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The relationship between vehicle routing and scheduling and green logistics - a literature survey

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The Relationship between Vehicle Routing & Scheduling and Green Logistics - A Literature Survey

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Abstract.

The basic Vehicle Routing and Scheduling Problem (VRSP) is described followed by an outline of solution approaches. Different variations of the basic VRSP are examined that involve the consideration of additional constraints or other changes in the structure of the appropriate model. An introduction is provided to Green Logistics issues that are relevant to vehicle routing and scheduling including discussion of the environmental objectives that should be considered. Particular consideration is given to VRSP models that relate to environmental issues including the time-dependent VRSP, the transportation of hazardous materials and dynamic VRSP models. Finally some conclusions are drawn about further research needs in this area and the relation to road pricing.

Keywords: vehicle routing, scheduling, emission, congestion, environment, green logistics

1 Introduction

The Vehicle Routing and Scheduling Problem (VRSP) concerns the determination of routes and schedules for a fleet of vehicles to satisfy the demands of a set of customers. The basic Capacitated Vehicle Routing Problem (CVRP) can be described in the following way. We are given a set of homogeneous vehicles each of capacity Q, located at a central depot and a set of customers with known locations and demands to be satisfied by deliveries from the central depot. Each vehicle route must start and end at the central depot and the total customer demand satisfied by deliveries on each route must not exceed the vehicle capacity, Q. The objective is to determine a set of routes for the vehicles that will minimize the total cost. The total cost is usually proportional to the total distance traveled if the number of vehicles is fixed and may

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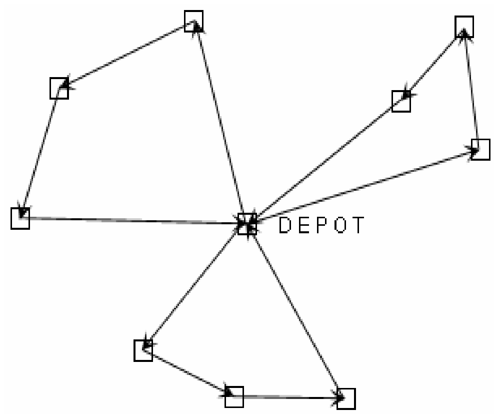
also include an additional term proportional to the number of vehicles used if the number of routes may vary.



The vehicle routing problem scheme

The CVRP and many of its variants have been well studied in the literature since its introduction by Danzig and Ramser in 1959 [17]. Its exact solution is difficult to determine for large-scale problems as it is a member of the class of NP-Hard problems, where no algorithms have yet been devised where the time to find a guaranteed optimal solution that is proportional to the size of the problem (in this case, the number of customers). Specialised algorithms are able to consistently find optimal solutions for cases with up to about 50 customers; larger problems have been solved to optimality in some cases, but often at the expense of considerable computing time.

In practice, other variations and additional constraints that must be taken into consideration usually make the vehicle routing problem even more difficult to solve to optimality. So many solution procedures are based on heuristic algorithms that are designed to provide good feasible solutions within an acceptable computing time, but without a guarantee of optimality.

There are several books and survey articles that have been written that summarise different approaches and provide references to the large number of journal articles that have been written on this topic, for example Golden and Assad (1988) [34] and Toth and Vigo (2001) [67]. There are many other research works about the classical CVRP; we may cite some exact methods for this problem, for example Laporte and Nobert (1987) [44] or Agarwal et al., (1989) [2] have proposed optimal approaches to solve the CVRP. Others have proposed approximate methods and heuristics due to the complexity of the problem and to try to solve it in a reasonable computing time: we cite, for example, Laporte and Semet (2002) [45] and Cordeau and Laporte (2004) [14], and Cordeau et al., (2005) [15] or Gendreau et al., (2002) [32]. Most of these approaches are based on local search techniques.

