JEAN-FRANÇOIS AUDY

INTER-FIRM COLLABORATION IN TRANSPORTATION

Thèse présentée
à la Faculté des études supérieures et postdoctorales de l'Université Laval
dans le cadre du programme de doctorat en génie mécanique
pour l'obtention du grade Philosophiae Doctor (Ph.D.)

DÉPARTEMENT DE GÉNIE MÉCANIQUE
FACULTÉ DES SCIENCES ET GÉNIE
UNIVERSITÉ LAVAL
QUÉBEC

2013

Résumé

Dans la littérature académique et professionnelle relative au transport de marchandise, il y a longtemps que les méthodes de planification avancées ont été identifiées comme un moyen de dégager des économies grâce à une efficacité accrue des opérations de transport. Plus récemment, la collaboration interentreprises dans la planification du transport a été étudiée comme une source de gain supplémentaire en efficacité et, par conséquent, une opportunité pour dégager de nouvelles économies pour les collaborateurs. Cependant, la mise en œuvre d'une collaboration interentreprises en transports soulève un certain nombre d'enjeux. Cette thèse aborde trois thèmes centraux de la collaboration interentreprises et démontre les contributions via des études de cas dans l'industrie forestière et du meuble. Premièrement, les moyens technologiques pour soutenir une collaboration en planification du transport sont étudiés. Un système d'aide à la décision supportant la collaboration en transport forestier est présenté. Deuxièmement, le partage entre les collaborateurs du coût commun en transport est étudié. Une méthode de répartition du coût de transport tenant compte de l'impact - l'augmentation du coût de transport - des exigences inégales entre des collaborateurs est proposée. Troisièmement, la création de groupes collaboratifs - des coalitions - dans un ensemble de collaborateurs potentiel est étudiée. Un modèle réseau pour la formation d'une coalition selon les intérêts d'un sous-ensemble de collaborateurs adoptant ou pas un comportement opportuniste est détaillé. De plus, pour soutenir l'étude des thèmes précédents, la thèse comprend deux revues de la littérature. Premièrement, une revue sur les méthodes de planification et les systèmes d'aide à la décision en transport forestier est présenté. Deuxièmement, à travers la proposition d'un cadre pour créer et gérer une collaboration en transport et, plus généralement en logistique, une revue de travaux sur le transport et la logistique collaborative est offerte.

Abstract

In the academic and professional literature on freight transportation, computer-based planning methods have a long time ago been identified as a means to achieve cost reduction through enhanced transportation operations efficiency. More recently, inter-firm collaboration in transportation planning has been investigated as a means to provide further gains in efficiency and, in turn, to achieve additional cost reduction for the collaborators. However, implementation of inter-firm collaboration in transportation raises a number of issues. This thesis addresses three central themes in inter-firm collaboration and exemplifies the contributions in case studies involving collaboration in furniture and forest transportation. First, technological means to enable collaboration in transportation planning are studied. Embedding a computer-based planning method for truck routing, a decision support system enabling collaborative transportation is presented. Second, sharing the common transportation cost among collaborators is studied. A cost allocation method taking into account the impact – an increase of the transportation cost – of uneven requirements among collaborators is proposed. Third, building collaborating groups (i.e. coalitions) among a set of potential collaborators is studied. A network model for coalition formation by a subset of self-interested collaborators adopting or not an opportunistic behaviour is detailed. Moreover, to support the study of the aforementioned themes, the thesis includes two literature reviews. First, a survey on planning methods and decision support systems for vehicle routing problem in forest transportation is presented. Second, through the proposition of a framework for building and managing collaboration in transportation and, more generally in logistics, a survey of works on collaborative transportation and logistics is given.

Acknowledgements

Firstly, I would like to sincerely thank my research director, Dr. Sophie D'Amours for her support, trust and openness to my projects-involvements initiatives, her enthusiastic sharing of a go-getter attitude and passion for the Production and Operations Management & Logistics & Supply Chain Management fields. Sophie, it has truly been a privilege. I also want to express my gratitude to my co-supervisor, Dr. Louis-Martin Rousseau, and to close collaborator Dr. Mikael Rönnqvist for their respective essential contributions to this research, their support and their constructive suggestions.

Secondly, I would like to thank the graduate students - in particular colleagues from the 3516 laboratory and "L'Agence" - professors, research professionals and administrative staff associated with the FORAC Research Consortium, CIRRELT and the Department, for the privilege of being able to perform my research within a dynamic, professional and multidisciplinary context. For having been the 'impetus' for my first contact with the newborn FORAC Research Consortium, I want to thank Dr. Denis Brière, at that time Dean of the Faculty of Forestry and Geomatics, Université Laval. For the valuable exchanges, a special thanks to international researchers met/contacted during this research, especially Alexandra Marques (Universidade Técnica de Lisboa) and late Bertil Lidén (Skogforsk), a sincerely appreciated and conscientious Swedish researcher and collaborator.

Thirdly, for their contributions to this research, I especially want to recognize the help and assistance of certain persons and organizations:

First article: the eighteen persons cited as personal communication, i.e. Gert Andersson, Frédéric Boutin, Mark Brown, Mikael Frisk, Catherine Gingras, Dale Greene, Patrick Hirsch, Frédéric Jacqmin, Dave Lepage, Bertil Lidén, Matt Ludbrook, Jan Michaelsen, Claudio Parada, Jaime Rodriguez, Hannu Rummukainen, Hector Soriano, Rien Visser and Andres Weintraub.

Third article: Alain Rousseau, Benaissa Charrouf, Jonathan Gaudreault, Line Simoneau and Philippe Marier (FORAC Research Consortium); Eugene Gagné and Pierre Courtemanche (Groupe Transforêt); Jan Michaelsen and Jean Favreau (FPInnovations).

Fourth article: Alain Pomerleau (AP Industrie); André Gagné et Denis Provençal (Amisco); Charles Doucet and Jean-François Michaud (Quebec Furniture Manufacturers' Association); Jean-Charles Lacasse et Jean-François Mercier (Meubles Laurier); Johanne Poulin et Noël Gingras (Le Meuble Villageois); Philippe Marier (FORAC Research Consortium).

Fifth article: Forestry Research Institute of Sweden (Skogforsk); Philippe Marier (FORAC Research Consortium).

Fourth, I would like to acknowledge the essential financial support of the private and public partners of the FORAC Research Consortium as well as a number of scholarships: Bourse d'Excellence de rédaction au doctorat 2010 (CIRRELT); Bourse Programme de stages internationaux 2010 (Fonds québécois de la recherche sur la nature et les technologies); Bourse Coopération Montréal-Québec 2008 & 2009 (CIRRELT); Bourse Canadien National au doctorat 2006 (Université Laval).

Fifth, I would like to thank Dr. Reino Pulkki and Dr. André Thomas for consenting to be jury members for the evaluation of this thesis as well as Dr. Jacques Renaud for his participation in the admission exam of this PhD program.

Last but far from least, I am particularly grateful to my wonderful spouse and my family for their support during these years.

Montréal, September 2012

Jean-François Audy

Foreword

This thesis was supervised by my director, Professor Sophie D'Amours (Université Laval), and partially by my co-director, Professor Louis-Martin Rousseau (École Polytechnique de Montréal), and by Professor Mikael Rönnqvist (formerly at Norwegian School of Economics and Business Administration and now at Université Laval). The research was conducted within the FORAC Research Consortium and the Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT), formerly the Network Organization Technology Research Centre (CENTOR).

This thesis has been written according to the article insertion principle. The main contributions of this thesis include five articles of which I am the principal author. Two of them are literature reviews and, for chronological purposes, they are introduced first in the thesis. In four of the five articles, I acted as the leading researcher and the co-authors reviewed the draft of the articles until the final version was submitted/accepted for publication. In the second article, all the co-authors, mainly Dr. Nadia Lehoux, participated in the writing of the draft.

The first article "Planning methods and decision support systems in vehicle routing problems for timber transportation: a review" is co-signed by Drs. D'Amours and Rönnqvist and was submitted in September 2012 to the European Journal of Operational Research. The version inserted in this thesis is virtually identical to the submitted one which can be found in Research Paper CIRRELT-2012-38.

The second article "A framework for an efficient implementation of logistics collaborations" is co-signed by Drs. Lehoux, D'Amours and Rönnqvist, and was published in International Transactions in Operational Research, 19(5): 633-657, 2012. The version inserted in this thesis is virtually identical to the published one while the submitted one is found in Research Paper CIRRELT-2010-24. The article is partially based on the following conference proceedings:

- Audy, J.-F., D’Amours, S., Lehoux, N., Rönnqvist, M., 2009. A review on collaborative logistics. International Conference on Industrial Engineering and Systems Management, May 13-15, Montreal, Canada.

- Lehoux, N., Audy, J.-F., D’Amours, S., Rönnqvist, M., 2009. Issues and experiences in logistics collaboration. In: Camarinha-Matos, L., Paraskakis, I., Afsarmanesh, H., eds. IFIP International Federation for Information Processing, Volume 307, Leveraging Knowledge for Innovation in Collaborative Networks. 10th IFIP Working Conference on Virtual Enterprises, October 7-9, Thessaloniki, Greece. 69-77.

- Audy, J.-F., D’Amours, S., Lehoux, N., Rönnqvist, M., 2010. Generic mechanisms for coordinating operations and sharing financial benefits in collaborative logistics. In: Camarinha-Matos, L., Boucher, X., Afsarmanesh, H., eds. IFIP, Volume 336, Collaborative Networks for a Sustainable World. 11th IFIP Working Conference on Virtual Enterprises, Saint-Étienne, France. 537-544.

The third article “Virtual Transportation Manager: A decision support system for collaborative forest transportation” is co-signed by Drs. D’Amours and Rousseau and will be submitted shortly. The reported work contributed to a joint research project between FORAC Research Consortium (Université Laval) and FPInnovations (formerly Forest Engineering Research Institute of Canada), and was conducted with the cooperation of a number of Canadian forest companies, in particular the company Groupe Transforêt. The article is partially based on the following conference proceedings in which I acted as the leading researcher:

- Audy, J.-F., D’Amours, S., Rousseau, L.-M., 2007. Collaborative planning in a log truck pickup and delivery problem. In: Bierlaire, M., Mirchandani, P., Nielsen, O.A., Savelsbergh, M., eds. 6th Triennial Symposium on Transportation Analysis, June 10-15, Phuket Island, Thailand.

- Marier, P., Audy, J.-F., Gingras, C., D’Amours, S., 2007. Collaborative wood transportation with the Virtual Transportation Manager. In: Blanchet, P., ed. International

Scientific Conference on Hardwood Processing, September 24-26, Quebec City, Canada. 191-198.

- Audy, J.-F., D'Amours, S., Rousseau, L.-M., Favreau, J., Marier, P., 2007. Virtual transportation manager: a web-based system for transportation optimization in a network of business units. In: Gingras, J.-F., ed. 3rd Forest Engineering Conference, October 1-4, Mont-Tremblant. Canada. *This proceeding won the Council on Forest Engineering Student Communication Award 2007*.

- Audy, J.-F., Lidén, B., Favreau, J., 2011. Issues and solutions for implementing operational decision support system – An application in timber truck routing system. In: Ackerman, P., Ham, H., Gleasure, E., eds. 4th Forest Engineering Conference, April 5-7, White River, South Africa. Stellenbosch University, 94-97.

The fourth article "Cost allocation in the establishment of a collaborative transportation agreement – An application in the furniture industry" is co-signed by Drs. D'Amours and Rousseau and was published in the Journal of the Operational Research Society, 62(6): 960-970, 2011. The version inserted in this thesis is virtually identical to the published one while the submitted one is found in Research Paper CIRRELT-2008-50. This article was a finalist for the Young Research Award 2010 of the International Transport Forum. The reported work contributed to two research mandates from the Quebec Furniture Manufacturers' Association (QFMA) and, was conducted with the cooperation of the QFMQ and four furniture companies: Amisco, AP Industrie, Le Meuble Villageois and Meubles Laurier. The article is partially based on the following conference proceedings in which I acted as the leading researcher:

- Audy, J.-F., D'Amours, S., 2008. Impact of benefit sharing among companies in the implantation of a collaborative transportation system – An application in the furniture industry. In: Camarinha-Matos, L., Picard, W., eds. IFIP International Federation for Information Processing, Volume 283, Pervasive Collaborative Networks, 9th IFIP Working Conference on Virtual Enterprises, September 8-10, Poznań, Poland. 519-532.

The fifth article "An empirical study on coalition formation and cost/savings allocation" is co-signed by Drs. D'Amours and Rönnqvist and was published in International Journal Production Economics, 136(1): 13-27, 2012. The version inserted in this thesis is virtually identical to the one published while the submitted one is found in Research Paper CIRRELT-2009-26. The article is partially based on the following conference proceedings in which I acted as the leading researcher:

- Audy, J.-F., D'Amours, S., Rönnqvist, M., 2006. Business models for collaborative planning in transportation: an application to wood products. In: Maula, M., Hannula, M., Seppä, M., Tommila, J., eds. International Conference on Electronic Business and Research Forum to Understand Business in Knowledge Society, November 28 – December 2, Tampere, Finland. 533-539.

