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July 2012

CIRRELT-2012-38

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Planning Methods and Decision Support Systems in Vehicle Routing Problems for Timber Transportation: A Review

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Abstract. Transportation operations account for a significant part of the wood procurement cost. Therefore, reduction in transportation costs through enhanced efficiency of these operations has motivated a considerable amount of research effort in many countries. A substantial part of the research has been dedicated to the vehicle routing problem, i.e. the planning of the set of routes to be taken by a fleet of trucks to deliver timber from harvest areas to industries. This constitutes the operational part of transportation planning and is the part we focus on. The paper surveys the planning methods and decision support systems regarding the vehicle routing problem for timber transportation. Also, a general description of this problem is proposed, based on a summary of the main attributes encountered in each method proposed and/or implemented.

Keywords: Vehicle routing problem, decision support system, forestry.

Acknowledgements. The authors would like to acknowledge the financial support of the private and public partners of the FORAC Research Consortium.

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Dépôt légal – Bibliothèque et Archives nationales du Québec
Bibliothèque et Archives Canada, 2012

Introduction

Transportation from harvest areas to industries accounts for an average of 36% of the operational costs to deliver timber to a Canadian mill (Michaelsen, 2012). Similar values have also been reported in other countries [e.g. 18-25% in Australia (Brown, 2012); 25-35% Southern US (Greene, 2012); 30-40% in Sweden (Anderson, 2012); 40% in New Zealand (Rien, 2012) and ≥45% in Chile (Weintraub, 2012)]. Annually, this adds up to more than 2 billion Canadian dollars for the Canadian forest industry and about 600 million euros for the Swedish forest industry. With all this money spent on transportation, even a small cost reduction can lead to substantial savings (Palmgren et al., 2004). Therefore, there is considerable interest worldwide in finding ways toward cost-savings opportunities in transportation (Murphy, 2003), including making transportation operations more efficient with better planning. Moreover, fuel cost representing a significant proportion of transportation costs [e.g. roughly one-third in Canada (Michaelsen, 2012)], there are additional drivers to improve transportation efficiency such as volatile crude oil world markets, growing environmental concerns, reduction in fuel consumption and, in turn, greenhouse gases emissions. Other reasons are that truck drivers need more support as they work in larger and more unknown areas, truck fleets become more heterogeneous and industries require more customised and fresh wood assortments (defined by e.g. specie, dimension and quality).

Transportation planning in forestry operations involves many decisions commonly managed according to four time-perspective horizons: strategic (up to five years), tactical (six months to five years), operational (one to 180 days), and real-time (<one day) (Rönnqvist, 2003). We provide a summary of some of them but for a more exhaustive survey, we refer to Rönnqvist (2003), Epstein et al. (2007) and D'Amours et al. (2008).

Decisions at the strategic level are concerned with the construction/maintenance of transportation infrastructures (e.g. road, terminal) and the selection of transportation modes (e.g. deployment of train, ship or heavy-load truck multimodal system). Tactical decisions mainly address upgrading of the transportation infrastructures (e.g. road class or terminal storage-capacity increase) and the adjustment of the transportation equipment capacity and utilisation (e.g. number of wagons in the train route and train route frequency). Operational decisions deal with volume allocation from supply points to demand points, design of truck back-haulage tours, truck routing and scheduling of the transportation equipment/crew. Real-time decisions principally concern truck dispatching with the assignment of the next load (or more) to a truck as the transportation operations occur.

In this paper, we focus on one operational planning decision: how to determine the set of routes to be performed by a fleet of trucks to deliver timber from harvest areas (i.e. origin) to industries (i.e. destination). In the literature, this planning problem is known as the Vehicle Routing Problem (VRP). Since its introduction by Dantzig and Ramser (1959), VRP is one of the most important and well-studied combinatorial optimisation problems (Toth and Vigo, 2002). Each day a VRP is faced by thousands of public and private entities involved in the transportation of freight or people (Cordeau et al., 2007). VRP in timber transportation has been studied in many countries (e.g. Austria, Canada, Chile, Finland, New Zealand, Sweden and USA) and several computer-based planning methods have been proposed to solve it. Moreover, to allow timber transportation decision makers to benefit from these computer-based planning methods, decision support systems embedding solution methods have been developed and deployed in the industry.

The contribution of this paper is threefold. First, a general description of a VRP in timber transportation is proposed. This description is supported by the second contribution: a literature review of the solution methods for VRP in timber transportation and a summary of the main attributes of the VRP addressed in each method. Third, a literature review of decision support systems for VRP in timber transportation is presented.

The paper is organised as follows. Section 1 introduces the general description of VRP in timber transportation. Next, Section 2 provides a review of the planning methods for VRP in timber transportation as well as the main attributes of the VRP addressed in each method. A survey of decision support systems in timber transportation is presented in Section 3 with a discussion of some issues related to the implementation of planning methods and DSS in timber transportation. Finally, a conclusion is provided.

1. Description of the vehicle routing problem in timber transportation

The VRP in timber transportation is a variant of the *pick-up and delivery vehicle routing problem*, more commonly designated a *pick-up and delivery problem* (PDP). In a PDP, entities (e.g. commodities, disabled persons) have to be transported between origin and destination sites by a given fleet of vehicles. The PDP consists of constructing a set of vehicle routes according to a given objective and subject to a set of constraints. When time windows are used, the problem is called a VRP with Time Windows (VRPTW). Often when more general time constraints are considered in vehicle routing, the problem is usually called *vehicle scheduling* (or vehicle routing and scheduling) and the vehicle route is usually called *vehicle schedule*. For a survey of the models and solution methods for PDPs, we refer to Berbeglia et al. (2007) and Parragh et al. (2008); and for a survey of VRPs and their several variants such as the PDP, we refer to book chapters in Toth and Vigo (2002), Barnhart and Laporte (2007) and Golden et al. (2008).

The availability of information at planning time (Berbeglia et al., 2007) is an important dimension present in PDP. In *static* problems, all information is assumed to be known a priori, while in *dynamic* problems, information is revealed gradually and/or subject to change over time. Thus, a planning method for a dynamic PDP requires the possibility of adjusting the current solution as new and/or updated information is obtained. Nearly all papers in the literature on VRP in timber transportation address static PDPs, while Rönnqvist and Ryan (1995) and Rönnqvist et al. (1998) are exceptions by proposing a truck dispatching solution method for a dynamic PDP. In these papers, the information about the actual situation is released continuously. However, it is critical to be able to anticipate the future and make a full day plan that can be changed later. Routing is revised as soon as a new event such as delivery at mill, pickup at harvest area, revised supply or demand levels, etc. triggers a re-optimisation. A key component for such a system is to be able to re-optimise given a current partial solution. Also, the information handed back to the trucks is only information about the next trip in a dull route, as the route (except confirmed or trip under way) may change at any time.

Another distinction in PDPs is related to uncertainty of the available information at planning time. In *deterministic* problems, all the data are assumed to be known with certainty, while in *stochastic* problems some data (e.g. vehicle travel time or supply/demand levels) are random variables whose distributions are usually known (Berbeglia et al., 2007). Nearly all papers in the literature on VRP in timber transportation address deterministic problems while certain simulation-based planning methods include some stochastic data (e.g. McDonald et al. (2001a,b)).

