., & Srivastava, R. (1998). Combined location routing problems: A synthesis and future research directions. *European Journal of Operational Research, 108*, 1–15.

Nagy, G., & Salhi, S. (2005). Heuristic algorithms for single and multiple depot vehicle routing problems with pickups and deliveries. *European Journal of Operational Research, 162*, 126–141.

Nanry, P. W., & Barnes, J. W. (2000). Solving the pickup and delivery problem with time windows using the reactive tabu search. *Transportation Research Part B, 34*(2), 107–121.

O'Connor, A. D., & De Wald, C. A. (1970). A sequential deletion algorithm for the design of optimal transportation networks 37th national meeting of the Operations Research Society of America. *Bulletin of the Operations Research Society of America, 18*(1).

Osman, I. H., & Kelly, J. P. (1996). Meta-heuristics: An overview. In I. H. Osman & J. P. Kelly (Eds.), *Meta-heuristics: Theory and applications* (pp. 1–21). Boston: Kluwer Academic Publishers.

Osman, I. H., & Laporte, G. (1996). Metaheuristics: A bibliography. Metaheuristics in combinatorial optimization In G. Laporte, I. H. Osman (Eds.), *Annals of operations research* (Vol. 63, pp. 513–628).

Park, Y.-B., & Hong, S.-C. (2003). A performance evaluation of vehicle routing heuristics in a stochastic environment. *International Journal of Industrial Engineering: Theory Applications and Practice, 10*(4), 435–441.

Partyka, J. G., & Hall, R. W. (2000). On the road to service. *ORMS Today, 27*(4), 26–30.

Powell, W. B. (1986). A stochastic model of the dynamic vehicle allocation problem. *Transportation Science, 20*(2), 117–129.

Powell, W. B., & Shapiro, J. A. (1999). A Representational paradigm for dynamic resource transformation problems. Technical report, Princeton University, Princeton, NJ, CL-99-01.

Psaraftis, H. N. (1995). Dynamic vehicle routing: Status and prospects. *Annals of Operations Research, 61*, 143–164.

Rego, C., & Roucairol, C. (1995). Using tabu search for solving a dynamic multi-terminal truck dispatching problem. *European Journal of Operational Research, 83*, 411–429.

Reisman, A. (1992). *Management science knowledge: It's creation generalization and consolidation*. Westport, CT: Quorum Books Publishing Company.

Reisman, A. (1993). *Operations management: Time for meta research. Prospectives in operations management: Essays in honor of Elwood S. Buffa* (PP. 471–482). Boston, MA: Springer. January.

Reisman, A. (2004). How can OR/MS educators benefit from creating and using taxonomies. *INFORMS: Transactions on Education, 4*(3). <http://ssrn.com/author=161264>, <http://ite.pubs.informs.org/Vol4No3/Reisman/>, May (On-line).

Reisman, A., Cem, K. B., & Oral, M. (in press). Meta research in OR/MS: A taxonomy, bibliography and classification of the literature. *International Journal of Operations and Quantitative Methods*. <http://ssrn.com/abstract=605223>.

Reisman, A., & Oral, M. (2005). Soft systems methodology: A context within a 50-year retrospective of ORMS. *Interfaces, 35*(2), 164–178.

Roberts, D., & Hadjiconstantinou, E. 1998. A computational approach to the vehicle routing problem with stochastic demands. In P. Borne, M. Ksouri, A. Elkamel (Eds.), *Computational engineering in systems applications: 16th European conference on operational research (EURO XVI), Brussels, Belgium*, IEEE (pp. 139–144).

Saez, D., Cortes, C. E., & Nunez, A. (2008). Hybrid adaptive predictive control for the multi-vehicle dynamic pick-up and delivery problem based on genetic algorithms and fuzzy clustering. *Computers and Operations Research, 35*, 3412–3438.

Savelsbergh, M. W. P., & Sol, M. (1998). DRIVE: Dynamic routing of independent vehicles. *Operations Research, 46*, 474–490.

Solomon, M. (1983). Vehicle routing and scheduling with time window constraints: Models and algorithms. Technical report, College of Business Admin., Northeastern University, No. 83-42.

Sural, H., & Bookbinder, J. H. (2003). The single-vehicle routing problem with unrestricted backhauls. *Networks, 41*(3), 127–136.

Tan, K. K., & Tang, K. Z. (2001). Vehicle dispatching system based on Taguchi-tuned fuzzy rules. *European Journal of Operational Research, 128*, 545–557.

Teodorovic, D., & Pavkovic, G. (1996). The fuzzy set theory approach to the vehicle routing problem when demand at nodes is uncertain. *Fuzzy Sets and Systems, 82*, 307–317.

Toth, P., & Vigo, D. (1998). Exact algorithms for vehicle routing. In T. Crainic & G. Laporte (Eds.), *Fleet management and logistics* (pp. 1–31). Boston, MA: Kluwer Academic Publishers.

Toth, P., & Vigo, D. (1999). A heuristic algorithm for the symmetric and asymmetric vehicle routing problem with backhauls. *European Journal of Operational Research, 113*, 528–543.

Trudeau, P., & Dror, M. (1992). Stochastic inventory routing: Route design with stockouts and route failures. *Transportation Science, 26*(3), 171–184.

Vogel, D. R., & Weterbe, J. C. (1984). MIS research: A profile of leading journals and universities, Data base, Fall (pp. 3–14).

Wasserman, P. D. (1989). *Neural computing: Theory and practice*. New York: VanNostrand Reinhold.

Wilson, N., & Sussman, J. (1971). Implementation of computer algorithms for the dial-a-bus system 39th national meeting of the Operations Research Society of America. *Bulletin of the Operations Research Society of America, 19*(1).

Yaohuang, G., Binglei, X., & Qiang, G. (2002). Overview of stochastic vehicle routing problems. *Journal of Southwest Jiaotong University (English Edition), 10*(2), 113–121.

Zagrafos, K. G., & Androutsopulos, K. N. (2004). A heuristic algorithm for solving hazardous materials distribution problems. *European Journal of Operational Research, 152*, 507–519.