- Audy, J.-F., D'Amours, S., Rönnqvist, M., 2007. Business models for collaborative planning in transportation: an application to wood products. In: Camarinha-Matos, L., Afsarmanesh, H., Novais, P., Analide, C., eds. IFIP International Federation for Information Processing, Volume 243, Establishing the Foundation of Collaborative Networks. 8th IFIP Working Conference on Virtual Enterprises, September 10-12, Guimarães, Portugal. 667-676.

To innovators

« *Your brain may give birth to any technology, but other brains will decide whether the technology thrives. The number of possible technologies is infinite, and only a few pass this test of affinity with human nature.* »

Robert Wright, *Nonzero: The Logic of Human Destiny*

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1 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 (Visser, 2012) and ≥45% in Chile (Weintraub, 2012)]. With an average of 155 million cubic metres harvested annually from 2005-2010 (CCFM, 2012), transportation represents an expense of at least two billion Canadian dollars a year for Canadian forest companies. Further expenses also have to be considered for transportation downstream in the value creation network of the forest products industry, i.e. from wood fibre flow between industries to the finished wood products deliveries to worldwide markets.

With all this money spent on forest transportation, even a small cost reduction can lead to substantial savings (Palmgren et al., 2004). Therefore, there is considerable interest worldwide in finding cost-savings opportunities in forest transportation (Murphy, 2003), including making transportation operations more efficient with enhanced planning through computer-based planning methods. Different benefits, including potential/real cost-savings of 0.8-35%, from computer-based planning methods in forest transportation have already been reported in several countries such as Chile, Finland, New Zealand, Sweden and US. Fuel cost representing a significant proportion of transportation costs [e.g. roughly one-third in Canada (Michaelsen, 2012)], volatile crude oil world markets and growing environmental concerns (i.e. greenhouse gases emissions reduction) are also drivers to improve transportation efficiency. Other reasons fostering computer-based planning methods include the facts that transportation decision makers need more support as they work in larger and more unknown areas, truck fleets have become more heterogeneous and industries require more customized and fresh wood assortments (defined by e.g. species, dimension and quality).

Recently in Canada, a number of research initiatives have been devoted to computer-based planning methods in forest transportation (see e.g. Gingras et al., 2007; El Hachemi et al., 2009, 2011, 2013; Rix et al., 2011) and other research initiatives are ongoing (see e.g. projects associated to NSERC Strategic Research Network on Value Chain Optimization).

These research initiatives have contributed (and will continue to do so) to a number of initiatives outside the academic domain. For instance, during recent years, a number of analyses with the planning method by Gingras et al. (2007) have been conducted on historical transportation data of Canadian forest companies and, in the six most exhaustive cases, potential cost savings (travelling time reduction) between 4-7% (5-9%) have been identified (Lepage, 2012). Overall, these initiatives report significant potential benefits – including cost-savings – as well as a notable level of interest and openness by the industry to improve efficiency of forest transportation with computer-based planning methods.

In the academic and professional literature on freight transportation, inter-firm collaboration in transportation planning has been investiguated as a way to gain efficiency in transportation operations and, in turn, provide benefits – including cost-savings – to the collaborators. We refer interested readers to e.g. le Blanc et al. (2007), Cruijssen et al. (2007b), Ergun et al. (2007), Özener and Ergun (2008), Krajewska et al. (2007), Clifton et al. (2008) and Dai and Chen (2012). Case studies with inter-firm collaboration in transportation planning have also been conducted in the forest products industry, see e.g. Forsberg et al. (2005), Palander and Väätäinen (2005), Lehoux et al. (2009), Marier et al. (2009) and Frisk et al. (2010). What is highly interesting is that a substantial part of the reported benefits come directly from the collaboration and not from gains in efficiency identified by the computer-based planning method. For instance, in the case studies by Marier et al. (2009) and by Lehoux et al. (2009), collaboration accounts for a proportion of 23.8% and 61.3% of the total cost reduction obtained by the computer-based planning method, respectively.

Therefore, inter-firm collaboration in transportation planning represents an opportunity for substantial additional benefits. However, implementation of an inter-firm collaboration raises a number of issues. Three central themes in inter-firm collaboration are addressed in this thesis written according to the article insertion principle. Each theme is addressed in a separate article (articles #3-5) and contributions are exemplified in distinct case studies involving collaboration in timber and furniture transportation. Moreover, articles #3-5 are supported by a literature review divided into two articles (articles #1-2). Figure 1 illustrates the organization of the articles presented in this thesis. For chronological purposes, the review articles are introduced first in the thesis. Each article presented in Sections 2-6 is introduced below. Section 7 concludes the thesis with a summary of the main contributions of each article included and a discussion of further research directions.

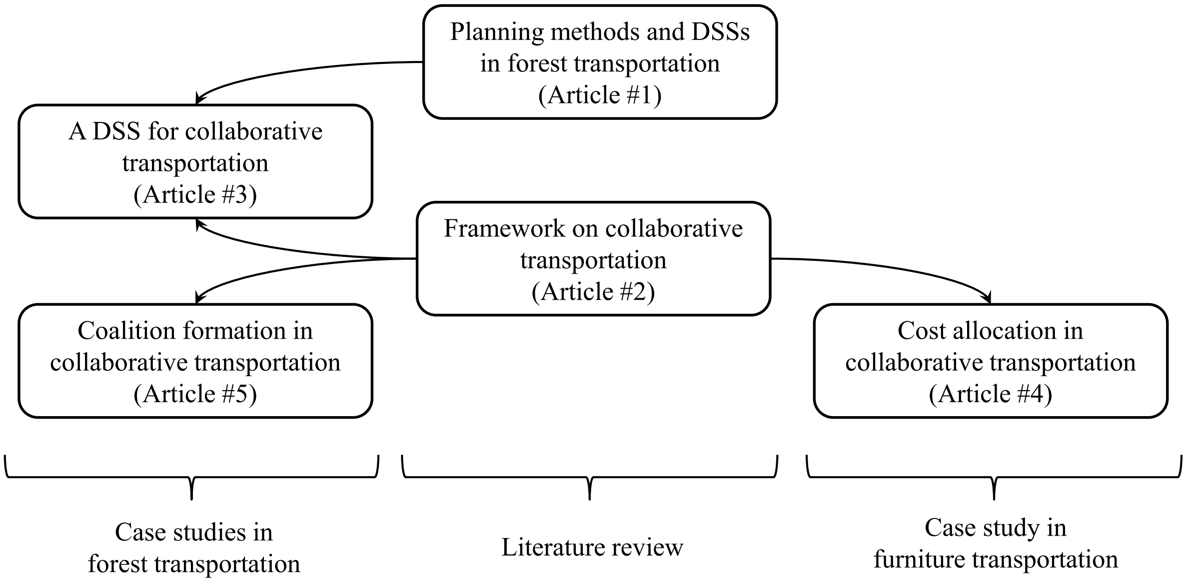

Figure 1 : Organization of the paper-based thesis.

The first article (Section 2) presents a literature review on two central subjects in the third article. First, a survey of planning methods for vehicle routing problem (VRP): the planning of the set of routes to be taken by a fleet of trucks to deliver timber from harvest areas to industries. Second, a survey on decision support systems (DSS) for VRP in timber transportation.

The second article (Section 3) proposes a framework for building and managing collaboration in transportation, and more generally in logistics. Based on a literature review of works in collaborative transportation and logistics, the framework surveys a number of central and peripheral themes discussed in the three following articles.

The third article (Section 4) presents a DSS for forest truck routing that is specifically designed to address collaborative transportation of different product types while respecting data confidentiality and standards. The main components of the system are described as well as how transportation collaboration is organized with the system. Also, through the presentation of an industrial case study in which system usage is illustrated and numerical results reported, a computer-based planning method is proposed to solve a detailed VRP in forest transportation.

The fourth article (Section 5) proposes a cost allocation method that is specifically designed for collaborative transportation. The method accounts for a minimum bottom-line cost-savings percentage for all collaborators, the presence of non-transferable costs and the impact (i.e. additional cost) of uneven requirements among the collaborators. Through the presentation of a case study, the method is validated and some sensitivity analyses are performed.

The fifth article (Section 6) proposes a network model for the formation of coalition(s) in collaborative transportation. In the model, a coalition is sequentially built by recruiting one collaborator at a time and according to the self-interested objective of a subset of the potential collaborators. This subset of leading collaborators can adopt or not an opportunistic behaviour in the sharing of the savings. The model is tested in a case study with different subsets of leading collaborators and results show that different solution characteristics can be achieved.

(Aforementioned references are after Section 7)

2 Literature review on planning methods and decision support systems in forest transportation

This chapter presents the article entitled "Planning methods and decision support systems in vehicle routing problems for timber transportation: A review" which was submitted in September 2012 to the European Journal of Operational Research. Here is an abstract of the article in French.

2.1 Résumé

Les opérations de transport représentent une partie importante du coût d'approvisionnement en bois. Par conséquent, la réduction des coûts de transport grâce à une efficacité accrue de ces opérations a incité un effort de recherche considérable dans plusieurs pays. Une partie substantielle de la recherche a été consacrée au problème de routage de véhicules, à savoir la planification des itinéraires d'une flotte de camions pour la livraison du bois des parterres de récolte aux industries. Ceci constitue la partie opérationnelle de la planification du transport et c'est sur cette partie que nous nous concentrons. Nous passons en revue les méthodes de planification et les systèmes d'aide à la décision consacrés au problème de routage de véhicules pour le transport du bois. De plus, basée sur un résumé des principaux attributs rencontrés dans chaque méthode proposée et/ou mis en œuvre, une description générale de ce problème est proposée.

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 devoted 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

2.2 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 (Visser, 2012) and ≥45% in Chile (Weintraub, 2012)]. Annually, this adds up to more than two 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. Fuel cost representing a significant proportion of transportation costs [e.g. roughly one-third in Canada (Michaelsen, 2012)], volatile crude oil world markets and growing environmental concerns (i.e. greenhouse gases emissions reduction) are also drivers to improve transportation efficiency. Other reasons fostering computer-based planning methods are that transportation decision makers need more support as they work in larger and more unknown areas, truck fleets become more heterogeneous and industries require more customized and fresh wood assortments (defined by e.g. species, dimension and quality).

Transportation planning in forestry operations involves many decisions commonly managed according to four time-perspective horizons [i.e. strategic (up to five years), tactical (six months to one year), operational (one to 180 days), and real-time (<one day)] where the exact planning horizons used by transportation decision makers are related to their context. 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 of transportation infrastructures (e.g. primary road network, terminal) and the selection of transportation modes (e.g. deployment of train, ship or heavy-load truck multimodal system with associated acquiring of transportation equipment). 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 aggregated utilization level (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 optimization 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 US) 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 organized as follows. Section 2.3 introduces the general description of VRP in timber transportation. Next, Section 2.4 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 2.5 with a discussion of some issues related to the implementation of planning methods and DSS in timber transportation. Finally, a conclusion is provided.

2.3 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. trigger a re-optimization. A key component for such a system is to be able to quickly re-optimize given a current partial solution. Also, the information handed back to each truck's driver is usually only information about their next trip, as their expected planned route may change after a re-optimization.

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 2.4 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 a 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 a 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 longer than 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 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 and most are heuristic based.

A route must respect different time constraints such as a vehicle's potential working hours (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. Of course, vehicle types without a crane (i.e. not self-loading) must be scheduled inside both time windows. Truck waiting time is usually allowed, e.g. when a vehicle arrives before the beginning of a mandatory time window or for queuing of trucks on a site. 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). As named by Xu et al. (2003), we refer to *multiple time windows* to designate the site's daily opening hours that can change according to the day of the week. PDP can also address queuing of trucks at mill gates, which is typical for large industries with several specialized production lines. In such a case, it is necessary to come up with a good queuing strategy in order to minimize the waiting time at the millyard as well as to minimize additional movements in the millyard transportation from log-piles to production lines. An approach based on revenue management principles has been tested at 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;

- it involves mostly full truckload shipments 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 vehicles, vehicle routing considers the availability of on-site loader(s) and can include their scheduling;

- the total volume at all supply points is usually greater than the total volume at all demand points (applied only for many-to-many structure);

- it involves 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);

- it is possible to allow product substitution, i.e. 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.

2.4 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.

Table 1 : Overview of the main planning approaches.

Reference	**Main planning approach**
Shen and Sessions (1989)	Network LP with the out-of-kilter algorithm
Robinson (1994)	DP and branch-and-bound method
Linnainmaa et al. (1995)	Hybrid method with exact 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. (2011)	Hybrid method with CP and IP
El Hachemi et al. (2013)	Hybrid method with MIP, local search and CP
Hirsch (2011)	Hybrid method with LP, IP and tabu search
Legend : Constraint programming (CP); Dynamic programming (DP); Integer programming (IP); Linear programming (LP); Mixed integer programming (MIP)	

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.