Most papers assume that the costs and times of traveling between the depot and the customers and between customers are known and fixed. They are either given or calculated using a shortest path algorithm on the graph or network representing the locations. In practice, the times and shortest paths may vary, particularly by time of day and this feature will be discussed more fully in Section 3.

The following section outlines other variations on the basic CVRP which are important in practical distribution problems.

1.1 Distance or time constraints for each route

In some formulations, a constraint on the maximum distance that can be traveled by any vehicle before it completes its route is imposed. In other cases, the constraint concerns the maximum time taken for each route which may relate to a legal constraint on the working time of the driver. There may be a distinction between a constraint on the driving time that only includes time when the vehicle is traveling and a constraint on the total time that also includes time to load the vehicle and to service each customer on the route. The reader may refer to some articles (see Desrochers et al., (1988) [20]). We also cite the work developed in Laporte et al., (2005) [43].

1.2 Time Window constraints

These constraints restrict the times at which a customer is available to receive a delivery. We call this typical problem the Vehicle Routing Problem with Time Window (VRPTW). These time window constraints are usually expressed in terms of a time interval or intervals within which service must begin for each customer. If a vehicle arrives at a customer before the start of a time window, then it must normally wait until the start of the time window before service can commence. Other formulations may treat the time windows as soft constraints where early or late service may be allowed but at the expense of a penalty in the objective function. Some exact and approximate methods have been tailored especially to solve the VRPTW. One example is an optimization algorithm developed for the VRPTW and attributed to Kolen et al., (1987) [41]. Other more recent papers include, for example, Kallehauge et al., (2006) [38] who have developed an exact algorithm. Approximate and heuristic methods have also been built, for example, Potvin and Rousseau (1993) [60], Braysy (2002) [9] or Lau et al., (2003) [46].

1.3 CVRP with Backhauls

In this variation, there are two subsets of customers: the first subset requires deliveries from the depot and the second subset requires goods to be picked up to be delivered to the depot. Normally all deliveries on each route must be completed before any pick-ups. The total deliveries and the total pick-ups on each route must separately be less than the capacity of each vehicle, Q. The reader may refer to Goetschalckx and Jacobs-Blecha (1993) [33] and Casco et al., (1988) [11].

1.4 CVRP with Pick-up and Delivery

This situation concerns a set of customer orders where a single commodity is to be picked up from one location and delivered to a second location. The vehicle routes, starting and finishing at a central depot, must be constructed so that the route visits the pick-up location for an order before the corresponding delivery location and the load on each vehicle never exceeds the capacity, Q. We recall here some research addressed to this type of VRSP, for example, Desaulniers et al., (2001) [21] and Derigs and Metz (1992) [19]. More can be found in Toth and Vigo (2001) [67].

1.5 CVRP with non-homogeneous vehicle fleet

In practice, many vehicle routing problems are addressed by a non-homogeneous vehicle fleet where vehicles of different capacities may be used. The vehicles may also have differences in other operating characteristics such as the average speed of travel or the service time at a customer (e.g. due to different goods handling equipment).

1.6 Open VRSP

The term “Open” is applied to problems where each vehicle is not required to return to the central depot after visiting the final customer, i.e. the vehicle routes are open paths instead of closed circuits. This formulation may be appropriate for a situation where vehicles are hired from a third party and the cost of the hire is based on the distance traveled while the vehicles are loaded. For more details, one may refer to Brandaõ (2004) [8] and Fu et al., (2005) [29]. An exact method for the Open VRSP is to be found in Letchford et al., (2006) [48].

One variant of the Open VRSP includes the constraint that each route terminates at one of the driver nodes which are specified beforehand. Driver nodes practically correspond to parking lots or homes of drivers. The presence of such fixed driver nodes suits especially those situations in which deliveries to customers are outsourced to a shipping company, or drivers use the same vehicles to commute between home and depot.