In their classification scheme for PDPs, Berbeglia et al. (2007) differentiate three *structures* to describe the number of origins and destinations of the commodities involved in the PDP. The first is *many-to-many,* in which any site can serve as a source or as a destination for any commodity. The second is *one-to-many-to-one,* in which commodities are initially available at the depot (i.e. a site where the fleet of trucks is based) and are destined to the customers; in addition, commodities available to customers are destined to the depot. The third is *one-to-one,* in which a commodity has a given origin and a given destination. The papers in the literature on static PDPs in timber transportation can be classified into the first and the third structure depending on whether the supply and demand points are paired (i.e. *one-to-one*) or unpaired (i.e. *many-to-many*). This means that in the *many-to-many* structure, the PDP includes allocation decisions (i.e. which supply points satisfy which demand points in what volume of a given product) in addition to the truck routing decisions. With reference to both structures, we provide a general description of the main attributes defining PDP in timber transportation (see Section 2 for all the attributes encountered in each PDP reviewed). By involving several attributes and large-sized problems, VRP in timber transportation could be referred to as Rich VRPs (see e.g. Hartl et al., 2006).

In a PDP in timber transportation, a set of vehicle routes must be generated in order to deliver a set of *requests* (one-to-one structure) or to satisfy a set of *demand points* (many-to-many structure) according to a given objective (e.g. total minimum cost and/or total minimum empty driving distance) and subject to a set of constraints. A *request* specifies a volume, an assortment, the site where it is to be picked up (origin) and the site where it is to be delivered (destination). Time constraint(s) can be added onto a request (e.g. a latest delivery time or a time window when the pick-up must be made). A *demand point* is a location requiring specific volume in an assortment group (defined by one or several assortments). To satisfy the set of demand points, a set of *supply points* is available; each supply point is a location that can provide specific volume in an assortment. Both the origin/supply and destination/demand sites can be visited more than once. This is the typical situation as the volume available usually exceeds one truckload. On a planning horizon over a day, the entire demand can be divided into daily minimum and maximum accumulated volume, while the entire supply can be released into daily volume. This allows spreading out the deliveries/pick ups at a demand/supply site over the whole planning horizon and, for the latter, representing a daily production (e.g. by a harvest team) at supply site. Transportation priority can be put on e.g. certain urgent requests to deliver or critical supply/demand points to empty/fulfil.

To execute the transportation, a fleet of vehicles is available. This fleet of vehicles may consist of the same (homogenous) or different (heterogeneous) vehicle types, each with a unique set of transportation-relevant characteristics (e.g. capacity, set of assortments allowed to haul, fuel consumption, trucks with or without a crane, set of sites not allowed or impossible to visit). The vehicles are spread throughout a set of sites (multi-depot) or based in only one site (single depot). A route usually starts and ends at the vehicle's depot. For a planning horizon exceeding one day, the vehicle may be allowed to come back to the depot (or home base) not fully unloaded (i.e. stay loaded overnight), in which case the delivery must be performed the following day. Usually, no transshipments are allowed, i.e. a vehicle is not allowed to temporarily drop a volume and pick it up later, even if done by another vehicle. Multiple pickups may be necessary before the truck is full, which is the typical situation when the harvesting is finished and there is a need to clean off all piles, including some with less-than-truckload size. To fill-up the truck, some piles are subject to a partial pick-up and this complicates the planning process. Different approaches are used to deal with this; most are heuristic based.

A route must respect different time constraints such as vehicle's working hours availability (e.g. to disallow working at night), length of driver's work shift, time windows at supply/demand points, etc. More than one driver's work shift could be scheduled on a vehicle. The change of driver can be performed from among a set of predefined changes over sites or only at the truck's depot. Time windows at supply/demand points consist mainly of two forms: opening hours and on-site loader(s) operation hours. The first specifies the site's opening hours in which a vehicle can perform a pickup/delivery, while the second specifies the hours in which on-site loader(s) are available for (un)loading operations. Vehicle types without crane must be scheduled inside both time windows at any site while usually, vehicle type with a crane (i.e. self-loading) must be scheduled inside both time windows only at delivery site. Waiting time is generally allowed when a vehicle arrives before the beginning of a mandatory time window and waiting time for vehicle queuing can also be computed (e.g. when a vehicle waits for a loader already in use by another vehicle). Rather than specify predefined time windows for on-site loader(s) operation hours, the PDP can also include the scheduling of on-site loader(s). We refer to *multiple time windows* (as in Xu et al., 2003) to designate e.g. the site's daily opening hours that can change according to the day of the week. It is also possible to address queuing of trucks at mill gates, which is typical for large industries with several specialised production lines. In such a case, it is necessary to come up with a good queuing strategy in order to minimise the waiting time in the industry's yard as well as to minimise additional movements in the yard transportation from log-piles to productions lines. An approach based on revenue management principles has been tested in a Portuguese pulp and paper mill by Marques et al. (2012).

In summary, the main attributes that distinguish a PDP in timber transportation from a more general PDP are:

- the volume of the requests or at supply points is usually greater than a full truckload;
- involve mostly full truckload shipment but remaining less-than-truckload shipments can involve vehicle route with multiple pick-ups before the delivery;
- an origin/destination site or supply/demand point can be visited more than once on the same vehicle route;
- when allowed, driver changeover can be performed at different sites than the truck's depot only, allowing more flexibility for vehicle routing;
- except for self-loading vehicle at delivery site, vehicle routing considers the availability of on-site loader(s) and can include their scheduling;
- the volume at supply points is usually greater than the volume at demand points (applied only for many-to-many structure);
- involve allocation decisions, i.e. which supply points satisfy which demand points in what volume of a given assortment (applied only for many-to-many structure);

- product substitution: a demand point can be expressed as an assortment group allowing its fulfilment with different assortments (applied only for many-to-many structure);
- a demand point usually allows fulfilment flexibility on a planning horizon over a day (applied only for many-to-many structure).

To solve PDP in timber transportation, several planning methods have been proposed in the literature. In the next section, we review these solution methods as well as the main attributes of the PDP addressed by each method.

2. **Planning methods for static PDP in timber transportation**

Several planning methods of PDP in timber transportation have been proposed in the literature.

Table **1** provides an overview of the planning approach used in the reviewed papers. Each paper is discussed at the end of this section.

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Table 1 : Overview of the planning approach**.**

It is likely that the differences in the transportation context for each country/company explain why, among the reviewed papers, there is no standard definition of a PDP in timber transportation. Table 2 provides a summary of the main attributes of the PDP addressed in each paper reviewed. For each paper, the objective or truck assignment rule and the planning horizon of the solution method is given. Details on the attributes concerning the time windows, the request or supply/demand points (according to the one-to-one or many-to-many structure), the truck fleet and driver, the depot as well as the loader and operator are also given. The last column gives some statistics on the larger-sized problems that were solved and reported in the literature.

Please insert here: Table 2 : Main attributes of the PDP in each planning method.

Shen and Sessions (1989) propose a network-based method to generate a daily truck schedule that meets a mill delivery program with multiple time windows. The formulated capacitated network is solved with the primal-dual method out-of-kilter algorithm and the number of trucks and their routes are obtained from the solution to the LP formulation. We note that the problem is formulated as a network flow problem and the solution furnishes information on how many trucks are needed (given an assumption on full truckload and homogeneous truck type). The scheduling of individual trucks is determined in a second phase. Robinson (1994) also uses a network flow formulation and suggests a brand-and-bound procedure to solve it.

Linnainmaa et al. (1995) propose a three-phase method. First, based on both the distance between the supply and demands points and the relative volume size at a demand point, a heuristic allocates supply volume to demand points. Second, a set of not-detailed exact mathematical programming methods and heuristics are used to generate a preliminary solution (i.e. a weekly truck schedule). Third, for potential error correction or any other modification to the preliminary solution, a semi-manual post processing is performed by a transportation planner for the daily routes.