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

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	MTW starting time per truck	Min-Max in truckload	Min-Max in truckload per MTW	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; MTW for pickup/delivery per SP/DP	Volume in an assortment per MTW	Volume in an assortment per MTW	WS Max duration; Truck exclusivity at specific SP	MD		Field data (-,-,20,-)

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)**
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 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,-)

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)**
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)

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)
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; MTW for pickup per SP; MTW for delivery per assortment per DP; MTW per truck for the driver changeover or rest period; MTW 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)

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)
El Hachemi et al. (2013)	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 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									

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)
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)

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)**
Gronalt and Hirsch (2007)	MIN empty travelling distance	Daily	Opening hours per DS; Working hours 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; MTW 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 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)

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)**
El Hachemi et al. (2011)	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 : Assigned 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 (MTW); Number (Nb); Origin site (OS); Single depot (SD); Supply point (SP); Working shift (WS);									

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 provides 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 branch-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 exact mathematical programming methods and heuristics (not-detailed by the authors) is 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 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 generalized 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. The Integer Programming (IP) model by Rey et al. (2009) takes into account different types of trucks. 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-optimization 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-step procedure. In the first step, an LP problem is solved to generate a destination solution given in flows. Then in the second step, a heuristic or a more general MIP model is used to generate full truckloads going between supply and demand points and these full truckloads define aformentioned transportation nodes. In the second phase of Flisberg et al. (2009) method, 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 requests by splitting a large volume at a supply point or by consolidating LTL-size requests together. In the second phase, an MIP model allocates these truckloads to demand sites as determined by transportation costs minimization, demand fulfilment and different organizational 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 utilized to enhance their schedule and find any cost-effective opportunity to leave the crane of a (loaded) truck at a supply point. No instance of solved problems 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' 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 Marier 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 tonne and kilometre) is scheduled with a CP model and kept in a solution base. Then, the volumes to deliver are updated before initializing a new iteration of the heuristic.

In their respective two-phase method, El Hachemi et al. (2009) and El Hachemi et al. (2013) 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 synchronization of forest loaders and truck arrivals. 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. (2013), the same task is performed through an MIP model solved on a standard optimization solver. In the second phase by El Hachemi et al. (2009), a two-step procedure is proposed. In the first step, a local search algorithm enhanced with a tabu component improves the generated daily routes in the first phase. Then in the second step, a greedy heuristic schedules all (un)loading operations on each previous route. In the second phase by El Hachemi et al. (2013), 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. (2013) is also presented in Gendreau et al. (2009).

El Hachemi et al. (2011) 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 optimization 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 optimization 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 optimization solver, a machine-job scheduling model where each loader/route is modelled as a machine/job.

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.

2.4.1 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. The planning horizon for a VRP is typically one day. When the industrial demand is given for one week, the planning of the VRP is typically done sequentially (in an heuristic approach) for each day in a rolling horizon to capture the full week. There are also a few approaches which integrate all days. In these optimal approaches, the model size increases considerably and special care must also be used to control a more flexible demand per day. Moreover, 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 queuing can be noted and therefore the development of solution methods for better coordination with the scheduling of the loading equipment. An approach combining optimization and simulation to anticipate *a priori* truck queuing problem (as well as any problems caused by the stochastic events intrinsic to forest transportation) with the real-life execution of a routing plan has recently been proposed by Marques et al. (2013). Tested on wood yard operations at a Portuguese paper mill, this “optimization for simulation” approach uses optimization to generate candidate solutions for the simulation engine, where these solutions are properly assessed and an optimal or near optimal solution is reached.

By improving transportation efficiency, all reviewed solution 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 main approaches 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. Since the available supply usually exceeds the demand, not all volume in the PDP is delivered in the first approach while the second approach involves the delivery of all the volume (i.e. available requests) in the PDP. Furthermore, among the solution methods, there may be large differences in the exact definition of the same objective. The most notable example is the number of potential costs (e.g. fuel, queuing, loading) that could be taken into account in the total transport cost minimization 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. Indeed, an 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 hauling distance increases over time. One approach to avoid this is to require that the average hauling distance should remain the same.

Finally, it appears that 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 weather on the transportation activities is reported. The ownership of the road network as well as the need to build it is also detailed. Finaly, the largest-sized VRP reported in the literature is provided.

Table 3 : Transportation figures/characteristics in some countries.

	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 tonnes (Rodriguez, 2012)	26-28 tonnes (Greene, 2012)	38 tonnes but can go up to 165 tonnes for non-standard truck (Michaelsen, 2012)	37-42 tonnes (Anderson, 2012), tests with up to 60 tonnes	20-25 tonnes (Hirsch, 2012)	28-30 tonnes but can go up to 80 tonnes for non-standard truck (Visser, 2012)
Weather 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 ownership and construction	Mainly private and already built (Rodriguez, 20120)	Essentially private and already built but almost all trucking is done on public road network (Greene, 2012) .	Mainly public and mainly to build	Public and private, mostly already built but all companies can use all roads with a fee	Mainly private and mainly already built (Hirsch, 2012)	Essentially 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)						

2.5 Decision support systems for vehicle routing problem in timber transportation

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). How the transportation planning is done, by whom and to what level of detail vary significantly among companies (Rönnqvist, 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, a LSP is a single point-of-contact integrated service provider for a company that coordinates, on its 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). Some companies also merge their whole wood procurement function into one independent and, usually, non-profit corporate entity, responsible for supplying each of them. For instance, established by the merger of four Finnish forest products companies, Tehdaspuu company eliminated four overlapping organizations and, specifically for transportation, made it possible to avoid cross-hauling between its customers-owners (Pulkki, 1984). In summary, for truck routing/dispatching decisions, there is a gradient from a completely decentralized approach (where each driver makes his own decision) to a completely centralized 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, Canada), fleet ownership is highly fragmented among carriers operating one (usually, owner-operated truck) to a few trucks. In Canada, approximately 80% of the timber truck fleet belongs to independent owner-operator truckers (Boutin, 2012). 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). Independent owner-operator truckers 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 centralized and for trucks to increase their working area (Epstein et al., 2007). Such a trend increases the relevance of computer-based planning methods. Indeed, on larger and more complex transportation problems involved in centralized planning, they are more cost-effective than manual planning by a decision maker (DM). Thus, in order to allow a 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. Two earlier DSSs in timber transportation are also discussed by Pulkki (1984) and by Tolkki and Koskelo (1993). The system in Pulkki (1984) can be used to solve a number of transportation decisions, mainly at the tactical level (e.g. wood procurement areas, terminal service area), and also account for several transportation methods (i.e. road, rail, water channel, bundle floating). The system in Tolkki and Koskelo (1993) solves two transportation decisions: monthly wood procurement area by mill and weekly volume allocation by carrier.

In a literature review on DSS in the transportation domain, Zak (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 DSS 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 2.5.5, 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: mostly in Chile with DSSs ASICAM and ForesTruck (see Section 2.5.5 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, unreliable 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.

2.5.1 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 metres) or weight (e.g. tonnes). It is preferable that the demand 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 or green tonnes 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 or over bark, solid or loose cubic metres 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 are used in several countries. In Sweden, there is a central forest organization which deals with standards and how the measurement should be done. Moreover, as in other countries, this independent organization also deals with the scaling of trucks in order to guarantee that correct information is used in the invoicing between organizations. Finally, to communicate the data, there are different standards depending on the availability and coverage of mobile telephone networks.

2.5.2 Road network information accuracy

When solving a routing/dispatching problem, finding correct truck travelling distances and times is required and critical. One motivation is that transportation payments and invoicing are often based on the distance driven. This can be done using company-specific road databases, or a general one such as Google Maps web service or Microsoft MapPoint software. However, one problem is that the selection is often based on shortest or quickest distance (and/or time) and these distances may not be the ones preferred (and driven) by the truck drivers, as they also consider parameters such as road quality, road classification, road ownership (e.g. toll road), etc. For instance, a comparison of over 1000 routes by Swedish carriers shows that, on average, computed shortest distances are about 7.4% shorter than the preferred and driven ones (Flisberg et al., 2012b). In a practical planning situation, this must be dealt with and an approach to compute distances based on 55 parameters (representing both drivers' and forest companies' preferences) is proposed by Flisberg et al. (2012b).

To find the travelling distances and times, common road databases where the information is collected from several companies and organizations can also be utilized 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 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.

2.5.3 Solutions from the tactical planning level to the operational level

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.

2.5.4 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 organizational 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 organization of transportation efficiencies among the transportation actors. Enhanced payment methods providing all transportation actors with a fair and sustainable financial incentive to accomplish 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) organized 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.

2.5.5 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 (backhauling), 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 utilized for further manual analysis. Finally, the DSS has or not been successfully implemented/used by a company.

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

	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	backhauling	allocation and backhauling	backhauling	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

The DSSs presented in Table 4 can be grouped together into three groups according to the backhauling, routing or dispatching decisions they address.

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. back-haulage 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 controlled by one or two DMs. 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 optimization] 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., 2012a) 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., 2012a) 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 10 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, a multi-use truck trailer increases the number of possibilities for back-haulage tours and thus, additional cost savings can be realized. For example, Gingras et al. (2007) report an additional savings of 1.1% with the addition of multi-use truck trailers 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 trailers 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') has been utilized 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) working for the forest company. For validation before its execution, this global solution is then separated into parts to be locally analyzed 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 optimization] was developed from 2003-2007 by the Forestry Research Institute of Sweden and produces, the daily working schedule for a fleet of up to 110 trucks for up to five days. 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 standardization 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 (see e.g., Dorval et al., 2012).

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 total volume at all supply points 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 customized 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 system usage (Soriano, 2012).

2.5.5.1 Discussion on reviewed DSSs in timber transportation

With a DSS designed to be used in a dynamic mode, a 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 (i.e. FLO and ForesTruck) 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 organizational 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 support analysis based on historical data. Training is another example where 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 decentralized 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.

2.6 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 topics 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 for 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.

2.7 Acknowledgements

The authors would like to acknowledge the financial support of the private and public partners of the FORAC Research Consortium as well as the valuable cooperation of the seventeen persons cited as personal communication, especially the late Bertil Lidén.

2.8 References

Acuna, M., Brown, M., Mirowski, L., 2011. Improving forestry transport efficiency through truck schedule optimization: a case study and software tool for the Australian industry. Austro 2011 & FORMEC 2011, October 9-12, Graz and Rein, Austria.

Andersson, G., Flisberg, P., Lidén, B., Rönnqvist, M., 2008. RuttOpt: a decision support system for routing of logging trucks. Canadian Journal of Forest Research, 38(7): 1784-1796.

Andersson, G., Forestry Research Institute of Sweden, personal communication, March and June 2012.

Audy, J.-F., D'Amours,S., Rousseau, L.-M., Favreau, J., Marier, P., 2007. Virtual transportation manager: a web-based system for transportation optimization in a network of business units. 3rd Forest Engineering Conference, October 1-4, Mont-Tremblant, Canada. 8 p.

Audy, J.-F., El Hachemi, N., Michel, L., Rousseau, L.-M., 2011a. Solving a combined routing and scheduling problem in forestry. International Conference on Industrial Engineering and Systems Management, May 25-27, Metz, France.

Audy, J.-F., Lidén, B., Favreau, J., 2011b. Issues and solutions for implementing operational decision support system – An application in timber truck routing system. In: Ackerman, P., Ham, H., Gleasure, E., (Eds.). 4th Forest Engineering Conference, April 5-7, White River, South Africa. Stellenbosch University, 94-97.

Audy, J.-F., D'Amours, S., Rönnqvist, M., 2012a. An empirical study on coalition formation and cost/savings allocation. International Journal Production Economics, 136(1): 13-27.

Audy, J.-F., Pinotti, M., Westlund, K., D'Amours, S., LeBel, L., Rönnqvist, M., 2012b. Alternative logistic concepts fitting different wood supply situations and markets. CIRRELT Research Document, 2012-24, 348 p.

Barnhart, C., Laporte, G. (Eds.), 2007. Transportation, Handbooks in Operations Research and Management Science, Volume 14. Amsterdam: North-Holland.

Berbeglia, G, Cordeau, J.-F., Gribkovskaia, I, Laporte, G., 2007. Static pickup and delivery problems: A classification scheme and survey. TOP, 15(1): 1–31.

Berbeglia, G, Cordeau, J.-F., Laporte, G., 2010. Dynamic pickup and delivery problems. European Journal of Operational Research, 202(1): 8-15.

Boutin, F., FPInnovations, personal communication, September 2012.

Broman, H., Frisk, M., Rönnqvist, M., 2009. Supply chain planning of harvest operations and transportation after the storm Gudrun. Information Systems and Operational Research, 47(3): 235-245.