1.7 Period VRSP

This problem can be defined as the problem of finding routes for all days of a given T-day period to minimize total costs. These types of problems are also called allocation/routing problems. The allocation part consists of the assignment of customers to days of the period, while the routing part governs for the daily planning. Some articles dealing with this variant of the VRSP are available in the literature, for example, Cordeau et al., (1997) [16] and Mourgaya and Vanderbeck (2006) [56].

1.8 Other variations

Many other variations of the basic CVRP have been studied that may include some of the features already described. These include multi-depot models where a set of depots replaces the single central depot. If the capacity of the available fleet of vehicles cannot service the required demand, then the objective may be focused on satisfying as many customers as possible using the available fleet. There may also be considerations due to different types of commodities that imply additional constraints. For example, in delivering groceries with vehicles where only the front section of the trailer is refrigerated, frozen goods must be loaded first into the trailer and other non-frozen goods loaded behind. This may lead to a constraint of delivering all non-frozen goods, before frozen goods can be unloaded. Distribution managers may also need to construct routes where a single vehicle is away from the central depot over more than one day and provision must be made for a suitable location for the vehicle to be parked over night while the driver rests before continuing the route the following day. We cite here some of the articles dealing with other variants of the VRSP, for example, Anily and Federgruen (1990) [1] and

Baldacciet al., (2006) [5]. For the case of shipping, we cite Barnes-Schuster and Bassok (1997) [4].

1.9 Arc Routing Problems

These vehicle routing problems are significantly different to all the VRSPs described so far. These have all been Node Routing Problems because the customer demands are all located at points or at the nodes of an underlying graph or network. In Arc Routing Problems, the demands are associated with the links between the nodes, called edges (in the undirected case) or arcs (in the directed case). These represent roads or carriageways in the underlying road network. Such problems arise naturally in several applications such as garbage collection, mail delivery, snow clearing, meter reading, school bus routing, police patrols, and winter gritting. In these cases, a service must be carried out which involves the vehicle traveling the length of road section performing the required service. This is often done at a different speed from when a vehicle is simply traveling along one of the roads without servicing it, which is often referred to as "deadheading". These problems may also have similar variations to those described for Node Routing Problems such as the existence of time window constraints for the service.

A comprehensive survey of Arc Routing Problems is provided in the book edited by Dror (2000) [23].

1.10 Stochastic VRSP

The customer demand in many cases is known before the routes need to be planned because orders have been received at the central depot. However in some situations, the size of demand from a customer may be unknown until the vehicle arrives at the customer. This is an example of a stochastic vehicle routing problem where routes must be planned based on the probability distribution of the demand at any customer. In such problems, there needs to be a strategy defined that explains what happens when a vehicle runs out of the commodity it is carrying before it has completed all its deliveries, for example returning to the depot by the shortest route in order to reload (for more details see Stewart and Golden (1983) [66], Dror et al., (1993) [24] and Yang et al., (2000) [68]).

The stochastic nature of these problems may take many forms. As well as the level of demand, the timing and location of demand may vary. The availability of resources may vary as well due to service times, dock times and operations in other zones, regions or areas of operation. More details can be found in Secomandi (2001) [64] and Laporte et al., (1992) [42].

1.11 Dynamic or Real-time VRSP

Models discussed so far have been suitable for planning the operations of a vehicle fleet in advance. However models are also being developed to assist in the real-time management and control of a distribution operation. To be effective, these rely on up-to-date information. One type of dynamic model may consider new customer orders that arise after the routes had been initially planned, see Bagchi and Nag (1991) [3]. With a common commodity, the original vehicle routes may be modified to include the new demand. Another issue is the incorporation of real-time information on the location of the vehicles and current information on road conditions (such as unexpected congestion due to an accident). One can refer to Papastavrou [59]. There may be the opportunity to re-route vehicles in the light of this information to reduce costs and to meet customer service time windows. The dynamic behavior has given a name to a typical variant of the VRSP, we name the Dynamic Vehicle Routing Problem: Minkoff (1993) [54].