Weintraub et al. (1996) propose a simulation-based method with embedded heuristic rules that assigns, on a moving time horizon, one load at a time to available trucks and thus, generates a daily truck schedule. The simulation method accounts for vehicle queuing (i.e. waiting time) at supply and demand points but no improvement procedures are used to enhance the first solution found. This method also makes available the loading schedule for each loader. McDonald et al. (2001a,b) and Mendell et al. (2006) also propose a simulation-based method to generate daily route schedules for a fleet of trucks. In McDonald et al. (2001a,b), a system is studied where the trucks drop unloaded trailers at the supply sites and start with already loaded ones (or wait for a loaded one). Different heuristic rules were developed to find the more efficient one to assign trucks (with unloaded trailer) to supply sites and only the more efficient assignment rule is reported in Table 2. In Mendell et al. (2006), the heuristic rule assigning trucks to supply sites allows, when efficient to do so, a truck to stay loaded overnight to carry out a delivery the next day directly from the depot. These models do not require any explicit model as the heuristic can deal with any combinatorial aspects needed.

Palmgren et al. (2003, 2004) and Rey et al. (2009) propose a column generation method in which each column corresponds to one feasible route for a truck. These models are based on generalised set partitioning models or general column-based Mixed Integer Programming (MIP) models. In these models, the integer part comes from columns representing a particular route, and the continuous part from inventory levels, for example. The Integer Programming (IP) model by Rey et al. (2009) takes into account different types of truck. These column generation solution methods involve two main phases. The first phase consists in solving a linear relaxation of the IP or MIP model where new columns (routes) to insert are generated a priori using a heuristic (Palmgren et al., 2003) or dynamically by solving a constrained shortest path problem (Palmgren et al., 2004; Rey et al., 2009). The second phase consists in obtaining an integer solution by applying a specific branch-and-price procedure based on the columns generated.

Gronalt and Hirsch (2007) propose a Tabu Search (TS) method to generate a daily truck schedule to deliver a set of requests. With a regret heuristic, an initial solution is found and then improved using one of the specific TS strategies. A post-optimisation heuristic is used to find the last solution. The method is based on the *unified tabu search algorithm* (UTSA) for a general VRP with time windows proposed by Cordeau et al. (2001) and two modified TS strategies are introduced. In their two-phase method, Flisberg et al. (2009) also propose an extended version of the UTSA. In the first phase, the many-to-many structure of the initial PDP is transformed into a one-to-one structure by creating *transportation nodes* (i.e. comparable to a request with a maximal volume of one full truckload) with a two-phase procedure. First, an LP problem is solved to generate a destination solution given in flows. Second, a heuristic or a more general MIP model is used to generate full truckloads going between supply and demand points. This solution defines the transportation nodes. In the second phase, a heuristic generates an initial solution by assembling the transportation nodes in a set of routes and then the extended version of the UTSA is applied repeatedly until a stop criterion is reached. Flisberg et al. (2009) proposed one of the two planning methods (the other was proposed by Rummukainen et al., 2009) that support the consolidation of less-than-truckload (LTL) size requests in full (or nearly) truckload-size request. Indeed, during the creation of the transportation node, LTL-size requests with the same destination are, under some conditions, allowed to be included in one request of full (or nearly) truckload size.

Rummukainen et al. (2009) propose a three-phase method. In the first phase, a TS heuristic creates full (or nearly) truckload-size request by splitting large volume at supply point or by consolidating LTL-size request together. In the second phase, an MIP model allocates these truckloads to demand sites as determined by transportation costs minimisation, demand fulfilment and different organisational aspects. Thus, the many-to-many structure of the initial PDP is transformed into a one-to-one structure. In the third phase, a TS heuristic is used to generate the route and a dynamic programming algorithm is utilised to enhance their schedule and find any cost-effective opportunity to leave the crane of a (loaded) truck at a supply point. No instance is reported in Rummukainen et al. (2009) but according to Rummukainen (2012), the planning method is able to provide a solution for a fleet of 250 trucks supplying 100 demand sites from 10,000 ‘wood batches’, i.e. defined by a given quantity in a given assortment at a given location.

The greedy heuristic with a tabu component and Constraint Programming (CP) models proposed by Marrier et al. (2007) also deals with LTL-size requests but does not consolidate them in the first step of the planning method (as in Flisberg et al. (2009) and Rummukainen et al. (2009)). At each iteration, the volume from all available requests is assigned to a predefined or generated itinerary (i.e. a sequence of sites) from which only the best one (i.e. that provides the lowest cost per ton and kilometre) is scheduled with a CP model and kept in a solution base. Then, the volumes to deliver are updated before initialising a new iteration of the heuristic.

In their respective two-phase method, El Hachemi et al. (2009) and El Hachemi et al. (2011b) transform the many-to-many structure of their initial weekly PDP into a one-to-one structure of a daily PDP. In both methods, attention is given to the synchronisation of forest loaders and trucks arrival. In the first phase by El Hachemi et al. (2009), a local search algorithm enhanced with a tabu component determines the seven daily sets of requests that must be delivered to fulfil the daily demand points. In the first phase by El Hachemi et al. (2011b), the same task is performed through an MIP model solved on a standard optimisation solver. In the second phase by El Hachemi et al. (2009), a two-sequential stage heuristic is proposed. First, a local search algorithm enhanced with a tabu component improves the generated daily routes in the first phase. Then, a greedy heuristic schedules all (un)loading operations on each previous route. In the second phase by El Hachemi et al. (2011b), a constraint-based local search model is formulated and two solving approaches are proposed: an iterated local search algorithm and a hybrid algorithm combining previous iterated local search algorithm and CP. An earlier version of the method in El Hachemi et al. (2011b) is also presented in Gendreau et al. (2009).

El Hachemi et al. (2011a) propose a hybrid method based on a CP model and an IP model. In the generation of daily route schedules, the CP model is constrained to use specific numbers of deadhead trips (i.e. unloaded route segment between a pair of destination and origin sites) extracted from the solution of an IP model. The hybrid method accounts for waiting time of both trucks and loaders at supply sites. An earlier version of this method is presented in El Hachemi et al. (2008).

For two case studies, Murphy (2003) proposed two similar IP models that are solved with a standard optimisation solver and these models rely on an arc-based formulation of a VRP.

Hirsch (2011) proposes a three-phase method. In the first phase, an LP flow model is used for allocation decisions on a given (e.g. month) planning horizon. This model is the well-known *transportation model* in OR that could be modified to deal with the notions of assortment and assortment group (see e.g. Epstein et al., 2007). From the volume allocation, a number of requests are deduced. The second phase allocates each request to a specific day of the planning horizon, taking into account an even distribution of the workload among the carriers and the destination sites. Formulated as an LP model, this problem is designated as the Timber Transport Order Smoothing Problem and could be solved with a standard optimisation solver. The third phase addresses a daily PDP with a one-to-one structure. Based on Gronalt and Hirsch (2007), a TS method is proposed and two modified TS strategies are introduced.

Audy et al. (2011a) propose a three-phase method to solve a weekly small-size PDP. The first phase generates a large set of potential routes equivalent to one working shift of a driver. In the second phase, a set covering problem and then an MIP model are consecutively solved to select, from the previous large set, a subset of routes per truck that satisfies the weekly demand. In the last phase, this subset of routes is scheduled by solving, on a CP optimisation solver, a machine-job scheduling model where each route/loader is modelled as a job/machine.

McDonald et al. (2010) propose a simulated annealing method where each iteration consists of generating a new solution (by using one or several specified procedures to make modifications to the routes in a current solution), evaluating the new solution (using a multi-objectives function of four transportation metrics) and, subject to a certain probability, keeping the new solution (if there is an improvement compared to the previous one). New iterations are performed until no further improvement is found.

2.1. Discussion of reviewed planning methods

Growing interest in VRP in timber transportation can be observed in the research community. Indeed, since the mid-2000s there have been a number of publications that propose various planning approaches with a preference toward hybrid methods where the initial PDP is decomposed into sub-problems with, in some methods, different planning horizons. Also, these new approaches allow for the incorporation, in the solution methods, of additional operational constraints (see e.g. constraints discussed in Karanta et al., 2000) as well as additional business considerations (e.g. share of workload among the carriers, supply regions or destinations). Furthermore, in recent years, increasing concerns about truck waiting time (i.e. queuing) can be noted and therefore the development of solution methods for better coordination with the scheduling of the loading equipment.