Brown, M., Michaelsen, J., Hickman, A., Provencher, Y., 2003. Potential for multi-use trailers in the Canadian forest industry. CR-0196-1, Forest Engineering Research Institute of Canada, Canada.

Brown, M.W., University of the Sunshine Coast and CRC for Forestry, personal communication, March 2012.

Clarke, G., Wright, J.R., 1964. Scheduling of vehicles from a central depot to a number of delivery points. Operations Research 12(4): 568-581.

Cordeau, J.-F., Laporte, G., Mercier, A., 2001. A unified tabu search heuristic for vehicle routing problems with time windows. Journal of the Operational Research Society, 52(8): 928–936.

Cordeau, J.-F., Laporte, G., Potvin, J.-Y, Savelsbergh, M.W.P., 2007. Transportation on demand. In: Barnhart, C., Laporte, G. (Eds.). Transportation, Handbooks in Operations Research and Management Science, Volume 14, Chapter 7, Amsterdam: North-Holland. 429-466.

Dantzig, G.B., Ramser, J.H., 1959. The truck dispatching problem. Management Science, 6(1): 80-91.

D'Amours, S., Rönnqvist, M., Weintraub, A., 2008. Using operational research for supply chain planning in the forest products industry. Information Systems and Operational Research, 46(4): 265-281.

Dorval, J.S., Lehoux, N., Gaudreault, J., Marier, P., 2012. Collaboration in transportation management – Case study for the forest industry. In: 4th International Conference on Information Systems, Logistics and Supply Chain, August 26-29, Quebec City, Canada.

El Hachemi, N., Gendreau, M, Rousseau, L.-M., 2008. Solving a log-truck scheduling problem with constraint programming. In: Perron, L., Trick, M.A., (Eds.). 5th International Conference on Integration of AI and OR Techniques in Constraint Programming for Combinatorial Optimization Problems, Lecture Notes in Computer Science, Vol. 5015. Springer. 293–297.

El Hachemi, N., Gendreau, M, Rousseau, L.-M., 2009. A heuristic to solve the weekly log-truck scheduling problem. In: International Conference on Industrial Engineering and Systems Management, May 13-15, Montreal, Canada.

El Hachemi, N., Gendreau, M, Rousseau, L.-M., 2011. A hybrid constraint programming approach to the log-truck scheduling problem. Annals of Operational Research, 184(1): 163-178.

El Hachemi, N., Gendreau, M, Rousseau, L.-M., 2013. A heuristic to solve the synchronized log-truck scheduling problem. Computers and Operations Research, 40(3): 666-673.

Emeyriat, R., Bigot, M., 2006. Management of wood haulage through GIS/GPS tools in maritime pine forest (France). In: P. A. Ackerman, P.A, Längin, D.W., Antonides, M.C., (Eds.). International Precision Forestry Symposium, March 5-10, Stellenbosch, South Africa. Stellenbosch: Stellenbosch University. 331-340.

Epstein, R., Morales, R., Serón, J., Weintraub, A., 1999. Use of OR systems in the Chilean forest industries. Interfaces, 29(1): 7-29.

Epstein, R., Karlsson, J., Rönnqvist, M., Weintraub, A., 2007. Forest transportation. In: Weintraub, A., Romero, C., Bjorndal, T., Epstein, R., (Eds.). Handbook of Operations Research in Natural Resources, International Series in Operations Research and Management Science, Vol. 99, Chapter 20. New York: Kluwer Academic Publishers. 391-403.

Eriksson, J., Rönnqvist, M., 2003. Transportation and route planning: Åkarweb - a web-based planning system. In: Iwarsson Wide, M., Hallberg, I., (Eds.). 2nd Forest Engineering Conference, May 12-15, Växjö, Sweden. Uppsala: SkogForsk. 48-57.

Flisberg, P., Lidén, B., Rönnqvist, M., 2009. A hybrid method based on linear programming and tabu search for routing of logging trucks. Computers and Operations Research, 36(4): 1122-1144.

Flisberg, P., Frisk, M., Rönnqvist, M., 2012a. FuelOpt -A decision support system for forest fuel logistics. Journal of the Operational Research Society, doi: 10.1057/jors.2011.157.

Flisberg, P., Lidén, B., Rönnqvist, M., Selander, J., 2012b. Route selection for best distances in road databases based on drivers' and customers' preferences. Canadian Journal of Forest Research, 42(6): 1126-1140.

Forsberg, M., Frisk, M., Rönnqvist, M., 2005. FlowOpt: a decision support tool for strategic and tactical transportation planning in forestry. International Journal of Forest Engineering, 16(2): 101-114.

Frisk, M., Jörnsten, K., Göthe-Lundgren, M., Rönnqvist, M., 2010. Cost allocation in collaborative forest transportation. European Journal of Operational Research, 205 (2), 448-458.

Frisk, M., Forestry Research Institute of Sweden, personal communication, March-April 2012.

Gendreau, M., El Hachemi, N., Rousseau, L.-M., 2009. A hybrid LS/CP approach to solve the weekly log-truck scheduling problem. 8th Metaheuristics International Conference, July 13-16, Hamburg, Germany.

Gingras, C., Cordeau, J.-F., Laporte, G., 2007. Un algorithme de minimisation du transport à vide appliqué à l'industrie forestière [An algorithm for minimizing unloaded transportation applied to the forest industry]. Information Systems and Operational Research, 45(1): 41-47.

Gingras, C., Planora, personal communication, March 2012

Golden, B., Raghavan, S., Wasil, E., (Eds.), 2008. The Vehicle Routing Problem – Latest Advances and New Challenges. New York: Springer Science+Business Media.

Greene, D., University of Georgia, personal communication, March and June 2012.

Gronalt, M., Hirsch, P., 2007. Log-truck scheduling with a tabu search strategy. In: Doerner, K.F., Gendreau, M., Greistorfer, P., Gutjahr, W.J., Hartl, R.F., Reimann, M. (Eds.). Metaheuristics - Progress in Complex Systems Optimization. New York: Springer. 65-88.

Hartl, R. F., Hasle, G., Janssens, G. K., 2006. Special issue on Rich Vehicle Routing Problems. Central European Journal of Operations Research, 14(2): 103-104.

Hirsch, P., 2011. Minimizing empty truck loads in round timber transport with tabu search strategies. International Journal of Information Systems and Supply Chain Management, 4(2): 15-41.

Hirsch, P., University of Natural Resources and Life Sciences, personal communication, June 2012.

Jacqmin, F., Trimble Forestry Automation, personal communication, April 2011 and February-March 2012.

Karanta, I., Jokinen, O., Mikkola, T., Savola, J., Bounsaythip, C., 2000. Requirements for a vehicle routing and scheduling system in timber transport. In: Sjöström, K., (Eds.). 1st World Symposium on Logistics in the Forest Sector, May 15-16, Helsinki, Finland. Helsinki: Timber Logistics Club. 235-251.

Kokenge. K.S., 2011. Opportunities and challenges for decision support systems in log truck scheduling and dispatching. Master thesis, Oregon State University, US.

Lepage, D., FPInnovations, personal communication, March 2012.

Lidén, B., Forestry Research Institute of Sweden, personal communication, December 2011.

Linnainmaa, S., Savola, J., Jokinen, O., 1995. EPO: A knowledge based system for wood procurement management. In: Aikins, J,m Shrobe, H., (Eds.). 7th Conference on Innovative Applications of Artificial Intelligence, August 20-23, Montreal, Canada. Menlo Park: AAAI Press. 107-113.

Ludbrook, M., Asset Forestry Logistics, personal communication, August 2011.

Marier, P., Audy, J.-F., Gingras, C., D'Amours, S., 2007. Collaborative wood transportation with the Virtual Transportation Manager. In: Blanchet, P., (Eds.). International Scientific Conference on Hardwood Processing, September 24-26, Quebec City, Canada. Quebec: FPInnovations-Forintek. 191-198.

Marques, A., Pinho de Sousa, J., Rönnqvist, M., Jafe, R. 2013. Combining optimization and simulation tools for short-term planning and analysis in forest operations. Fortcoming in Scandinavian Journal of Forest Research.

Marques, A.F., Rönnqvist, M., D'Amours, S., Weintraub, A., Gonçalves, J., Borges, J.G., Flisberg, P. 2012. Solving the raw materials reception problem using revenue management principles: an application to a Portuguese pulp mill, CIRRELT Research Document, 2012-29, 27 p.

Marshall, H., 2007. Log merchandizing model used in mechanical harvesting. In Weintraub, A., Romero, C., Bjorndal, T., Epstein, R. (eds) Handbook of Operations Research in Natural Resources, International Series in Operations Research and Management Science. Kluwer Academic Publishers, New York, pp. 379–389.

McCary, J., 2009. Coaching strategies – An always-thinking contractor teams up with his wood source to boost efficiency and profitability. Southern Loggin' Times. August 2009.

McDonald, T., Taylor, S., Rummer, R.B., Valenzuela, J., 2001a. Information needs for increasing log transport efficiency. In: 1st International Precision Forestry Cooperative Symposium, June 17-20, Seattle, United-States. Seattle: College of Forest Resources. 181-184.

McDonald, T., Taylor, S., Valenzuela, J., 2001b. Potential for shared log transport services. In: Wang, J., Wolford, M., McNeel, J., (Eds.). 24th Annual COFE Meeting, July 15-19 Snowshoe, United-States. Corvallis: Council on Forest Engineering. 115-120.

McDonald, T., Haridass, K., Valenzuela, J., 2010. Mileage savings from optimization of coordinated trucking. In: 33rd Annual COFE Meeting, June 6-9, Auburn, United-States.

Mendell, B. C., Haber, J. A., Sydor, T., 2006. Evaluating the potential for shared log truck resources in middle Georgia. Southern Journal of Applied Forestry, 30 (2): 86-91.

Michaelsen, J., 2009. Reduction of energy intensity by the use of a multipurpose semi-trailer, FPInnovations-FERIC, Advantage 11(9).

Michaelsen, J., FPInnovations, personal communication, March, April and June, 2012.

Murphy, G., 2003. Reducing trucks on the road through optimal route scheduling and shared log transport services. Southern Journal of Applied Forestry, 27(3): 198-205.

Palmgren, M., Rönnqvist, M., Varbrand, P., 2003. A solution approach for log truck scheduling based on composite pricing and branch and bound. International Transactions in Operations Research. 10(5): 433-447.

Palmgren, M., Rönnqvist, M., Varbrand, P., 2004. A near-exact method to solve the log-truck scheduling problem. International Transactions in Operations Research. 11(4): 447-464.

Parada, C., Forestal CMPC, personal communication, June 2012.

Parragh, S.N., Doerner, K.F., Hartl, R.F., 2008. A survey on pickup and delivery problems - Part II: Tansportation between pickup and delivery locations. Journal für Betriebswirtschaft, 58(2): 81-117.

Pillac, V., Gendreau, M., Guéret, C., Medaglia, A.L., 2011. A review of dynamic vehicle routing problems. Technical report, CIRRELT-2011-62, CIRRELT, Canada, 29 p.

Pulkki, R., 1984. A spatial database – heuristic programming system for aiding decision-making in long-distance transport of wood. Acta Forestalia Fennica, 188.

Rauch, P., 2010. Stochastic simulation of supply chain risks in forest fuel procurement. Scandinavian Journal of Forest Research, 25(6): 574-584.

Rey, P.A., Muñoz, J.A., Weintraub, A., 2009. A column generation model for truck routing in the Chilean forest industry. Information Systems and Operational Research, 47(3): 215-221.

Robinson, T.F., 1994. Tour generation for log truck scheduling. In: 30th Annual Conference of the Operational Research Society of New Zealand, August 31- September 1, Palmerston-North, New Zealand. 166–171.

Rodriguez, J., former at Masisa, personal communication, June 2012.

Rönnqvist, M., Ryan, D., 1995. Solving truck despatch problems in real time. In: 31th Annual Conference of the Operational Research Society of New Zealand, August 31- September 1, Wellington, New Zealand. 165–172.

Rönnqvist, M., Sahlin, H., Carlsson, D., 1998. Operative planning and dispatching of forestry transportation. Research paper LiTH-MAT-R-1998-18, Linköping University, Sweden.

Rönnqvist, M., 2003. Optimization in forestry. Mathematical Programming, 97(1-2) : 267-284.

Rönnqvist, M., 2012. OR challenges and experiences from solving industrial applications. International Transactions in Operational Research, 19(1-2): 227-251.

Rummukainen, H., Kinnari, T., Laakso, M., 2009. Optimization of wood transportation. In: Madetoja, E., Niskanen, H., Hämäläinen, J. (Eds.). Papermaking Research Symposium, Kuopio, Finland, June 1-4, Kuopio: University of Kuopio.

Rummukainen, H., VTT Technical Research Centre of Finland, personal communication, April 2012.

Savola, J., Rummukainen, H., Jokinen, O., 2004. KUORMA: A collection of APS-algorithms for forest industry wood transport. ERCIM News, 56: 29-31.