The dynamic vehicle routing problem calls for online algorithms that work in real-time since the immediate requests should be served, if possible. As conventional static vehicle routing problems are NP - hard, it is not always possible to find optimal solutions to problems of realistic sizes in a reasonable amount of computation time. This implies that the dynamic vehicle routing problem also belongs to the class of NP-hard problems, since a static VRP should be solved each time a new immediate request is received. Generally, the more restricted and complex the routing problem is, the more complicated the insertion of new dynamic customers will be (see Hvattum et al., (2006) [36]). For instance, the insertion of new customers in a time window constrained routing problem will usually be much more difficult than in a non-time constrained problem. Note that in an online routing system customers may even be denied service, if it is not possible to find a feasible spot to insert them. Often this policy of rejecting customers includes an offer to serve the customers the following day of operation. However, in some systems - as for instance the pick-up of long-distance courier mail - the service provider (distributor) will have to forward the customer to a competitor when they are not able to serve them. Others article dealing with the DVRP include Gendreau and Potvin (1998) [31] and Montemanni et al., (2005) [55]. A case study on pharmaceutical distribution is relted in de Magalhães and de Sousa [52]. More details on the DVRP can be found in Zeimpekis and Giaglis (2006) [69].

2 Green Logistics Agenda

The consideration of environmental costs is essentially changing the transportation policy in developed countries, especially those within the European Union. The new environmental sensitivity in today's societies and governments has been described in several studies, such as INFRAS/ IWW and UNITE (INFRAS/IWW [37], Betancor and Nombela [7], Samson et al., [65]). The European Conference of Ministers of Transport [28] urged European Governments to develop new instruments to incorporate externalities and environmental costs in transport management accounting. Therefore, environmental concerns have highlighted the importance of sustainable transport design.

Road transport is predicted in the EC to grow by a further 33% in the next 20 years ([1]). These trends indicate that, despite technological advances, the environmental impacts of transport will grow unless action is taken at all levels - by government, business and individuals. There is a continuing need to reduce the environmental impacts of some forms of transport - particularly road and air travel - and promote more environmentally friendly transport options such as cycling, public transport and walking.

Road transport services account for 1.6% of the European GDP and give jobs to 4.5 million people in the EU. The whole economy and society depends heavily on efficient road transport, 44% of the goods are moved by trucks and 85% of the persons by cars, buses or coaches.

The aim of the Community's land transport policy is to promote sustainable mobility that is efficient, safe and with reduced negative effects on the environment.

The objectives for road transport are therefore to promote efficient road freight and passengers transport services, to create fair conditions for competition, to promote and harmonise safer and more environmental friendly technical standards, to ensure a minimum fiscal and social harmonisation and to make sure that the rules in road transport are effectively applied without bad ecological impact.

Carbon dioxide emissions from transport have risen throughout the 1990s and now account for around one quarter of the UK's total carbon dioxide emissions. These emissions contribute to climate change that has grave domestic and global consequences. The Government has recently shown international leadership by committing the UK to work towards a 60% reduction in its car-

[1] Information may be consulted on `www.europa.eu` (accessed 13/01/2007)

bon dioxide emissions by 2050. For a first model one can refer to Davis et al., (2005) [18].

Transport contributes to poor air quality. Although discharges of many of the most damaging air pollutants have declined over the last decade, there are still "hot spots" in some city centres and along motorway corridors where concentrations of nitrogen dioxide and particulates from road vehicles exceed safe levels. The Department of Health estimates that there are between 12,000 and 24,000 early deaths each year resulting from poor air quality in our cities. More can be found in London Development Agency Report, March 2004 ([2]).

