Dynamic Vehicle Routing Systems – Survey and Classification

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Introduction

The vehicle routing problem (VRP) has received an immense attention from the scientific community during the last three to four decades as it often play a vital role in the design of distribution systems. Basically, the VRP consists of designing routes for a set of capacitated vehicles that are to service a set of geographically dispersed customers at the least cost. In real-life contexts restrictions such as time windows for when the service can commence make up important side-constraints to the problem. The basic VRP deals with customers who are known in advance to the planning process. Furthermore, all other information such as the driving time between the customers and the service times at the customers are used to be known prior to the planning. This provides that perfect set-up for applying advanced mathematical based optimization methods such as set partitioning. However, when dealing with real-life applications the information often tends to be uncertain or even unknown at the time of the planning. The traditional VRP can be said to be static as well as deterministic. In contrast to this, the dynamic vehicle routing problem (DVRP) considers a VRP in which a subset (or the full set) of customers arrive after the day of operation has begun. The DVRP will have to be able to consider how to include the new requests into the already designed routes.

The major technological advances during the recent years mean that the majority of new vehicles are equipped with advanced GPS/GIS systems. Hence, the distribution companies are now able to monitor the vehicles' position and status at any given time. Furthermore, the development and implementation of Enterprise Resource Planning (ERP) systems now means that the distribution companies also are able to link the customer data with inventory information etc. Until recently advanced distribution planning systems were usually only seen in big enterprises. However, the before mentioned technological achievements implies that also medium sized distribution companies now implement advanced distribution planning systems. The next step will be to move the implementation of advanced systems based on DVRP's into the small enterprises. This development will probably be accelerated during the coming years as it seems inevitable that the demand for logistics based on the just-in-time (JIT) concept will keep on growing year by year. An example of this could be the transportation of the elderly and handicapped. Until now, most services required the passengers to book their transport the day before the travel was to take place. However, with the increased access to the internet these services will experience a growing demand for on-the-day booking. This means that the service provider will have to implement a routing system which is able to insert the requests for service which is received during the day of operation into the planned routes.

We will discuss important characteristics seen within dynamic vehicle routing problems. We discuss the difference between the traditional static vehicle routing problems and its dynamic counterparts. We give an in-depth introduction to the degree of dynamism measure which can be used to classify dynamic vehicle routing systems. Methods for evaluation of the performance of algorithms that solve on-line routing problems are discussed and we list some of the important issues to include in the system objective. Finally, we provide a three-echelon classification of dynamic vehicle routing systems based on their degree of dynamism and the system objective.

The Dynamic Vehicle Routing Problem

In order to give a definition of the Dynamic Vehicle Routing Problem we take a look at the work by Psaraftis who was among the very first to consider the dynamic extension of the traditional static VRP. Psaraftis uses the following classification of the static routing problem;

- *"if the output of a certain formulation is a set of preplanned routes that are not re-optimized and are computed from inputs that do not evolve in real-time".*

While he refers to a problem as being dynamic;

- *"if the output is not a set of routes, but rather a policy that prescribes how the routes should evolve as a function of those inputs that evolve in real-time".*

In the above definition by Psaraftis the temporal dimension plays a vital role for the categorizing of a vehicle routing problem. In this chapter we will demonstrate that the time of when relevant information is made known to the planner distinguishes dynamic from static vehicle routing problems.

In the definition given below we verbally define what we mean when we talk about a static vehicle routing problem.

The Static Vehicle Routing Problem

- All information relevant to the planning of the routes is assumed to be known by the planner before the routing process begins.
- Information relevant to the routing does not change after the routes have been constructed.

The information which is assumed to be relevant includes all attributes of the customers such as the geographical location of the customers, the on-site service time and the demand of each customer. Furthermore, system information as for example the travel times of the vehicle between the customers must be known by the planner.

The dynamic counterpart of the static vehicle routing problem as defined in the above definition could then be formulated as:

The Dynamic Vehicle Routing Problem

- Not all information relevant to the planning of the routes is known by the planner when the routing process begins.
- Information can change after the initial routes have been constructed.

In many DVRP, the vehicles service two types of requests:

1. *Advance requests*, which can also be referred to as static customers as these requests for service has been received before the routing process was begun.
2. *Immediate requests*, which can also be referred to as dynamic customers as these will appear in real-time during the execution of the routes.

Ideally, the new customers should be inserted into the already planned routes without the order of the non-visited customers being changed and with minimal delay. However, in practice, the insertion of new customers will usually be a much more complicated task and will imply either partial or full re-planning of the non-visited part of the route.

Generally, the more restricted and complex the routing problem is, the more complicated the insertion of new dynamic customers will be. 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 on-line 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.

The Degree of Dynamism

Measuring the performance of a dynamic vehicle routing system is not a trivial assignment. In contrast to a deterministic and static vehicle routing problem the performance of the dynamic counterpart is assumed to be dependent not only on the number of customers and their spatial distribution, but also the number of dynamic events and the time when these events actually take place. Therefore, a single measure for describing the system's ``dynamism'' would be very valuable when one wants to examine the performance of a specific algorithm under varying conditions.

In this presentation it will be demonstrated how measures that might seem promising for describing dynamism for one system might turn out to be inadequate for describing the dynamism of other systems. We will first discuss measures for dynamism in systems without time windows and then examine systems with the presence of time windows.

The Objectives

When measuring the performance of a DVRP system multiple objectives are often met. Sometimes, these objectives may even be conflicting. Naturally, the final objective of DVRP algorithms differs from one application to the next. However, some elements are almost always relevant to consider when defining the objective. We will discuss three kinds of objectives: Minimizing distribution costs, maximizing service level, and maximizing throughput.

Three-Echelon Framework for DVRP’s

After having discussed various characteristics of the DVRP we will now use the degree of dynamism measure and the objectives to categorize a variety of DVRP's into a three echelon framework. The framework distinguishes between weakly, moderately and strongly dynamic systems.

References

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