Selviaridis, K., Spring, M., 2007. Third party logistics: a literature review and research agenda. International Journal of Logistics Management, 18(1): 125-150.

Shen, Z., Sessions, J., 1989. Log truck scheduling by network programming. Forest Products Journal, 39(10): 47-50.

Soriano, H.O., West Ingeniería Ltda, personal communication, April-June 2012.

Tolkki, S., Koskelo, I., 1993. Seeing the trees through the forest: GPS streamlines Finish logging operation. GPS World, October, 21-27.

Toth, P., Vigo, D. (Eds.), 2002. The Vehicle Routing Problem, SIAM Monographs on Discrete Mathematics and Applications. Philadelphia: Society for Industrial and Applied Mathematics.

Visser, R., University of Canterbury, personal communication, March and June 2012.

Weintraub, A., Epstein, R., Morales, R., Seron, J., Traverso, P., 1996. A truck scheduling system improves efficiency in the forest industries. Interfaces, 26(4): 1-12.

Weintraub, A., Universidad de Chile, personal communication, February and March 2012.

Xu, H., Chen, Z.-L., Rajagopal, S., Arunapuram, S., 2003. Solving a practical pickup and delivery problem. Transportation Science, 37(3): 347-364.

Zahedi, F. M., Song, J., Jarupathirun, S., 2008. Web-based decision support. In: Burstein, F., Holsapple, C.W., (Eds.). Handbook on Decision Support Systems 1, International Handbook on Information Systems, Chapter 16. Springer. 315-338.

Zak, J., 2010. Decision support systems in transportation. In: Jain, L.C., Lim, C.P., (Eds.). Handbook on Decision Making, ISRL 4, Chapter 11. Springer. 249-294.

Zazgornik, J., Gronalt, M., Hirsch, P., 2012. A comprehensive approach to planning the deployment of transportation assets in distributing forest products. International Journal of Revenue Management, 6(1/2): 45-61.

3 Literature review on collaborative transportation

This chapter presents the article entitled “A framework for an efficient implementation of logistics collaborations” which was published in International Transactions in Operational Research, 19(5): 633-657, 2012. Here is an abstract of the article in French.

3.1 Résumé

Pour demeurer compétitif, accéder à de nouveaux marchés et respecter les contraintes opérationnelles, sociales et environnementales, les entreprises établissent des collaborations avec d’autres entreprises. De plus, en partageant des coûts et de l'information, les entreprises ont la possibilité d'optimiser leurs activités logistiques. Toutefois, chaque entreprise a ses propres objectifs d’affaires et prend généralement ses propres décisions de planification pour les atteindre. Par conséquent, il devient crucial de déterminer comment les entreprises vont travailler ensemble ainsi que la valeur de la collaboration. Plus précisément, il est nécessaire de déterminer comment les activités logistiques seront planifiées et exécutées, qui assumera la direction de la collaboration et comment les bénéfices issus de la collaboration seront partagés. Dans cet article, nous expliquons comment établir et gérer efficacement les relations inter-entreprises. En outre, nous proposons cinq mécanismes de coordination qui contribuent au partage de l'information, à la coordination des activités logistiques et au partage des bénéfices. Des études de cas sont utilisées pour démontrer l'utilité des mécanismes.

A framework for an efficient implementation of logistics collaborations

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Abstract. In order to remain competitive, access new markets and respect operational, social and environmental constraints, enterprises establish collaborations with many other business entities. Furthermore, by sharing costs and information, it becomes possible for organizations to optimize their logistics activities. However, each enterprise has its own objectives and typically makes its own planning decisions to meet these objectives. Therefore, it is crucial to determine how business entities will work together as well as quantify the value of the collaboration. Specifically, it is necessary to identify how logistics activities will be planned and executed, who will assume leadership of the collaboration, and how benefits will be shared. In this article, we explain how to build and manage inter-firm relationships efficiently. Moreover, we propose five coordination mechanisms that contribute to ensure information sharing, coordination of logistics activities, and sharing of benefits. Case studies are used to demonstrate the utility of the framework.

Keywords: Enterprise collaborations; Logistics and transportation; Coordination mechanisms, Collaborative planning, Incentives, Contracts, Cost allocation, Operational research.

3.2 Introduction

In the current economic context, logistics collaboration is emerging as a new opportunity for improving key activities such as warehousing, transportation and distribution. This is driven by heightened competitive pressure on a global scale, increased environmental concerns and implementation of new business models. Moreover, collaboration in logistics has been identified as one means of reducing the cost of executing logistics activities, increasing the service level, gaining market shares, enhancing capacities, and reducing negative impacts of the bullwhip effect (e.g., Lee et al., 1997, Moyaux et al., 2007). In addition, it has a positive environmental impact by making the operations more efficient.

On the other hand, logistics collaborations raise the need for specific methods to support the decision-making process and ensure the stability of the relationship. Partners will typically be ready to collaborate if they can obtain greater benefits than the ones obtained individually. Therefore, it becomes crucial to determine how to build and manage collaborations efficiently, as well as how to share benefits equitably to ensure the long-term stability of the collaboration. In particular, it is necessary to determine which entity or entities should lead the relationship, what the specific objectives are to aim for, and which information should be shared to support the collaboration. It is also essential to identify the value of the collaboration as well as how benefits will be shared.

In this paper, we explore how to build and manage profitable logistics collaborations (Figure 2). Specifically, we first explain the main stages for building an inter-firm relationship, namely the objectives to reach, the organization of the collaboration to implement, and the partners to select. Afterwards, we describe how to manage collaborations in order to ensure profitable long-term relationships. Therefore, different types of leadership are examined. Five generic coordination mechanisms are also proposed to support information sharing, planning and execution of logistics activities, and benefits sharing. These mechanisms aim to help managers design their collaboration schemes.

Moreover, the nature of the information to share and the tools to implement so as to support the partnership are analyzed. Finally, we present three case studies that show how enterprises have implemented logistics collaborations in practice and we relate these case studies to the generic coordination mechanisms proposed. Some concluding remarks end the paper.

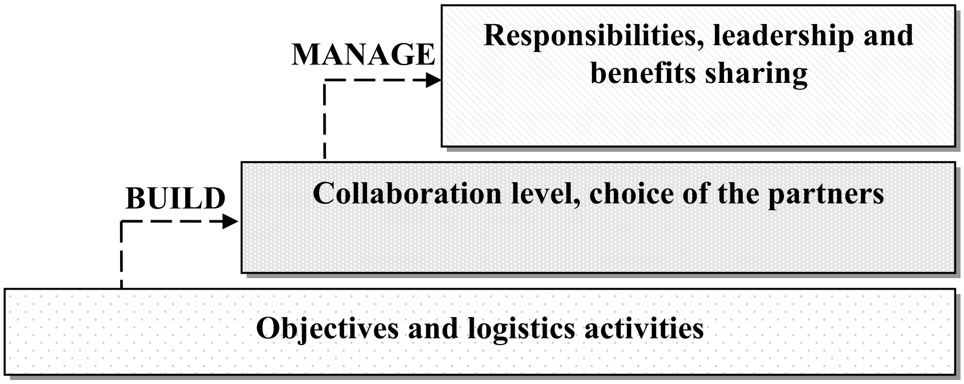


Figure 2 : Building and managing logistics collaborations.

3.3 Building logistics collaborations

Collaborations have been extensively studied in the literature for different business contexts, e.g., Lambert et al. (1996), Chen (2003), Subrabami (2004), Bagchi and Skjoett-Larsen (2005), van der Vaart and van Donk (2008). Many definitions have also been proposed to describe the concept, e.g. Table 1 in Fugate et al. (2009). Here, we consider that collaboration occurs when two or more entities form a coalition and exchange or share resources (including information), with the goal of making decisions or engaging in activities that will generate benefits that they cannot (or only partially) generate individually.

Futhermore, since collaborative relationships between organizations can vary in complexity, many frameworks have been proposed to describe their forms, e.g. Frayret et al. (2003). As shown in Figure 3, the nature of the information shared (i.e. on the Y axis) as well as the degree of interaction between partners (i.e. on the X axis) will differ depending on the type of relationships implemented. For example, two companies that choose to adopt a simple form of collaboration may exchange only transactional information such as orders, payments, delivery confirmations, etc. On the other hand, companies that decide to jointly plan operations need to agree on objectives, share strategic information such as customer demand, forecasts and operational capacities, and decide on key performance indicators. A co-evolution relationship also involves a more complex form of partnership that can lead to the creation of a new entity such as a consortium or a joint venture.

In this paper, we will focus on collaborations that involve either joint planning or collaborative planning and execution (framed in dotted lines in Figure 3).

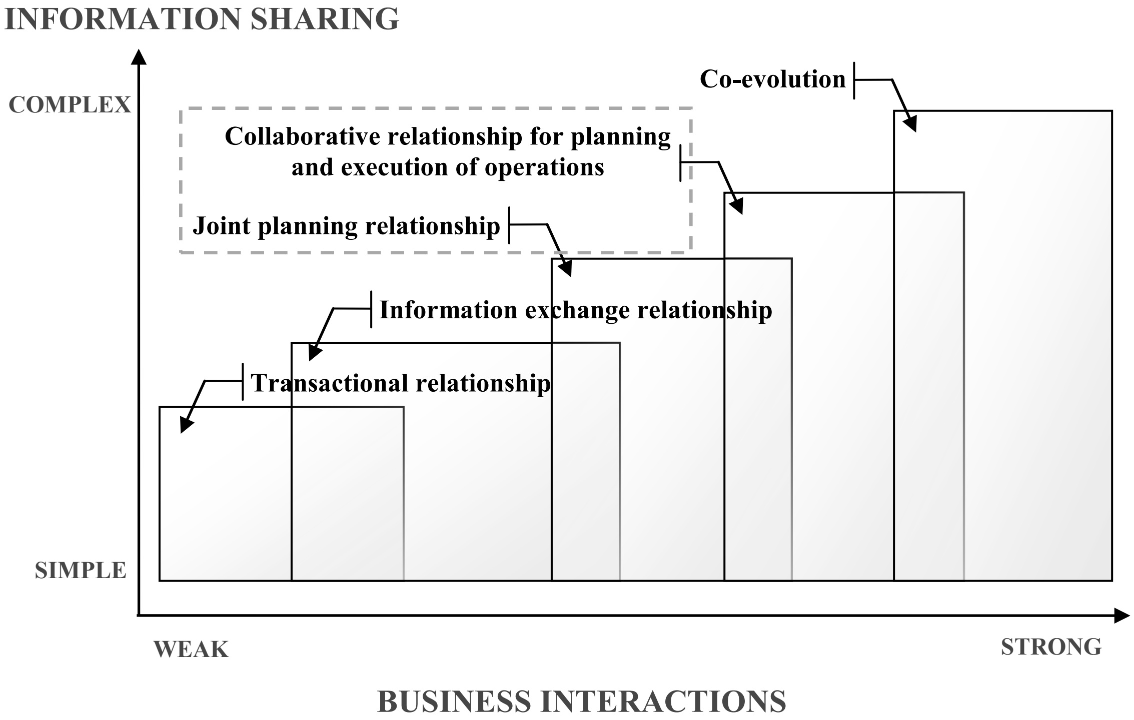


Figure 3 : Forms of collaborative relationships (Frayret et al., 2003).

3.3.1 Collaboration objectives

With the creation of inter-firm relationships, it becomes possible to increase the effectiveness of logistics operations. Logistics operations are costly activities that involve multiple actors to move and store products as they flow through the supply chain, thus they provide many opportunities for collaboration.

In transportation, the supply chain entities (e.g., carriers, shippers, customers, third party logistics (3PL), etc.) can optimize loaded travelling time, load capacity usage and asset utilization. They share information in such a way that, in road transport for instance, the pick-up and delivery routing problems capture the benefits of a denser network of freight (Ergun et al. 2007a, 2007b). Backhauling represents another opportunity to reduce the unloaded travelling distance. Carlsson and Rönnqvist (2007) have presented a survey on this concept applied to forestry transportation. The supply chain members can also face high transportation costs and aim to deploy new transportation infrastructures that will provide them with a competitive advantage over others.

In addition, actors may collaborate to increase responsiveness and reduce costs such as the inventory holding cost. In such cases, they share demand and consumption information in a timely manner and use different approaches to synchronize their activities efficiently (Lehoux et al., 2009a). Another common practice in collaborative logistics is to share spare parts between different entities.

What is important is that partners agree on the common objectives and are willing to act in such a way that these objectives will be attained. This commitment is crucial to establish long-term relationships (Ryu et al., 2009).