2.1 Some statistics

Some backgrounds statistics recorded by the Department of Transport from the UK Government are mentioned below:

- Over the past 25 years the number of journeys made by car have increased while those by foot, rail, bus and cycle have decreased. The majority of personal travel (93%) and freight movement (65%) is now made by road (10 year transport plan, DTLR 2000).
- Road traffic in the UK, at 7,800 vehicle kilometres for each member of the population, is 26% higher than the OECD Europe average (Environmental Performance Reviews, Organisation for Economic Co-operation and Development).
- Road transport accounts for around 22% of UK CO_2 emissions. For more details, see ([3]).
- Emissions from road transport are the main causes of chronic hot spots for particulates and nitrogen dioxide in major urban areas. Road transport emits 44% of the UK's nitrogen oxides and up to 75% or more of nitrogen oxides in conurbations. Similarly vehicles account for 20% of particles nationally but about twice this in conurbations (The Urban Environment in England and Wales - a detailed assessment, Environment Agency 2002).

[2] The Public Health Impact of Cities and Urban Planning, Karen Jochelson, The King's Fund, March 2004, www.lda.gov.uk/server/show/ConMediaFile.725 (accessed 15/12/2006)

[3] http://www.dft.gov.uk/stellent/groups/dft_transstats/documents/pdf/dft_transstats_pdf_026311.pdf (accessed 15/12/2006)

- The proportion of human - induced climate change accounted for by transport is three times greater than that of the equivalent amount of ground level emission of carbon dioxide. This is due to the range of greenhouse gases emitted by engines. For more details are available in the Publications of the Parliament, 19 July 2006 ([4]).

  The Vienna Declaration in 2006, included some important statistics and views on the fuel used in transport particularly the impact of oil. It said "*Transport accounts for about 70% of annual oil consumption in the EU. Ninety-six per cent of the fuel burned in internal-combustion engines comes from mineral oil. No other area of economic activity is so dependent on oil. In view of the foreseeable shortage of oil resources and the further price rises this will entail, all-out efforts must be made to develop oil substitutes for use in transport and, at the same time, to make transport operations far more energy-efficient. From an environmental perspective, there is no alternative to a strategy of weaning the economy off oil, and such a strategy cannot succeed unless it focuses on transport too. In all of this, however, protecting the climate must remain the overarching aim. The adverse impact of some oil substitutes, such as liquidised coal or mined shale, is so drastic that they cannot be contemplated as sustainable alternatives*". For more details see ([5])

3 Issues linking the VRSP and Green Logistics

There is not much literature that links VRSP models with the Green Logistics issues that have been discussed in the previous section. Most articles are concerned with objectives of minimizing economic costs. Commercial software is also designed to provide feasible solutions that will minimize economic costs. Many software vendors claim that the use of their VRSP package will result in economic benefits for their customers from reductions in the number of vehicles required and distance traveled compared with traditional manual methods. A recent survey of VRSP software packages has been published in `OR/MS Today` [57].

The reduction in total distance will in itself provide environmental benefits due to the reduction in fuel consumed and the consequent pollutants. However

[4] `http://www.publications.parliament.uk/pa/cm200506/cmselect/cmenvaud/981/981we20.htm` (accessed 6/12/2006)

[5] `http://www.greens-efa.org/cms/topics/dokbin/109/109638.vienna_declaration@en.pdf` (accessed 13/01/2007)

this is generally not measured or emphasized. Palmer (2004) [58] has studied the connection between vehicle routing and emission in the context of grocery home delivery vehicles.

There are some examples in the literature where there are some links between VRSP and the reduction of environmental pollution. These links may not be direct and such issues are discussed in the following subsections.

3.1 Time-dependent VRSP

The Time Dependent Vehicle Routing and Scheduling Problem, TDVRSP, consists in optimally routing a fleet of vehicles of fixed capacity when the traveling times between nodes depend on the time of the day that the trip on that arc was initiated. The optimization consists in finding the solution that minimizes the number of tours (the number of vehicles used) and the total traveling time. The traveling time is calculated by knowing the departing time and an accurate estimate of the average speed of the vehicle while traveling on the arc. This version of the VRSP is motivated by the fact that in so many circumstances, traffic conditions cannot be ignored, because at peak times, traffic congestion on popular routes will cause delays. By minimizing the total traveling time, the solutions produced will tend to direct vehicles to roads where they can travel at a faster speed instead of being caught in congestion. It may even be that some solutions imply a greater total travel distance, but there is likely to be environmental benefit because less pollution is created when vehicles are traveling at the best speeds for the environment and for shorter times.