By improving transportation efficiency, all reviewed solutions methods aim for the lowest transportation cost but use various objectives or truck assignment rules to attain it. Among the reviewed objectives and truck assignment rules, two contrasting goals can be identified: i) using available supply points, fulfilling the demand points at the lowest possible transportation cost versus ii) delivery of available requests at origin site at the lowest possible transportation cost. Furthermore, among the solutions methods, there may be large differences in the exact definition of the same objective, e.g. computing of one to several types of cost in the total transport cost minimisation objective. The objective is often based on several parts but different weights lump them together into one single objective. In many cases, no problems exist finding good weights as many are based on a dollar value as a basis. For example, fuel consumption can be converted into a dollar value. Also, working time where the salary or truck cost is known can be converted into a dollar value. We could continue with many similar examples. The problems appear when we consider fairness, for example. One issue appears when it becomes impossible to satisfy all demands. What is the penalty for missing this? Additional discussion with the industry is often required and moreover, it is critical that this should be established as it is very important to guarantee feasible solutions to the model. Another aspect to consider when supply exceeds demand is to avoid creaming of the supply points. If we do not take this into account, we will always use supplies that are closest and later the problem will appear as the average distance increases over time. One approach to avoid this is to require that the average transportation should remain the same.

Finally, the reviewed PDPs are closely linked to a studied country having its own transportation context. Table **3** differentiated a number of transportation figures/characteristics faced by the forest industry in countries from different parts of the world. For each country, the average hauling distance, the proportion of transportation cost on the operational procurement costs and the average truck's payload are given. The potential impact of the climate on the transportation activities is reported. The ownership of the road network as well as the need to build it is detailed. The largest-sized VRP reported in the literature is provided.

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Table 3 : Transportation figures/characteristics in some **countries**

3. Decision support systems for vehicle routing problem in timber transportation

How the transportation planning is done, by whom and to what level of detail vary significantly among companies (Rönnqvist et al., 2003). Some companies perform in-house transportation planning while others outsource it to transportation service providers (e.g. independent or associated carriers) or to logistics service providers (LSP). Relying on human expertise and information systems instead of physical assets such as trucks, LSP is a single point-of-contact integrated service provider for a company that coordinates, on her behalf, a set of asset-based transportation service providers (Selviaridis and Spring, 2007). For instance, Asset Forestry Logistics provides a transportation planning (and execution control) service for several forestry companies in New Zealand (Ludbrook, 2011). Typically, transportation from the harvest areas to the industries (i.e. customers) is the responsibility of the supplier but this responsibility may belong to customers (e.g. timber harvested from Polish public forest, Audy et al., 2012b). In summary, for truck routing/dispatching decisions, there is a gradient from a complete decentralisation approach (where each driver makes his own decision) to a complete centralisation approach (where one management entity makes the decision for the entire truck fleet).

Various fleet ownership structures can be found in the timber transportation industry. Mainly in the past, some forest companies operated their own private fleet but nowadays, large private fleets are less common. Some countries (e.g. France, Canada) have forest companies that maintain a limited internal fleet and complete their transportation needs with contracted carriers. One of the motivations for such a hybrid business strategy is to retain in-house knowledge of the operating costs and productivity of the equipment and thus be more aware of carriers' realities during contract negotiation (Audy et al., 2012b). In certain countries (e.g. central european countries), fleet ownership is highly fragmented among carriers operating one (usually, owner-operated truck) to a few trucks. In such a situation, forest companies will typically prefer to have a contract with a limited number of carriers (that will then sub-contract a portion of the volume to other carriers) or with a cooperative representing a number of independent carriers. In other countries (e.g. Southern US), each harvesting contractor typically owns a small fleet where each truck is assigned to serve one harvesting team (Audy et al., 2012b). Owner-operated trucks are used to fulfil punctual needs (e.g. under capacity in trucking).

Regardless of fleet ownership structures, there is a trend for transportation planning to become more centralised and for trucks to increase their working area (Epstein et al., 2007). Such a trend increases the relevance of computer-based planning methods: on larger and more complex transportation problems involved in centralised planning; they are more cost-effective than manual planning by a decision maker (DM). Thus, in order to allow DM in timber transportation to benefit from computer-based planning methods, decision support systems (DSS) embedding planning methods have been developed and deployed in the industry.

To the best of the authors' knowledge, the first mention of DSS in timber transportation is by Robinson (1994) who reports the development of a "mechanical [truck] despatching aid" in the 1960's by a New Zealand company that was still in use at the time of publication. In a literature review on DSS in the transportation domain, Zack (2010) reports two definitions of transportation DSS. The first definition gives a broader meaning to transportation DSS by including all computer-based tools supporting the decision-making processes in transportation. Thus, all information management systems, data analysis methods and spreadsheets applied to solve transportation decision problems can be designated as transportation DSSs according to this first definition. The timber transportation DDS reported in Emeyriat and Bigot (2006) falls into this first definition.

The second definition gives a narrower meaning to transportation DSS: it is "(…) an interactive computer-based system that supports the DM in solving a complex (…) transportation decision problem. (…) a [ideal] role of a 'computer-based assistant' that provides the DM specific transportation-focused information, enhances his/her knowledge of a certain transportation decision problem and amplifies the DM's skills in solving the considered transportation decision problems". In Section 3.5, we review a number of timber transportation DSSs that fall into the second definition.

Different benefits from efficiency improvement in the transportation operations, including potential/real cost-savings of 0.8-35%, are reported in the case studies/implementations with/of the planning methods and DSS reviewed. Despite such results, the adoption of computer-based planning methods and DSS by forest companies worldwide has been limited up to now, with one notable exception (i.e. mostly in Chile with DSSs ASICAM and ForesTruck, see Section 3.5 for details). Different issues related to their adoption are reported by Audy et al. (2011b), Kokenge (2011) and Rönnqvist (2012). We can find for instance: planning based on inaccurate/erroneous information, reliable communication, myopic planning, complexity of the set-up parameters that influence the planning method, sharing of sensitive information, trust between the transport stakeholders, opportunistic behaviour, software interoperability, paying for the DSS and sharing the savings. We will discuss some of them.

3.1. Data and communication standard

To have the capacity to work together, transportation actors must be able to define the transportation components according to standard. PapiNet (see http://www.papinet.org) and StanForD (see Marshall, 2007) are standards created to ensure efficient information exchange in some parts of the forest products industry. In timber transportation, we need to define the supply, demand, assortment, cost, etc. The supply needs to be given in volume (e.g. cubic meters) or weight (e.g. metric tons). It is preferable that the demand should be given in the same unit. However, in some applications this is neither possible nor the case. One example is for forest biomass where the supply is given in cubic metres but the demand in energy. In such cases, a conversion factor has to be given. Even if we use a volume-based measure for example, we also need to define if this is based on under bark, over bark or any other volume-based method. The selection depends on how the measurement is done, e.g. when a harvester is used, the production files from the harvester's computer can be used. In Sweden, there is a central forest organisation which deals with standards and how the measurement should be done. Moreover, as in other countries, this independent organisation also deals with the scaling of trucks in order to guarantee that correct information is used in the invoicing between organisations. Finally, to communicate the data, there are different standards depending on the availability and coverage of mobile networks.