3.3.2 Logistics activities and collaboration level

Collaboration can be strategic and, consequently, imply the sharing of key infrastructures or highly sensitive information. Examples of such collaborations could be the sharing of a costly infrastructure such as pipelines (e.g., crude oil and gas), terminals (e.g., forestry), warehouses (e.g., retailing) or transportation modes (e.g., integrating train, ship, truck in general transportation organizations). The location and the investment for such infrastructures are considered strategic for the entities involved. Other strategic collaboration relates to defining industry standards. This is the case when entities of a same industry collaborate in order to define business standards which improve the inter-operability of their systems. EDI is a good example of standards developed in order to share documents between organizations in a standardized electronic form and in an automated manner (Bhatt, 2001). PapiNet (see www.papinet.org) and StanForD (see Marshall, 2007) are other examples of standards created to ensure efficient information exchange in the forest products industry. Strategic collaboration can also imply a long-term business contract and sharing of demand and capacity information. At the strategic level, it is frequent to see entities exchanging a complete model of their demand or capacity, in order to compute the most accurate value of their collaboration and establish a sharing strategy (Montreuil et al., 1999, Frisk et al., 2010). If they do not share a complete model, they usually obtain suboptimal benefits (Simatupang and Sridharan, 2002).

Collaborations can also be implemented to optimize the tactical and operational planning of some specific logistics activities. For example, Frisk et al. (2010) present a case study of collaboration in tactical transportation planning between eight forest companies, while Erikson and Rönnqvist (2003) analyze the collaboration in operational transportation planning between two companies and several carriers (these case studies are discussed in more detail in Section 3.4). Generally, collaboration at the operational level involves low commitment as well as less information sharing.

3.3.3 Forms of collaboration

Many authors differentiate collaboration according to two main dimensions: vertical and horizontal. Figure 4, which is adapted from Barratt (2004), illustrates both dimensions from the perspective of a core company. In particular, the supply chain (b) includes the two production plants (the first two black circles inside the delimited area numbered 3 in Figure 4) and the warehouse of the core company (the third black circle above the two production plants in Figure 4).

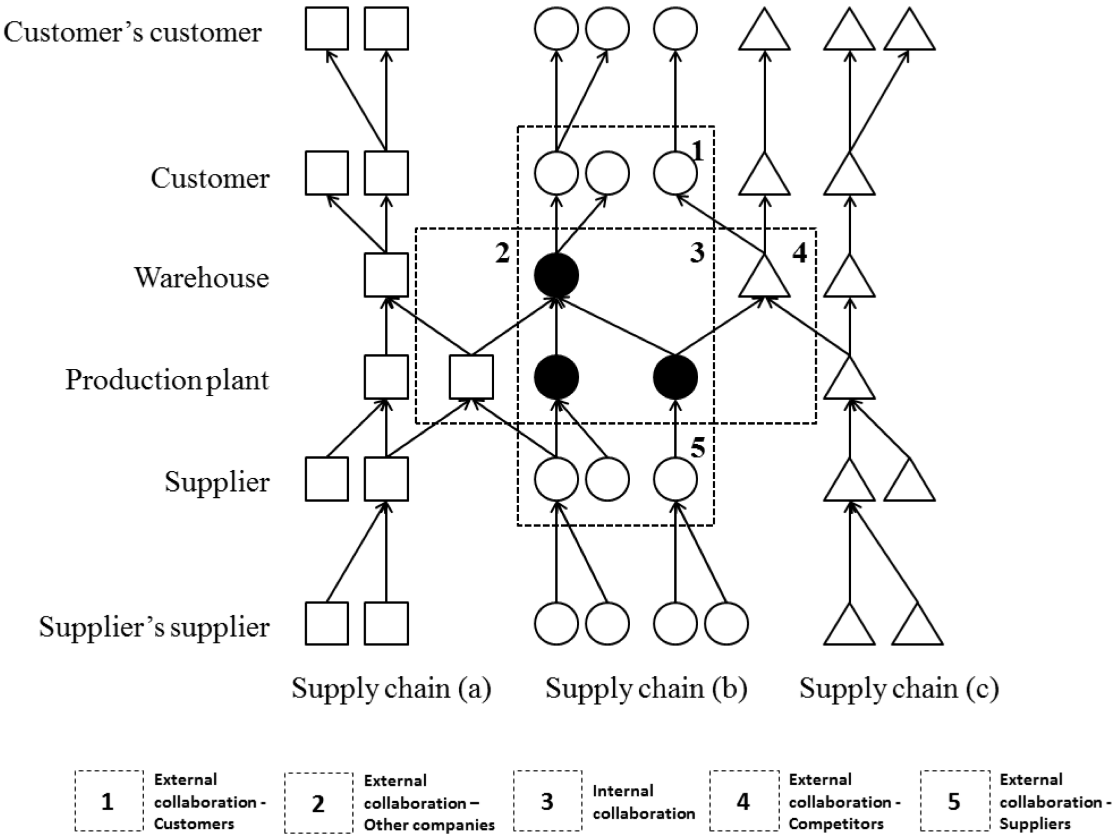


Figure 4 : Dimensions of the collaboration.

Vertical collaboration occurs with business units belonging to the same supply chain such as upstream with a supplier of the core company (delimited area numbered 5 in Figure 4) or downstream with a customer of the core company (delimited area numbered 1 in Figure 4). Sharing information to reduce the bullwhip effect is a typical example of vertical collaboration between various entities located at different echelons in the same supply chain.

Horizontal collaboration occurs with business units outside the supply chain, such as a competitor company with whom the core company can share warehousing capacity (delimited area numbered 4 in Figure 4) or a non-competitor company with whom the core company can share production capacity (delimited area numbered 2 in Figure 4). Group purchasing organizations are a typical example of horizontal collaborations among buyers belonging to different business units. Both vertical and horizontal collaborations can also occur within the core company between its own business units (delimited area numbered 3 in Figure 4).

A third dimension of collaboration, which is the combining of both vertical and horizontal collaborations, has also been differentiated and designated as lateral, diagonal or synergistic collaboration (for example, see case studies in Mason et al., 2007).

3.3.4 Choice of the partners

Collaborations can bring together two or many entities. When two partners decide to work together, they can take the time to really know each other and build a trusting relationship. However, in a many-to-many context, complexity increases. The design of proper collaboration mechanisms becomes difficult, mainly because the exchanges are not bilateral as in a supplier-customer relationship (Quélin, 2002). Moreover, some entities may enter with a lot to provide and little to gain, while others can benefit greatly with little to offer (see for example the case study involving eight entities in Frisk et al., 2010). The right number of partners also depends on the industrial context. It is typically based on economic parameters as well as social factors (Kang et al., 2007). However, larger collaborations are usually associated with an increase in coordination problems and in transactional costs. Furthermore, they may tend towards smaller benefits because of cooperation costs between partners. In game theory, this is called non-superadditive environments (Sombattheera and Ghose, 2006). Therefore, it is sometimes necessary to change some specific goals and even the culture of the relationship when new members are admitted into the coalition (Sreedharan and Vollmer, 2009).

In all cases, the selection of one or many partners needs to be made carefully. In several business contexts, the right partner is the one who has a similar organization size, culture and philosophy. It also wants to pursue common goals and objectives, it is ready to share benefits as well as risk, and it uses similar technologies and planning techniques (Liu et al., 2006). Moreover, it needs to contribute positively to the value of the collaboration. Ryu et al. (2009) have specified that trusting partnerships must be based on a cooperation strategy, complementary resources, and organizational compatibility. Based on 58 key performance indicators found through in-depth interviews and a literature study, Naesens et al. (2007)

have also proposed an evaluation method for strategic compatibility between two potential partners.

Nevertheless, collaboration can sometimes be imposed by one of the leading entities of the supply chain. For example, when Wal-Mart implemented RFID systems with all its major suppliers, the company imposed the technology on the different supply chain entities. Other imposed schemes can also be set by public policies. For example, natural resources can be managed by governmental authorities and the allocation rules may impose collaboration between many entities. This is the case in the forestry industry in Canada, where the different entities are asked to find harvesting plans which meet the coalition members' needs (Beaudoin et al., 2007).

3.4 Managing logistics collaborations

The management of collaboration in logistics involves determining who will be responsible for what, who will own the leadership, how benefits will be shared, and which type of information will be needed.

3.4.1 Defining responsibilities

In a context where a supplier and a customer aim for more efficiency in their logistics, they can evaluate the possibility of sharing more information and jointly plan their operations. Therefore, several responsibilities can be shifted from one entity to another in order to improve the global effectiveness of the relationship.

For example, under a Vendor Managed Inventory (VMI) agreement, the producer is responsible for managing the inventories of its customer. The customer provides the daily consumption to the producer so it can build a production-distribution plan that meets the fixed service level as well as optimizes the usage of its resources. This kind of strategy can contribute to increase the logistics performance as well as decrease the bullwhip effect. Danese (2006) reported the benefits gained by the pharmaceutical giant GlaxoSmithKline. De Toni and Zamolo (2005) also demonstrated how the application of VMI to the household electrical appliances sector resulted in more benefits than traditional replenishment systems. In addition, Dong et al. (2006) presented the benefits of implementing VMI for a context characterized by unknown demand. Another example of collaborative approach is Continuous Replenishment (CR), which is based on carrier capacity or production capacity. The replenishment is structured around a pre-scheduled reservation of capacity. For example, the collaboration may set a one-truck-per-day delivery to the customer. Then, the customer is responsible for setting the mix of products to be on the truck every day. This approach satisfies the needs of the customer over time and reduces the pressure on the producer. The same approach applies with capacity reservation, e.g., Shen and Pang (2004), Durango-Cohen and Yano (2006).

The Collaborative Planning, Forecasting and Replenishment business model (CPFR) is another illustration of collaborative models that aim to balance demand and production-distribution capacity upfront in order to define a win-win unique plan for both parties. To achieve this, information such as sales history, product availability, lead times, etc., must be shared so as to correctly synchronize activities and eliminate excess inventory. This method is also useful to rapidly identify any differences in forecasts or inventory, in order to correct problems before they negatively impact sales or profits. Thron et al. (2005) demonstrated that putting CPFR into practice can lead to substantial benefits, depending on the context studied. Cederlund et al. (2007) also reported a reduction of 50% of transportation costs and 30% of inventory holding costs at Motorola.

3.4.2 Leader of the collaboration

Depending on the business context, the leadership of the relationship will usually differ. The size of the companies involved in the collaboration, as well as their contribution and organization philosophy, are some examples of parameters that will influence the leadership ownership. Therefore, it is possible that an entity, or several, lead the collaboration, deciding who should be admitted and how benefits should be divided (Kilger et al., 2008). For example, Cruijssen et al. (2005) study a procedure allowing a 3PL (the leader in this case study) to form a coalition of shippers. Specifically, the 3PL uses the Shapley value (an economic model) to allocate the total transportation cost among the shippers involved. Levying a percentage of the collaboration savings, the 3PL aims to select the set of shippers inside the coalition that will generate the total higher savings. Other examples can be found in Cruijssen et al. (2007a) for the development of a hub distribution network among a set of shippers, and in Audy et al. (2009b) for the formation of a coalition of shippers by one or several of the shippers. Moreover, the ownership of the leadership can change over time or be exercised in different ways according to the evolution of the collaboration (Stadtler, 2009).

Audy et al. (2009a) have identified six different forms of leadership currently used for collaboration in transportation (Table 5). Such models can also be generalized to other logistics collaborations. In these models, the leader is either one entity which aims to optimize its own objectives, or a group of many that aims to optimize a common objective. These forms of leadership are based on different purposes that often depend on the attitude of the leader(s). Furthermore, they will greatly influence how sharing costs and benefits takes place.

Table 5 : Forms of leadership for collaborative logistics.

Model	**Description of the leadership**
1	A supplier/customer/producer leads the collaboration: it aims to minimize its transport costs by finding other customers/producers that can provide a good equilibrium (geographical, volume and time) between supply and demand.
2	A carrier/3PL leads the collaboration: it aims to maximize its profit by a better usage of its carrying capacity.
3	A coalition of suppliers/customers/producers shares the leadership of the collaboration: they aim to minimize their transportation costs.
4	A coalition of carriers/3PLs shares the leadership of the collaboration: they aim to maximize their profit by a better usage of their joint carrying capacity.
5	A coalition of carrier(s)/3PL(s) and supplier(s)/customer(s)/producers(s) shares the leadership of the collaboration: they aim to minimize their transportation costs by using the carrying capacity of the carriers.
6	A 4PL leads the collaboration: it aims to minimize/maximize the cost/profit of its partner.

3.4.3 Collaboration benefits

As observed by many authors (e.g., Barratt, 2004; D’Amours et al., 2006; Bailey and Francis, 2008; Cruijssen et al. 2007b; Ryu et al., 2009; Chambost et al., 2009; Lehoux et al., 2009c), several benefits can be achieved through collaboration. Some are quantitative (e.g., cost reduction) while others qualitative (e.g., learning new logistics skills).