Examples of this approach can be found in the following references Donati et al., (2003) [22], Malandraki and Daskin (1992) [53].

In fact when dealing with time constraints, like the delivery time windows for the customers, the optimal solutions known for the classic case become infeasible and the degree of infeasibility increases with the variability of traffic conditions. So an additional benefit of this approach is that it enables time window constraints to be satisfied more reliably. For the time dependent model, the travel times may also depend on other factors such as the day of the week, or the season of the year. These ideas have been treated in Haghani and Jung (2005) [35] and Chen et al., (2005) [12]. More recently, Eglese et al., (2006) [25] discussed the issues involved in order to construct a database of road times for a road network. More details are developed in Maden (2006) [51].

The data requirements for the TDVRSP are significantly higher than for conventional models. Instead of simply requiring a distance between nodes on the graph representing the road network, a set of travel times are also required for every time interval defined. The shortest time path between any two nodes may be different depending on the time of travel. This is developed in Fu and Rilett (2000) [30].

The TDVRSP approach is therefore likely to achieve environmental benefits, but in an indirect way and none of the articles referenced directly measure the environmental benefit of this approach. Part of the work in Work Package 6 of the Green Logistics project is designed to examine this issue.

3.2 Hazardous Materials Transportation

The transportation of hazardous materials (hazmat) is a significant environmental issue in the transportation industry. There are billions of tons of hazmat transported throughout the world every year, most of which are important raw materials used by various industries. During the transportation process, one of the most important issues is safety (see Erkut and Verter (1998) [26]). Accidents, though rarely happening, could have large impacts on humans and the natural environment, especially in large urban areas. As an important strategic and tactical problem, the transportation of hazmat has been studied extensively in the research literature. In the early 1990s, the problem was highlighted by researchers and modelled to achieve different objectives, including the minimization of risk, the minimization of risk to special population categories, the minimization of travelling time, and the minimization of property damage (for more details, the reader can refer to Zhang et al., (2005) [70]. According to List et al., (1991) [49], research in this field includes risk analysis, routing/scheduling and facility location. Karkazis and Boffey (1995) [39] introduce an improved routing model in the context of a realistic environment.

In his introduction to hazmat transportation, Erkut ([6]) says "*What else is relevant in this decision? For example, clearly, the shipment of hazardous waste will carry some risks to the public along the route, as well as to the environment. Accidents do happen, and the contents of the truck can be released in a serious accident. An accident can be quite costly to your company in several ways; for example the decision makers may be liable for (some of) the cleanup costs and damages, and they insurance premiums are likely to increase. Hence, they would like to consider minimizing risk, alongside cost. How should they quantify risk on a stretch of highway? Do they focus on the likelihood of an accident by the truck, or on the consequences of that accident,*

[6] `http://www.ualberta.ca/ERSC/pages/erhan.htm` (accessed 12/01/2007)

or both? Should they use historical accident rates on that highway (or highway class)? What about known danger spots, such as railroad crossings and left turns? To evaluate the population to be impacted, should they use the number of people that live within a certain distance of the highway? If so what should be this distance? How to include buildings with a high concentration of population (such as schools and hospitals) in their analysis? How to consider environmental risk? It seems that the problem of selecting the "best" route for hazardous waste shipment between two destinations is more complicated than the selection of the route for any long weekend trip."

There are two major sources of complexity in this problem: quantifying different objectives, and trading off the objectives. The first one is more of a technical problem; a problem of identifying the necessary data, collecting and processing it, and identifying certain good routes via the use of quantitative modeling techniques. The second one is more of a judgement problem.