3.2. Road network information accuracy

When solving a routing/dispatching problem, finding correct truck travelling distances and times is required. This can be done using company-specific road databases or a general one such as Google Maps web service and Microsoft MapPoint software. However, one problem is that the selection is often based on shortest or quickest distance (and/or duration) and these distances may not be the ones preferred by the truck drivers, as they also consider road quality, road classification, road ownership (e.g. toll road), etc. In Sweden, for example, the difference between a shortest distance and a preferred one was measured as high as 10% on average (Rönnqvist, 2012). In a practical planning situation, this must be dealt with.

To find the travelling distances and times, common road databases where the information is collected from several companies and organisations can also be utilised when they exist in the country concerned. An example is the Swedish road database NVDB that was jointly developed by the Swedish National Road Administration, the Central Office of the National Land Survey, the Swedish Association of Local Authorities, and the forest industry (Andersson et al., 2008). This database contains digital information of all Swedish roads, i.e. the state road network, the municipal road and street network, and private road networks. All roads, approximately over 500,000 km, are described geometrically, topologically, and with detailed information on each road segment. This includes road manager, road classification, road designation, height restrictions, load-bearing obstacles, surface material, width and traffic regulations. For transportation on forest roads, there are also special characteristics such as accessibility, turning radius, barriers, etc. and these characteristics are handled as an add-on to NVDB, thus creating the Forestry National Road Database (SNVDB). For any given user of a national road database, it is important that data should be up to date. This is handled through data registration at source, i.e. the road manager is responsible for supplying data within his/her fields of operation. This way, data are registered by a manager with knowledge of the conditions and continued updating can be ensured.

3.3. Solutions from the tactical planning level to the operational one

As in many planning problems, a solution needs to fit within a larger framework. In our case, it must fit with a tactical transportation planning problem (often an MIP model) typically providing aggregated solutions for the flow (i.e. allocation decisions), inventory and a sequence in how the harvest areas are harvested. Also, truck routing must typically satisfy a balanced supply and demand on a weekly/daily level.

3.4. New business models to foster transportation efficiencies

With a forest industry culture usually known to be conservative, we can expect that the most challenging issues will not be the technological ones but rather those related to organisational changes. Definition of new business models will be needed, especially when transportation efficiencies are achieved by collaboration (in e.g. Mendell et al., 2006; Marier et al., 2007; McDonald et al., 2010). A key aspect of these new business models consists in revising the transportation payment methods currently used by the industry that mostly do not foster the organisation of transportation efficiencies among the transportation actors. Enhanced payments methods providing all transportation actors with a fair and sustainable financial incentive to realise transportation efficiencies must be developed. Recently, a method has been proposed by Frisk et al. (2010) that involves sharing, as equally as possible in proportion, the cost-savings from two transportation efficiencies (i.e. back-haulage tours and wood volume exchanges) organised among collaborating forest companies. Another key aspect of these new business models is how to form the collaborating group. A network model determining the collaborating group is proposed by Audy et al. (2012a) and tests launching the group formation with different company(ies) show that very different results can be obtained.

3.5. Review of DSSs in timber transportation

This section reviews a number of DSSs in timber transportation. Table 4 reports some characteristics of the DSS and identifies which aforementioned planning decisions are addressed by the DSS: supply and demand points allocation (allocation), design of truck back-haulage tours (backhaul), truck routing (routing) or truck dispatching (dispatching). The DSS has a desktop or a web-based platform making the system accessible through an Internet connection (see Zahedi et al., 2008 for a review of web-based system). The system is designed to be used in a static mode (i.e. all planning is done a priori of the transportation activities) or in a dynamic mode (i.e. planning is gradually done/revised while the transportation activities are taking place). The solution of the DSS is expected to be used directly in an execution environment or utilised for further manual analysis (Rönnqvist, 2012). Finally, the DSS has been or not successfully implemented/used by a company.

Please insert here: Table 4 : Decision support system in VRP in timber transportation.

We divided the aforementioned DSSs into three groups and we discuss each of them.

The first group includes the DSSs named Åkarweb, FlowOpt and MaxTour. Even though these systems do not properly address truck routing/dispatching, we review them here because, in practice, the solution they provide (i.e. backhauling tours) is used by some DMs to support their manual truck routing/dispatching planning (Eriksson and Rönnqvist, 2003; Frisk, 2012; Lepage, 2012).

Åkarweb [combination of Swedish word ‘åkare’ for truck driver/owner and ‘web’] is a web-based system developed by a major Swedish forest company from 1999-2001. It computes, on a daily basis, all the best potential back-haulage tours combining two full truckloads within all the volumes under the management of a set of independent DMs. Thus, a back-haulage tour may involve two full truckloads within the volume of one DM or two. It then becomes up to the DMs to use them as a support in their further daily truck routing and to collaborate with other DMs on common routes. An analysis in the early years of the system use showed that, in practice, one-quarter of the potential cost-savings of 4% identified by Åkarweb was achieved (Frisk, 2012). The system is used by 50 DMs associated with the Swedish company and involves about 80 trucks (Andersson et al., 2008).

FlowOpt [combination of 'flow' to refer to a network flow model in Operational Research and 'opt' for optimisation] addresses the allocation decision of large supply areas (i.e. catchment areas) to demand points with the possibility of integrating transportation planning of the truck and train modes as well as by ship. Also, FlowOpt computes potential back-haulage tours with, in a case involving many companies, the cost-effective opportunities in wood volume exchanges between them. Case studies with two (Forsberg et al., 2005) and eight (Frisk et al., 2010) Swedish companies report savings of 5% and 12.8% respectively. The first version of the system was developed from 2002-2004 by the Forestry Research Institute of Sweden (Skogforsk). The DSS has been used in many case studies of Swedish and international forest companies (Flisberg et al., 2012) and, in particular, to update the whole transportation and logistics planning of a Swedish forest company after its supply areas were hit by a major storm (Broman et al., 2009). Furthermore, the system has recently been extended to address the procurement logistics of forest biomass (Flisberg et al., 2012) and won the EURO Excellence in Practice Award in 2012.

MaxTour [French acronym for 'Maximiser les Tournées' (Gingras, 2012)] is one of the planning methods in the FPInterface module within the forestry operations control platform FPSuite developed by FPInnovations (Lepage, 2012). This planning method was developed in partnership with researchers at HEC Montréal. Based on an adaptation of the well-known savings heuristic of Clarke and Wright (1964), MaxTour computes the potential in back-haulage tours within the volume of one or several types of products usually managed by distinct DM (e.g. round timber/bulk fibre delivered/shipped to/from a sawmill). About ten case studies with MaxTour have been done in Canadian companies and potential savings of between 2-7% have been identified (Marier et al., 2007). When several types of products are jointly planned, multi-products truck trailers (i.e. logs and bulk fibre trailers) are used in addition to classic (mono-product) truck trailers. By allowing the transportation of different types of products on the same truck trailer, multi-use truck trailer increases the number of possibilities in back-haulage tours and thus, additional cost savings can be realised. For example, Gingras et al. (2007) report an additional savings of 1.1% with the addition of multi-products truck trailer in the transportation of timber and bulk fibre in a large network of forests and mills of a Canadian company. Other case studies reporting benefits with the use of multi-use truck trailer can be found in e.g. Brown et al. (2003) and Michaelsen (2009).

The second group addresses truck routing decisions and includes the DSSs named ASICAM, EPO2/KUORMA, RuttOpt, VTM and ORTEC.

Since its development in the early 1990's, ASICAM (Spanish acronym from 'Asignador de Camiones') is utilised by several forest companies in Argentina, Brazil, Chile, South Africa, Uruguay and Venezuela (Epstein et al., 2007). The system was developed by researchers at the Universidad de Chile and received the Franz Edelman Award in 1998. The ASICAM system produces the daily working schedule for a fleet of more than 250 trucks and many loaders (Rey et al., 2009). Weintraub et al. (1996) and Epstein et al. (1999) report significant improvements due to system implementation in many forest companies, both quantitative (e.g. cost savings between 15-35%) and qualitative (e.g. better quality working environment for drivers and loader operators) results.