3.4.3.1 Evaluating benefits

In logistics, the evaluation of quantitative collaboration benefits is mainly conducted using Operational Research (OR) models, as in Cruijssen et al. (2005), Forsberg et al. (2005), Beaudoin et al. (2007), Cruijssen et al. (2007a), Ergun et al. (2007a, b), Agarwal and Ergun (2008a, b), Clifton et al. (2008), Lehoux et al. (2008, 2009a,b,c), Özener and Ergun (2008) and Frisk et al. (2010). More precisely, collaborations between entities involve many planning decisions and, consequently, many operational costs and constraints must be taken into account (production and distribution costs, lead times, distance, stock levels, etc.). This results in complex planning problems that are difficult to solve. Consequently, the use of OR models becomes useful to integrate all these parameters and constraints into mathematical models, in order to evaluate the cost of achieving the collaboration objectives. Since most logistics problems are based on a minimization objective, we will refer to a savings for the potential financial collaboration benefit, except when we mention it as a profit.

In addition, in many of the previously mentioned case studies, the savings are defined according to the difference between the sum of the cost of each stand-alone solution (i.e., logistics activities planning of each entity alone) and the cost of the common solution (i.e., logistics activities planning of all entities together). These case studies rely on the assumption that the savings from a coalition of entities can be defined independently of the coalitions formed by other entities (i.e. there are no externalities).

3.4.3.2 Developing the planning models

In the literature, there exist many models for the planning of logistics activities for one entity (i.e. stand-alone solution). Modifications to such models are usually required in a context of logistics collaboration between several autonomous and self-interested entities (i.e. common solution). For example, in a case study of raw material exchange between two companies, Forsberg et al. (2005) report some additional constraints to their supply allocation model according to a different exchange scenario (e.g., a limit on the total volume that could be exchanged between companies). By adding constraints to the common problem, such modifications frequently reduce the potential savings of the collaboration. In a case study of raw material exchange between three companies on a monthly basis, Lehoux et al. (2009a) report that each company must remain the main supplier for its own mills (e.g., specified minimum percentage of 50%) and raw material exchanges must be pair-wise equal (i.e., a company must supply each collaborator with the equivalent volume received from this collaborator). These two modifications (or constraints in the problem) decrease the potential savings (ranged between 5-20%) by 1-2% each month.

Modifications to the individual planning problem of some companies can also be required. As previously mentioned, the solution value of the individual problem of one specific company represents its expected stand-alone cost. Consequently, to obtain a realistic value, the individual problem should be representative of the stand-alone logistics context of each company. For example, if a company A uses less-than-truckload (LTL) carriers and wants to collaborate with a company B which uses only full-truckload (FT) carriers, the individual problem of both companies will have to be adapted since using FT carriers does not involve the same costs as using carriers LTL carriers, nor the same response time.

3.4.3.3 Sharing the benefits

As shown in Figure 5, collaboration benefits are usually classified into two main categories: qualitative and quantitative. While qualitative benefits typically cannot be shared among the entities, quantitative benefits can sometimes be shared (e.g. cost reduction), and sometimes not (e.g. delivery time reduction).

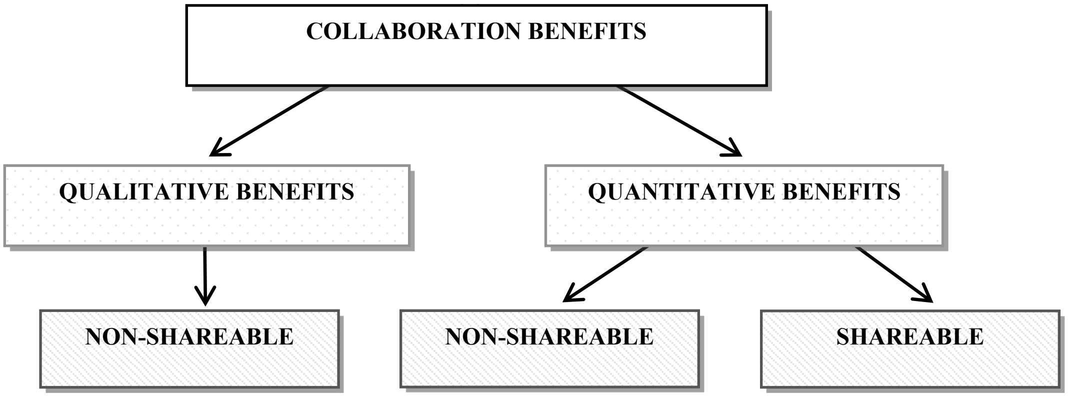


Figure 5 : Types of collaboration benefits.

Moreover, the level of benefits achieved by each entity may differ. Therefore, it is necessary to use methods which ensure that the benefits gained by each entity make the collaboration acceptable for everyone. The distinction between “shareable” and “non-shareable" benefits indicates how to change a situation for which the quantitative benefit gained by each entity makes the collaboration unacceptable for at least one entity.

Specifically, when a quantitative benefit is "shareable", a sharing method has to be used in order to redistribute the benefit among the entities in such a way that the collaboration becomes acceptable for everyone. However, if it is impossible for the entities to agree on a sharing method, no collaboration can be established (i.e. infeasible coalition). The addition/retreat of new/current entity(ies) to/from the infeasible coalition is consequently required to evaluate a new potential coalition.

When a quantitative benefit is "non-shareable", the planning problem needs to be modified since the solution of the planning problem will fix the distribution of the "non-sharable" benefits among the entities. This modification can be the addition of a constraint such as a maximum delivery date on each shipment, to ensure acceptable delivery time reductions for each entity. More complex modifications can also be required. For example, in their case study involving collaboration in transportation between four companies, Audy et al. (2008a) report that the planning problem using only full-truckload (FT) carriers did not respect the maximum delivery date for some shipments. Consequently, the planning problem was modified to allow the use of less-than-truckload (LTL) carriers in order to deliver these shipments on-time.

3.4.3.4 Coordination mechanisms

Usually, the logistics activities of the collaborating entities are first planned, and then benefits are computed and shared. However, new approaches have recently been proposed in the literature where both the planning of logistics activities and the sharing of benefits are computed simultaneously. Figure 6 shows five generic coordination mechanisms (CM) that illustrate these different approaches (each of them is described in the next subsections). These five generic coordination mechanisms are the result of a categorization exercise based on several sharing approaches discussed in the literature and used in various cases studies involving collaborative logistics. Each mechanism includes at least two collaborating business units (only two business units are illustrated to keep Figure 6 simple) having logistics activities (e.g. transportation) to be coordinated by a plan, and their own resources (e.g. carriers) available to achieve the plan. Even though collaborating entities may share resources (e.g. warehouses), this possibility is not illustrated to keep Figure 6 simple. Moreover, we restrict our discussion to financial benefits to simplify the description of each mechanism, despite the fact that these mechanisms support other benefits. A coordination process (illustrated by a diamond) ensures the planning of logistics activities and the sharing of the quantitative and shareable benefits. This coordination process can be performed by a third party or by the collaborating entities. In addition, information, decision, and financial flows in each mechanism are illustrated.

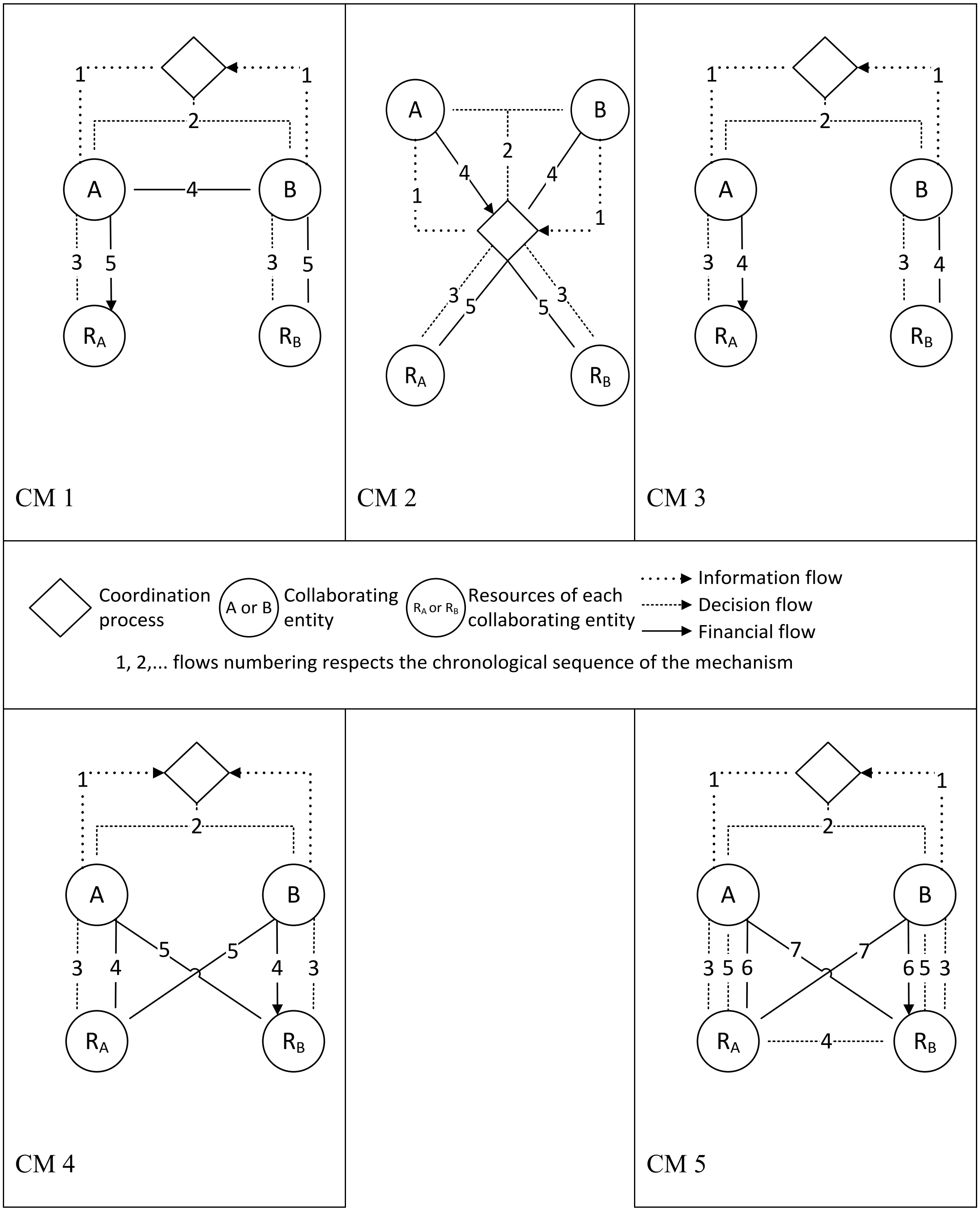


Figure 6 : Generic coordination mechanisms for the logistics activities.

These mechanisms are an adaptation of those proposed by Frayret et al. (2004) for collaborative logistics. More precisely, Frayret et al. (2004) present a classification scheme of the various coordination mechanisms for manufacturing activities in a distributed manufacturing system. A first class of coordination mechanisms, designated as 'coordination by plan' (from March and Simon, 1958), involves the establishment of predefined plans to coordinate a priori interdependent activities under the responsibility of autonomous and self-interested entities. This class is subdivided into three subclasses of mechanism: (i) 'direct supervision with plan', (ii) 'mediation with plan' and (iii) 'joint plan establishment'. The first two subclasses use a third party to perform the coordination. In particular, in subclass (i), the third party performs a centralized planning of all entities' activities and each entity must follow the centralized plan. In subclass (ii), each entity performs a first planning of their own activities and then, the third party performs an integration of these individual plans into one coherent-centralized plan that each entity must follow. Such integration involves modifications to the individual plans that are possible through the mediation between the third party and each entity. Therefore, the third party acts as a support (i.e. non-coercive) for the coordination rather than as a supervisor (i.e. coercive) as in subclass (i). In the third subclass (iii), with mutual adjustments between them, the entities perform joint planning of their activities to agree on a centralized plan that each company will follow.

Consequently, by adding benefits sharing within the mechanisms proposed by Frayret et al. (2004), we can address problems of coordinating interdependent (i.e. vertical collaboration) or similar (i.e. horizontal collaboration) logistics activities and building profitable inter-firm relationships.

3.4.3.4.1 Coordination mechanism 1 (CM 1)

In this mechanism, the coordination process solves an optimization problem in order to achieve maximum savings and then, the benefit sharing is addressed with a financial flow between the business units (Figure 6, CM 1). Such a financial flow is based on a predefined incentive rule such as pricing agreements or quantity discounts. A detailed review of these incentives can be found in Cachon (2003). Lehoux et al. (2009c) present a case study using coordination mechanism 1. The case study involves bilateral collaboration between a paper producer and a wholesaler. To establish the collaborative approach providing the greatest savings for the partnership as well as for both companies, the paper producer must share part of its transportation savings (i.e. incentive rule) with the wholesaler. Other examples can be found in Corbett et al. (2005), Sirias and Mehra (2005), Hu et al. (2007), Xu and Weng (2007), Burer et al. (2008), and Yan et al. (2010). This type of coordination mechanism may be useful to modify the behaviour of the partners and better coordinate their planning decisions, especially when partners are not ready to totally change their way of doing business (Lehoux et al., 2009b).