Erkut and Ingolfsson (2004) [27] suggest that avoiding a catastrophe (an accident with a very large consequence) is a relevant issue in routing hazardous materials and propose three models, two of which are computationally hard and therefore only offer theoretical insights. Leonelli et al., (2000) [47] employ a risk-analysis-based routing methodology to solve the hazmat transportation problem and formulate it as a minimum cost flow problem. A survey by Luedtke (2002) [50] summarizes some research results on hazmat transportation. Some models have been built as a bi-objective vehicle routing and scheduling problem.

There is also a unique paper by Kara and Verter (2004) [40] focusing on the nature of the relationship between the regulator and carriers. A government has the authority to close certain roads to hazmat transportation, while it is the carrier's strategy to choose roads to route their vehicles.

The safe transportation problem of hazmat is a variant of VRPTW, which considers the vehicle scheduling problem between a depot (a distribution centre of hazmat) and several customers. Each road segment has an upper bound for transportation quantity. The transportation is regarded as "safe" if the load does not exceed the upper bound when a vehicle is passing through a specific road segment. The objective is to minimize the number of vehicles used and the total travelling distance, provided that the transportation used is safe on all road segments. A model of safe transportation of hazardous materials based on VRPTW is such that each road segment (edge), (i, j), is associated with a value, v_{ij}, which is the upper bound of the load for vehicles passing along this road segment and determined by the nearby environment. Therefore, the complete scheduled transportation route is safe if the loads of all the vehicles do not exceed the upper bound of each road segment when passing along it.

Other approaches may aim to assign each vehicle to a different route in order to spread the risk. In this case the model assigns one and only one route for each vehicle between the depot and each customer or each pair of customers.

An alternative approach is not to consider the measure of risk as an additional constraint, but to assign a risk measure to the use of any road link and then find a set of routes that minimize the total risk as an objective.

Research has primarily addressed route-finding techniques that minimize either the total travel time, the expected number of accidents (fatal or otherwise), the accident probability, the residential population within a given distance from the route, the risk of spill, or some combination of these factors. This research has been surveyed by List et al., [49]. It is immediately apparent that such single objective models cannot take into account conflicting criteria such as truck operating costs and expected damage. In fact, other researchers have considered Hazmat transportation as a bi-objective problem where one objective relates to risk and the other to the cost of the route (see Zografos and Davis (1989) [71]).

3.3 Dynamic VRSP

There is potential for environmental benefits to arise from the use of dynamic or real-time models to manage a distribution activity. This is because vehicles may be redirected to avoid unexpected congestion due, for example, to an accident. However the implementation of these models requires real-time information on the locations of the vehicles, current traffic conditions and good communications between management and drivers (see Bianchi (2000) [6]).

Psaraftis (1980, 1988) [62][63] lists 12 issues where the dynamic vehicle routing problem differs from the conventional static routing problem. Below we give a brief summary of these issues as they are indeed very central to our discussion of static versus dynamic routing.

1. Time dimension is essential. In a static routing problem the time dimension may or may not be important. In the dynamic counterpart time is always essential. The dispatcher must as a minimum know the position of all vehicles at any given point in time and particularly when the request for service or other information is received by the dispatcher.

2. The problem may be open-ended. The process is often temporally bounded

in a static problem. The routes start and end at the depot. In a dynamic setting the process may very well be unbounded. Instead of routes one considers paths for the vehicles to follow.

3. Future information may be imprecise or unknown. In a static problem all information is assumed to be known and of the same quality. In a real-life dynamic routing problem the future is almost never known with certainty. At best probabilistic information about the future may be known.

4. Near-term events are more important. Due to the uniformity of the information quality and lack of input updates all events carry the same weight in a static routing problem, whereas in a dynamic setting it would be unwise immediately to commit vehicle resources to long-term requirements. The focus of the dispatcher should therefore be on near-term events when dealing with a dynamic routing problem.

5. Information update mechanisms are essential. Almost all inputs to a dynamic routing problem are subject to changes during the day of operation. It is therefore essential that information update mechanisms are integrated into the solution method. Naturally, information update mechanisms are not relevant within a static context.