EPO2 is the routing planning module in EPO, a system developed in the early 1990's by a major Finnish forest company to cover the strategic to operational planning of its procurement activities. The EPO2 system produces the weekly (or shorter when an update is required) working schedule for a fleet of about 20 trucks managed by a regional transportation planner. No result is reported specifically for the EPO2 module but annual cost savings of several million US dollars have been estimated for the whole EPO system. An additional 5% savings is anticipated with KUORMA (Finnish word for 'load'), the second-generation system which replaced EPO in 2002 (Savola et al., 2004). The new routing planning module in KUORMA provides a few days' working schedule for the entire fleet (about 250 trucks) carrying for the forest company. For validation before its execution, this global solution is then separated into parts to be locally analysed by regional transportation planners (Rummukainen, 2012). The planning method within the routing module of EPO and KUORMA was developed by the VTT Technical Research Centre of Finland.

RuttOpt [combination of the Swedish word 'rutt' for route and 'opt' for optimisation] was developed from 2003-2007 by the Forestry Research Institute of Sweden and produces, over up to five days, the daily working schedule for a fleet of up to 110 trucks. Potential cost-savings of 0.8-38% are reported in several case studies conducted in Swedish forest companies. Cost savings of up to 9% are also reported in different scenario analyses (e.g. all demand points are open 24 hours/day). This system is currently used to assess the truck routing efficiency in an association of Swedish carriers. In this project, carriers can identify opportunities to exchange loads between them with a data access on their on-board computer to the loads recently delivered by their fellows (Lidén, 2011).

VTM (abbreviation of 'Virtual Transportation Manager') is designed to capture cost-effective opportunities in joint routing among several forest companies. To manage the confidentiality and standardisation issues raised by the inter-firm collaborations, the web-based system has three distinct roles of users, each with different responsibilities and functionalities/data access rights. The system was jointly developed from 2003-2007 by researchers at FORAC Research Consortium (Université Laval) and FPInnovations (formerly Forest Engineering Research Institute of Canada). A case study with six regional transport planners reports potential cost-savings of 7-10%. An improved version of the system is currently being tested in other Canadian case studies.

The company ORTEC provides decision support software solutions for different industrial sectors. A tailored version of their truck routing system was implemented by a large industrial timberland owner in the US Pacific Northwest. From 2005-2007, the system provided the daily working schedule for a fleet of up to 100 trucks and resulted in a loaded efficiency increase from approximately 40-65% (Kokenge, 2011). In 2009, a tailored version of the ORTEC routing system was also tested in a dynamic mode (instead of a static one) for truck dispatching among three contractors of a major industrial timberland owner in Southern US (McCary, 2009).

The third group addresses truck dispatching and includes the DSSs named CADIS, FLO/Blue Ox and ForesTruck. In truck dispatching DSS, one load at a time is typically assigned to a driver (e.g. when he/she completes a delivery) and, consequently, this requires a planning method with short resolution time. However, longer resolution time is possible by planning forthcoming assignments without communicating them to the driver and by updating them according to different triggers (e.g. change in the supply or demand levels).

CADIS (acronym from ‘Computer Aided Dispatch’) was developed from 1994-1996 for a New Zealand multinational corporation with forestry activities. The dispatching module was developed by researchers at the University of Auckland. The system was successfully tested with a fleet of more than 120 trucks and met all the requirements, especially regarding the short response time (e.g. a few seconds) to assign a new load. Due to confidentiality reasons, no quantitative result is reported but the solutions provided were of high quality and particularly useful when the overall supply was low (Rönnqvist, 2012).

Despite the limited information available on the competitive market of software solutions in forestry, FLO/Blue Ox and ForesTruck are likely to be the most advanced DSSs in timber truck dispatching.

FLO (abbreviation of 'Forest Logistics and Optimization') is the former Blue Ox system with a first version developed in 2009 by Trimble Forestry Automation. The system is mainly used by US forest companies and transportation contractors to manage fleets of 50 trucks on average but the system is able to manage fleets of several hundred trucks (Jacqmin, 2012). Different systems configurations, with their required hardware (e.g. truck or loader onboard computer), service (e.g. satellite communication) and functionalities (e.g. various types of report, other applications), are proposed for an implementation customised to user's requirements. Kokenge (2011) reports quantitative results in two pilot tests of the Blue Ox system (e.g. daily loaded mileage increase of 31%) and many benefits from real implementations are advertised by the system provider (e.g. truck fleet and mileage reductions, increase in number of deliveries per truck).

Forestruck is an information system for the operational planning, control and analysis of the entire wood supply chain activities, from wood production (sourcing) to delivery management at the destination sites (sales). Truck dispatching is one of the modules. The first version of ForesTruck was developed in 2006 by West Ingeniería Ltda. The system is used by Chilean forest companies to manage any size fleet subject to reach limits in technology capacities (e.g. hardware, Internet). Implementation of a similar system has been initiated in other industrial sectors, i.e. oil distribution. The system implementations provide cost-savings according to two main factors: increased productivity of the equipment and lower fees in administration and required system use (Soriano, 2012).

3.6. Discussion on reviewed DSSs in timber transportation

With a DSS designed to be used in a dynamic mode, DM obtains computer-based support to tackle the stochastic events intrinsic to timber transportation (e.g. mill reception closure, long queuing time, equipment breakage) and a trend toward ‘dynamic’ DSSs can now be perceived. Indeed, the last two DSSs developed have the dynamic mode and a version of the existing ASICAM has been redesigned for a dynamic mode rather than a static one (Weintraub, 2012). In the literature on VRP in timber transportation, there are only two publications on solution methods for dynamic PDPs (i.e. Rönnqvist and Ryan, 1995 and Rönnqvist et al., 1998) while “(…) in the last decade there has been an increasing body of research on dynamic VRPs” (Berbeglia et al., 2010, see also Pillac et al., 2011). To foster contributions from these latest developments to dynamic DSSs in timber transportation, solution methods for dynamic PDP in timber transportation are identified as future research opportunities.

In general, to be implemented the dynamic mode needs higher operational requirements than the static mode. For some forest companies and carriers, some of these requirements can raise issues and risks for technological and/or organisational change reasons. Therefore, regardless of this trend toward the dynamic mode, DSSs dedicated to a use in static mode are the preferred mode to implement for some companies and carriers. Afterwards, based on their experiences, some of them can move to the dynamic mode. In addition, static DSSs remain valuable to e.g. support analysis based on historical data. Training is another example: the solutions from a static DSS can regularly be compared to those planned by a DM (e.g. a driver making his/her own routing decision in a decentralised approach) to foster his/her planning skills development. Finally, a general comment for the systems not addressed in the research literature is that they are often based on heuristics for truck routing/dispatching.

Conclusion

In this paper, a general description of a VRP in timber transportation is proposed. This description is supported by a literature review of the solution methods for VRP in timber transportation and a summary of the main attributes of the VRP addressed in each method. To allow decision makers in timber transportation to benefit from computer-based planning methods, DSSs embedding solutions methods for VRP have been developed. A literature review of DSSs in timber transportation is presented. Moreover, we also discuss some issues related to the implementation of computer-based planning methods and DSS in timber transportation.

Recently, planning methods for VRP in timber transportation with foldable containers (Zazgornik et al., 2012) or forest fuel with potential in-field chipping operations (e.g. Acuna et al., 2011) have been proposed in the literature. The solution method for these VRPs involves additional attributes not addressed in the VRPs reviewed in this paper. In the forest industry other variants of VRP in timber transportation also exist that are seldom or not at all addressed in the literature, e.g. VRP involving bi/multi-modal system or merchandising yard. We hope this survey will stimulate further research in the area of VRP and DSS in timber transportation.