6. Re-sequencing and reassigning decisions may be warranted. In dynamic routing new input may imply that decisions taken by the dispatcher become suboptimal. This forces the dispatcher to reroute or even reassign vehicles in order to respond to the new situation.

7. Faster computation times are necessary. In static settings the dispatcher may afford the luxury of waiting for a few hours in order to get a high quality solution, in some cases even an optimal one. In dynamic settings this is not possible, because the dispatcher wishes to know the solution to the current problem as soon as possible (preferably within minutes or seconds). The running-time constraint implies that rerouting and reassignments are often done by using local improvement heuristics like insertion and k-interchange.

8. Indefinite deferment mechanisms are essential. Indefinite deferment means the eventuality that the service of a particular demand be postponed indefinitely because of that demands unfavourable geographical characteristics relative to the other demands. This problem could for instance

be alleviated by using time window constraints or by using a nonlinear objective function penalizing excessive wait.

9. Objective function may be different. Traditional static objectives such as minimization of the total distance traveled or the overall duration of the schedule might be meaningless in a dynamic setting because the process may be open-ended. If no information about the future inputs is available, it might be reasonable to optimize only over known inputs. Some systems also use nonlinear objective functions in order to avoid undesirable phenomena such as the above mentioned indefinite deferment.

10. Time constraints may be different. Time constraints such as latest pickup times tend to be softer in a dynamic routing problem than in a static one. This is due to the fact that denying service to an immediate demand, if the time constraint is not met, is usually less attractive than violating the time constraint.

11. Flexibility to vary vehicle fleet size is lower. In static settings, the time gap between the execution of the algorithm and the execution of the routes usually allows adjustments of the vehicle fleet. However, within a dynamic setting the dispatcher may not have instant access to backup vehicles. Implications of this may mean that some customers receive lower quality of service.

12. Queueing considerations may become important. If the rate of customer demand exceeds a certain threshold, the system will become congested and the algorithms are bound to produce meaningless results. Although vehicle routing and queueing theory are two very well-studied disciplines, the effort to combine these has been scant.

4 Conclusions

"Classical" vehicle routing and scheduling models aim to minimize cost (usually related to the number of vehicles and distance). This will also provide some environmental benefit compared with solutions that use unnecessary distance (because there will be some fuel saving). In their INRETS report, Pronello and André (2000) [61] suggest that existing models to measure the pollution caused by a set of vehicle routes may be unreliable. This is because reliable pollution models require input measures which are not normally part of the output of VRSP models. For example, the time spent travelling by a vehicle when the engine is cold may have a significant effect on the pollution produced. Without these linking models it is difficult to quantify the environmental benefits of different VRSP solutions.

Even if it is difficult to measure the precise environmental benefit, there should be some value in versions of VRSP models that consider alternative objectives to pure economic considerations. For example, the time-dependent vehicle routing models represent an approach which should indirectly produce less pollution because vehicles will tend to be directed away from congestion.

A policy which is being considered is the introduction of “Road Pricing”. The use of roads would be charged in the UK and higher charges would be levied for vehicles using roads then tend to become congested at particular times of day. If this policy is adopted, then the development of VRSP models to minimise costs including the road price may also tend to produce environmental benefits and prevent congestion. However, the environmental benefits will depend heavily on the size of any additional charges and the schemes that are applied.

Road Pricing means that motorists pay directly for driving on a particular roadway or in a particular area. Value Pricing is a marketing term which emphasizes that road pricing can directly benefit motorists through reduced congestion or improved roadways. Economists have long advocated Road Pricing as an efficient and equitable way to pay roadway costs and encourage more efficient transportation. Road Pricing has two general objectives: revenue generation and congestion management.

However in this literature review of VRSP and Green Logistics, we have not encountered any models where the objective to be optimized is an environmental objective, in terms of a measure of pollution. This is a research challenge for the future.

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