Acknowledgements

The authors would like to acknowledge the financial support of the private and public partners of the FORAC Research Consortium.

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Reference	**Planning approach**
Shen and Sessions (1989)	LP with the out-of-kilter algorithm
Robinson (1994)	LP with a branch-and-bound method
Linnainmaa et al. (1995)	Hybrid method with MP methods and heuristics
Weintraub et al. (1996)	Simulation
McDonald et al. (2001a)	Simulation
McDonald et al. (2001b)	Simulation
Murphy (2003)	IP
Palmgren et al. (2003)	Column generation
Palmgren et al. (2004)	Column generation
Mendell et al. (2006)	Simulation
Gronalt and Hirsch (2007)	Tabu search
Marier et al. (2007)	Hybrid method with CP and heuristics
El Hachemi et al. (2009)	Hybrid method with local search and an heuristic
Flisberg et al. (2009)	Hybrid method with LP/heuristic and tabu search
Rey et al. (2009)	Column generation
Rummukainen et al. (2009)	Hybrid method with MIP and tabu search
McDonald et al. (2010)	Simulated annealing
Audy et al. (2011a)	Hybrid method with IP, MIP and a CP
El Hachemi et al. (2011a)	Hybrid method with CP and IP
El Hachemi et al. (2011b)	Hybrid method with MIP, local search and CP
Hirsch (2011)	Hybrid method with LP, IP and tabu search
Legend : Constraint programming (CP); Integer programming (IP); Linear programming (LP); Mathematical programming (MP); Mixed integer programming (MIP)	

Table 1 : Overview of the planning approach.

Reference	**Objective or truck assignment rule**	**Planning horizon**	**Time windows**	**Request or supply**	**Request or demand**	**Truck fleet and driver**	**Depot**	**Loader and operator**	**Problem solved** (nb of SP/OS, nb of DP/DS, nb of trucks, nb of truckloads)
Many-to-many structure									
Shen and Sessions (1989)	MIN transport costs	Daily	MTM starting time per truck	Min-Max in truckload	Min-Max in truckload per MTM	HoF	SD; Route starts/ends at the depot	Loading rate per SP	Small example (5,1,29,-)
Robinson (1994)	MIN transport costs	Daily	Opening hours per SP/DP	Nb of truckloads in an assortment	Nb of truckloads in an assortment	HeF; Incompatibility between pairs of trucks and assortments; Route Max duration;	MD; Route starts/ends at the depot.		Generated instance (16,9,-,74)
Linnainmaa et al. (1995)	MIN travelling distances	≤Weekly	Opening hours per SP/DP; MTM for pickup/delivery per SP/DP	Volume in an assortment per MTM	Volume in an assortment per MTM	WS Max duration; Truck exclusivity at specific SP	MD		Field data (-,-,20,-)

Weintraub et al. (1996)	AT the most critical level of demand to fulfil and according to a multi-criteria desirability index (i.e. transportation and congestion costs and three different priorities)	Daily	Working hours availability per truck/loader; Opening hours per SP/DP	Volume in an assortment; Pickup priority on specific SP	Volume in an assortment, Delivery priority on specific DP	HeF; WS Max duration (short overtime is allowed); Lunch break; Similar revenue between the trucks of the same truck type; Incompatibility between pairs of truck types and SP/DP; Waiting time computed	MD; Route starts/ends at SP/DP the closest as possible to the depot	WS Max duration (short overtime is allowed); Lunch break; Service time per loader; Max nb of trucks per time period;	Field data (90,30,300,-)
Murphy (2003)	MIN transportation costs	≥1 day		Daily Min-Max in truckload in an assortment; A minimal nb of truckloads dedicated to specific DP	Daily Min-Max in truckload in an assortment	HoF; Max daily nb of truckloads per truck; WS/driving time Max duration per truck	MD; Route starts/ends at the depot	Max nb of trucks per SP at the first time period; Service time per SP/DP	Field data (4,13,18,82)
Palmgren et al. (2003)	MIN transportation costs	Daily	Opening hours per SP/DP	Volume in an assortment	Volume in an assortment	HoF, WS Max duration	MD; Route starts/ends at the depot		Field data (266,15,28,-)
Palmgren et al. (2004)	MIN transportation costs	Daily	Opening hours per SP/DP	Volume in an assortment	Volume in an assortment	HoF, WS Max duration; Breaks (e.g. lunch)	MD; Route starts/ends at the depot		Field data (187,15,28,-)

El Hachemi et al. (2009)	First phase: MIN transportation costs and the daily opening of SPs. Second phase: MIN costs of unproductive activities (i.e. empty travelling distance and truck/loader waiting time)	First phase: weekly; Second phase: daily		Min-Max daily interval of truckloads in an assortment	Daily nb of truckloads in an assortment; Daily inventory limit in an assortment per DP	HoF; Daily total working hours limit for the fleet; Waiting time computed	The daily route of a truck starts at the site where he ended the previous day	Only one loader allowed per SP/DP; Daily Min-Max WS duration; Waiting time computed	Field data (6,5,14,400)
Flisberg et al. (2009)	First and second phases: MIN transportation costs and penalty costs for unfulfilled demand	1-5 days	Opening hours per SP/DP; Loader working hours per SP	Volume in an assortment; Pickup bonus on specific SP	Daily Min-Max interval volume in an assortment group; Delivery bonus on specific DP	HeF, WS Max duration; Nb of WS per truck; Set of specific sites for driver changeover	MD; Route starts/ends at the depot	Type of truck with crane	Field data (665,113,110, ≥2531)
Rey et al. (2009)	MIN transportation costs	Daily		Volume in an assortment	Volume in an assortment	HeF, Incompatibility between pairs of truck types and assortments; WS Max duration		Only one loader allowed per SP	Generated instance (20,6,-,439)

Rummukainen et al. (2009)	First phase: MIN pick-up time of truckloads and various penalties; Second and third phases: MIN transportation costs and various penalties;	First and second phases: a few weeks; Third phase: a few days	Opening hours per SP/DP; MTM for pickup per SP; MTM for delivery per assortment per DP; MTM per truck for the driver changeover or rest period; MTM starting time per truck	Volume in an assortment; Min truckload to deliver per transportation region;	Daily Min-Max in truckload in an assortment and, for major DPs, per transportation region; Daily Min in nb of truckload deliveries;	HoF; Incompatibility between pairs of trucks and truckload/DP; WS Max duration; Penalties for uneven WS duration; Nb of WS per truck; Set of specific sites for driver changeover or rest period with potential duration; Disallow/allow loaded truck at driver changeover; Min workload per truck	MD with a set of alternative depots per truck; Route starts/ends in one of the depots of the truck	Specific SP requires the detachment of the trailer before reaching them; At an SP, cost-effective detachment of the crane of a truck is allowed; Min time between two consecutive trucks (un)loading;	No instance
Audy et al. (2011a)	First phase: n.a. Second phase: MIN travelling time; Third phase: MIN makespan	5 days		Nb of truckloads in an assortment	Nb of truckloads in an assortment	HoF; WS Max duration; Total Min working hours per truck; Waiting time computed	MD; Route starts/ends at the depot	One to several loader(s) allowed per SP/DP; Waiting time computed	Field data (14,4,34,909)

El Hachemi et al. (2011b)	First phase: MIN transportation costs; Second phase: MIN costs of unproductive activities (i.e. empty travelling distance and truck/loader waiting time)	First phase: weekly; Second phase: daily		Daily Min-Max in truckloads in an assortment; Daily Min in nb of truckloads to deliver per SP with on-duty loader	Daily nb of truckloads in an assortment; Daily inventory limit in an assortment per DP	HoF; WS Max duration; Waiting time computed	MD with a set of alternative depots per truck; Route starts/ends in one of the depots of the truck	AT one loader Max per SP/DP; Daily Min nb of trucks loading per loader; Max total nb of loaders; Waiting time computed	Field data (6,5,32,700)
Hirsch (2011)	First phase: MIN transportation costs; Second phase: MIN the variation in daily workload among the carriers/DPs; Third phase: MIN empty travelling distance	First phase and second phase: ≥weekly; Third phase: daily	Opening hours per SP; Working hours availability per truck;	Volume in an assortment	Volume in an assortment	HeF; Incompatibility between pairs of trucks and SP; WS Max duration;	MD; Route starts/ends at the depot; Service time per depot	Fix/random service time per SP/DP	Generated instance (-,3,80,250)
One-to-one structure									

McDonald et al. (2001a)	AT the OS a priori assigned	Daily		Nb of available requests per OS	Variable travelling time; Distinction between the truck and the trailer; Waiting time computed		Variable service time per DS; Loading capacity at DS also used by trucks outside the simulated fleet	Generated instance (5,3,30,-)
McDonald et al. (2001b)	AT the OS with the higher waiting time for a trailer	Daily (for 30 days)		Nb of available requests per OS (defined by a set of probabilities)	WS Max duration; Distinction between the truck and the trailer; Waiting time computed	MD; Route starts/ends at the depot	Loading capacity at DS also used by trucks outside the simulated fleet; Loading rate per OS; Variable service time at DS; WS Max duration;	Generated instance (10,3,75,-)
Mendell et al. (2006)	AT the closest OS with request available and subject to inventory preferences and time constraints	Daily (for 4 days)	Opening hours per DS; Loader working hours per DS	Daily nb of available requests per OS; Daily Max nb of requests per DS	WS Max duration; Truck allowed to be loaded overnight	MD; Route starts/ends at the depot	Max nb of trucks per time period	Field data (6,15,18,205)

Gronalt and Hirsch (2007)	MIN empty travelling distance	Daily	Opening hours per DS; Working hours availability per truck	Nb of requests to deliver	HeF; WS Max duration; Incompatibility between pairs of truck and pickup sites	MD; Route starts/ends at the depot;	Service time per request	Generated instance (≤30,4,10,30)
Marier et al. (2007)	MIN transportation costs	Two weeks	Opening hours per OS/DS; Loader working hours per OS/DS; Earliest/latest pickup/delivery time per request; MTM starting time per truck	Nb of requests to deliver	HeF; Nb of trucks per transportation region; WS Max duration; Waiting time computed	MD with one pseudo-depot per transportation region. Route ends at the first pickup site or starts/ends at the pseudo-depot when the first/last pickup/delivery sites are outside the transportation region of the truck	Type of truck with crane	Field data (50,8,-,-)
McDonald et al. (2010)	MIN travelling distance	Daily (for 6 days)	Working hours availability per truck	Nb of requests to deliver	WS Max duration; Waiting time computed	SD; Route starts/ends at the depot	Service time per OS/DS	Field data (5,9,17,257)

El Hachemi et al. (2011a)	MIN costs of unproductive activities (i.e. empty travelling distance and truck/loader waiting time)	Daily	Opening hours per DS	Nb of requests to deliver	HoF; WS Max duration; Waiting time computed	MD with a set of alternative depots per truck; Route starts/ends in one of the depots of the truck	Only one loader allowed per OS/DS; Waiting time computed	Field data (6,5,18,70)
Legend : Assignation to (AT); Destination site (DS); Demand point (DP); Field undefined (−); Heterogeneous fleet (HeF); Homogenous fleet (HoF); Maximum (Max); Minimisation (MIN); Minimum (Min); Multi depot (MD); Multiple time windows (MTM); Number (Nb); Origin site (OS); Single depot (SD); Supply point (SP); Working shift (WS);								

Table 2 : Main attributes of the PDP in each planning method.

	Country					
	South America	North America		Northern Europe	Central Europe	Oceania
Characteristics	Chile	Southern US	Canada	Sweden	Austria	New Zealand
Transportation proportion on operational procurement costs	≥45% (Weintraub, 2012)	25-35% (Greene, 2012)	36% (Michaelsen, 2012)	30-40% in Sweden (Anderson, 2012)	30% (Hirsch, 2012)	40% (Visser, 2012)
Average hauling distance	60-120 Km (Parada, 2012; Rodriguez, 2012)	130 Km (Greene, 2012)	145 Km (Michaelsen, 2012)	90 Km (Anderson, 2012)	50-90 Km for larger sawmills (Hirsch, 2012)	50-60 Km (Visser, 2012)
Average truck's payload	28-31 tons (Rodriguez, 2012)	26-28 tons (Greene, 2012)	38 tons but can go up to 165 tons for non-standard truck (Michaelsen, 2012)	37-42 tons (Anderson, 2012), tests with up to 60 tons	20-25 tons (Hirsch, 2012)	28-30 tons but can go up to 80 tons for non-standard truck (Visser, 2012)
Climate impact	Rainy season requiring better quality roads to maintain transportation	Rainy season with regional rainy episodes temporarily suspend transportation	Winter requiring snow removal and thawing period suspend transportation for 6-8 weeks	Winter requiring snow removal and thawing period suspend transportation 1-4 weeks	Rainy periods or heavy snowfall temporarily suspend transportation (Rauch, 2010)	Virtually no impact (Visser, 2012)
Forest road network	Mainly private	Essentially	Mainly	Public and	Mainly private	Essentially

ownership and construction	and already built (Rodriguez, 20120)	private and already built but almost all trucking is done on public road network (Greene, 2012) .	public and mainly to build	private, mostly already built but all companies can use all roads with a fee	and mainly already built (Hirsch, 2012)	private and already built but almost all trucking is done on public road network (Visser, 2012)
VRP largest size reported (nb of SP/OS, nb of DP/DS, nb of trucks, nb of truckloads)	(90,30,300,-) Weintraub et al. (1996)	(6,15,18,205) Mendell et al. (2006)	(14,4,34,909) Audy et al. (2011a)	(665,113,110, ≥2531) Flisberg et al. (2009)	(-,3,80,250) Hirsch (2011)	(4,13,18,82) (Murphy, 2003)
Legend : Destination site (DS); Demand point (DP); Field undefined (−);Number (Nb); Origin site (OS); Supply point (SP)						

Table 3 : Transportation figures/characteristics in some countries

	DSS (reference)										
	CADIS (Rönnqvist and Ryan, 1995; Rönnqvist, 2012)	EPO2 (Linnainmaa et al., 1995) and KUORMA (Savola et al., 2004 ; Rummukainen et al., 2009)	ASICAM (Weintraub et al., 1996)	Åkarweb (Eriksson and Rönnqvist, 2003)	FlowOpt (Forsberg et al., 2005)	MaxTour (Lepage, 2012)	VTM (Audy et al., 2007)	RuttOpt (Andersson et al., 2008)	Blue Ox and FLO (Jacqmin, 2012)	ORTEC (Kokenge, 2011)	ForesTruck (Soriano, 2012)
Planning decision(s)	dispatching	allocation and routing	routing	backhaul	allocation and backhaul	backhaul	routing	allocation and routing	allocation, routing or dispatching	allocation and routing	allocation and dispatching
Operation model	dynamic	static	static	static	static	static	static	static	dynamic or static	static	dynamic
Solution use	execution	execution but subject to analysis	execution	analysis	analysis	analysis	execution	execution	execution	execution	execution
Platform	desktop	desktop	desktop	web-based	desktop	desktop	web-based	desktop	desktop or web-based	n.a.	web-based
Implemented	yes	yes	yes	yes	yes	yes	no	no	yes	yes	yes

Table 4 : Decision support system in VRP in timber transportation.