3.4.3.4.2 Coordination mechanism 2 (CM 2)

In this mechanism, the coordination process solves an optimization problem in order to achieve maximum savings and then, the benefit sharing is addressed with a sharing principle based on an economic model (i.e. cost allocation method) such as the Shapley value, the nucleolus, and the separable and non-separable costs (Figure 6, CM 2). These economic models, which are usually based on cooperative game theory, lead to the allocation of the total cost of the common-solution among the companies. Nevertheless, there is no single and all-purpose economic model to achieve a fair and stable cost allocation. Cooperative game theory provides a set of desirable properties (e.g. efficiency) and equilibrium concepts (e.g. core) to define, respectively, fairness and stability. Therefore, when choosing an existing cost allocation method or developing a new one, it is necessary to seek one that satisfies specific properties which are considered essential in the context of the collaboration.

With economic models, the common cost is divided among partners. However, such models do not specify the cost of each logistics activity. Consequently, each partner knows the global cost for all the logistics activities involved in the collaboration, without knowing the individual cost allocated to each one. Since accounting systems and payment rates are largely based on individual activity costs, a global cost may be confusing for certain companies.

A survey of these economic models and equilibrium concepts can be found in Young (1985) and Tijs and Driessen (1986), while a survey of their application in the field of Supply Chain Management can be found in Leng and Parlar (2005) and Nagarajan and

Sošic (2008). Case studies using coordination mechanism 2 include Cruijssen et al. (2005), Cruijssen et al. (2007a), Audy et al. (2009b), and Frisk et al. (2010) for transportation activities, and Guo and Ding (2006) and Leng and Parlar (2009) for demand information sharing.

3.4.3.4.3 Coordination mechanism 3 (CM 3)

In this mechanism, the coordination process solves an optimization problem in order to achieve maximum savings, with respect to an additional constraint related to the benefit sharing (Figure 6, CM 3). The optimization problem decides that certain activities belonging to an entity are accomplished by its own resource and others are accomplished by the resource of the second entity. Such decisions lead to the generation of two plans, one for each company. Since there is no financial flow between the entities or between the entity and the resource belonging to the other entity, the cost of the plan of each business unit must be, at least, less than the cost of their stand-alone plan. Furthermore, the absence of financial flow (other than the one between each entity and its own resource) makes CM 3 the simplest type of coordination mechanism for the management of accounting and payment.

In their case study involving three companies performing raw material pair-wise exchange, Lehoux et al. (2009a) report the use of this mechanism. These companies previously agreed with the sharing principle behind the Equal Profit Method (from Frisk et al., 2010), an economic model that aims to find a stable allocation such that the maximum difference in relative savings between all pairs of two collaborating companies is minimized. Thus, to come up with a plan for each company that results in a benefit sharing that each company could agree on, a new constraint has been added in the optimization problem. The new constraint states that each pair of companies must have the same relative savings.

3.4.3.4.4 Coordination mechanism 4 (CM 4)

In this mechanism, the coordination process simultaneously addresses the resolution of the optimization problem and the benefit sharing (Figure 6, CM 4). For each activity, the optimization problem determines the cost to be paid for its completion by a specific resource. The computation of the cost takes into account the cost incurred by the resource to realize the activity as well as the revenue associated with the activity. Therefore, in this mechanism, the coordination process solves the optimization problem in order to achieve maximum profit instead of savings as in the four other mechanisms. For all the activities, each company pays this cost to its resource or to that of the other company, according to which resource has been chosen in the planning. Thus, the benefit sharing is addressed with a financial flow between each company and the resource of the other company.

In Agarwal and Ergun (2008a), coordination mechanism 4 is used by sea container carriers sharing the loading capacity of their ships to deliver their respective customers' shipments. Other collaborative logistics case studies or examples using coordination mechanism 4 include Agarwal and Ergun (2008b) and Agarwal et al. (2009).

3.4.3.4.5 Coordination mechanism 5 (CM 5)

In this mechanism, the coordination process partially solves the optimization problem in order to achieve maximum savings (Figure 6, CM 5). However, the coordination process does not provide an individual plan as in the other mechanisms. Rather, the plan includes, for each entity's activity, a list of potential collaboration opportunities involving other activities. This means that an opportunity may appear among the entity's activities, as well as among the entity's activities and the ones of another (or several) entity. At the assignment of the activities, each entity provides its resource with the list of potential collaboration opportunities. Given these opportunities, it is then up to the resources to decide together to collaborate or not, and if they do collaborate, to decide together which resource will carry out the activities (i.e. Figure 6, flow 4). Since the resources are paid only for each activity they accomplish (i.e. Figure 6, flows 6 and 7), the decisions they make in flow 4 fix the benefit sharing.

Mechanism 5 is based on a generalization of the mechanism used in the case studied by Eriksson and Rönnqvist (2003). In this study, the potential collaboration opportunities are based on backhauling tours existing among the transportation activities of two forest companies. Moreover, this collaboration is conducted through the carrier (i.e. the resource) of the second company.

3.4.4 Information and advanced tools

If supply chain members want to build and manage efficient collaborations, they have to share information both upstream and downstream. Orders, sales forecasts, point of sales data, and customer surveys are examples of information that need to be sent top-down within the chain, while delivery plans, offers, promotion, capacity, and inventory availability have to be sent from the suppliers to the customers. In this way, the visibility is increased and each actor can make better planning decisions.

However, Fawcett et al. (2007) have observed four barriers that limit the positive impact of information sharing. The first barrier is the cost and the complexity of implementing advanced technologies. The investment can be very expensive and systems are sometimes not as high-performance as expected. The second barrier is incompatibility of systems, which can really complicate the exchange of data. The third barrier refers to the "connectivity" problem across the organization and across the value chain, reducing the positive impact of information sharing. Finally, there is a culture associated with the exchange of information and managers are not necessarily ready to share their knowledge with their partners. This is what the authors call "the willingness" dimension of information sharing. To this we add a fifth barrier: information security and confidentially. Several approaches have been proposed in the literature to address such a barrier. For example, Clifton et al. (2008) examine the use of cryptographic techniques to perform collaborative logistics among potential competitors' carriers without broker and with a strictly minimum share of information.

This challenge has motivated great efforts to standardize the information flow. Therefore, different standards such as RosettaNet (www.rosettanet.org) have been developed to support timeless and effective inter-operability within the supply chain. The aim is to eliminate the need for negotiating and agreeing on data definitions and formats with each trading entity, each time a possible transaction occurs. A common messaging interface enables the entities to exchange rapidly with many different entities by means of electronic data exchange technology, and to reduce errors in data treatment and exchange. Large corporations have started to use such standards to streamline their supply chain with their main customers (see for example www.papinet.org). Although multiple standards exist, many software companies develop their own model. In such cases, they typically use XML files to support the integration of the different technologies.

In order to support the information flow required for collaboration, systems such as platforms are regularly used. Internet based technologies also provide many ways to connect the different entities and support their collaboration.

More specifically, agent-based technologies are rising as a new body of approaches building on distributed computing techniques. They intend to tackle the need for reactive, reliable, and (re)configurable operation management systems. An agent-based system may be defined as a system made of interdependent software agents designed to (i) individually handle a part of a problem, such as planning an order or dispatching a task to a carrier, and (ii) collectively carry out specific higher functions such as planning a shared warehouse. Software agents generally exhibit characteristics that allow them to individually behave and interact with each other in order to fulfil the purpose of the entire system. In such systems, information flows are supported by conversation protocols and messages. A conversation protocol links messages to form a conversation. As for messages, they have their own purposes and move from one sender to one or many receivers. The platform to support the flows of messages can vary greatly going from a blackboard where messages are posted to a real collaborative logistics eHub. Application of an agent-based platform for vertical and horizontal dimensions of logistics collaborations is described respectively in Frayret et al. (2007) and Audy et al. (2008b). The latter illustrates the Virtual Transportation Manager which is a web-based application permitting entities to post their transportation needs on a platform which thereafter optimizes the multiple pick-up and delivery transportation planning problem. The optimized routes, once accepted by the entities, are proposed to carriers.

3.5 Examples of logistics collaborations in the industry

In order to demonstrate the utility of the previous concepts and to validate the coordination mechanisms proposed, this section discusses three case studies illustrating how enterprises have implemented logistics collaborations in practice. The first case considers coordinated transportation planning in Sweden involving eight forest companies. The second case was conducted with four North American furniture manufacturers aiming for co-distribution to the US, while the third case deals with a vertical collaboration between a pulp and paper producer and a wholesaler. These cases have been selected because they are good examples of logistics collaborations. Specifically, they illustrate what kind of logistics activities can be optimized, how joint planning and execution can be conducted, and how costs and profits can be shared. Moreover, the number of partners involved differs as well as the OR method used to solve the problem. Table 6 provides a summary of the properties of the three cases.

Table 6 : Summary of the case studies.

Case	**Total players**	**Leadership**	**CM**	**Industry**	**OR method**	**Stable equilibrium**	**Put into practice?**
1	8	3PL	3	Wood supply	LP	Yes - but not when implemented	Yes - by 3 players
2	4	Producer	2	Furniture	Heuristic	Yes - with cost allocation	Waiting
3	2	Producer	1	Paper	MILP	No - need incentives	Yes - CR
Legend: Third-party logistic (3PL); Coordination mechanism (CM); Continuous replenishment (CR); Linear programming (LP); Mixed integer linear programs (MILP); Operational research (OR)							

As shown in Table 6, each case study concerns the forest industry. While the first and the third one used linear and mixed-integer linear programs to plan activities, the second one was based on the use of a heuristic. In all cases, an entity was the leader of the coalition. The coordination mechanisms used differed from one case study to another, but they all had the same goal, namely creating a profitable relationship for each partner involved. The case studies below explain the results in more detail.

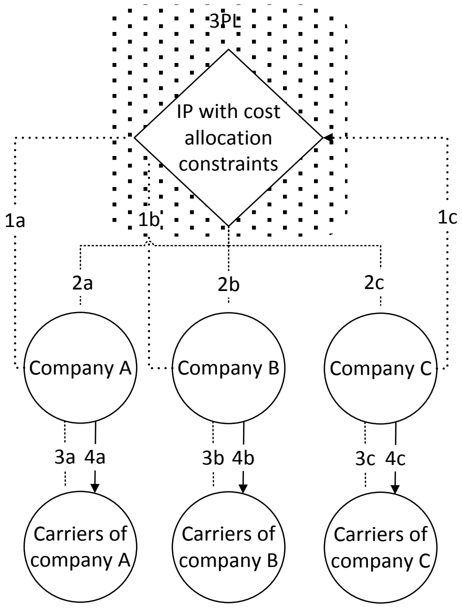
3.5.1 Wood supply collaboration in Sweden

This first case study is based on work done by the Forestry Research Institute of Sweden with eight forest companies involved in transportation of logs from forest harvest areas to industries such as pulp and paper mills and sawmills (Frisk et al., 2010). Transportation planning is an important part of the supply chain or wood flow chain in forestry. It often amounts to about a third of the raw material cost. There are often several forest companies operating in the same region and coordinated planning between two or more companies is rare. Wood bartering (or timber exchange) between forest companies to reduce transport cost is fairly common in Sweden. In wood bartering, two companies agree to deliver a specific volume to the other company's demand points. The company still plans its operations itself and there is no need to give away any sensitive information. Also, there is no need to provide information about its own savings to the other company.

In 2004, a group of eight forest companies in southern Sweden wanted to know the potential for coordinated transportation planning. Here, all companies viewed their supply and demand as common and a planning problem for one integrated artificial company could be done. This problem can be solved using the system FlowOpt (Forsberg et al., 2005). The optimization model can be solved with a Linear Programming (LP) model. It turned out that the potential saving was as high as 14.2%. A certain part comes from improved planning within each company and the part from collaboration was 8.7%. A very important question is how the savings or the cost should be distributed among the companies. Initially, the companies argued that the total cost should be based on their share of the overall volume. However, when the relative savings were computed, it ranged from 0.2-20%. This difference among the companies was too high and they were not able to agree. The reasons for this difference in relative savings are twofold. First, each company takes responsibility for its own supply (i.e. plans and organizes all the activities involved from the procurement of standing timber to its delivery at a consuming mill) and makes sure that it is delivered to the new destinations (coupling between supply and demand points). Secondly, the geographical distribution differs between companies and this affects the new distribution solution.

In order to come up with a sharing principle that the companies could agree on, several sharing principles based on economic models including Shapley value, the nucleolus, separable and non-separable costs, shadow prices, and volume weights were tested and analyzed. As a part of the analysis, a new approach, called Equal Profit Method (EPM), was developed. The motivation was to get an allocation that provides a relative profit that is as equal as possible among the participants. In addition, it satisfies core constraints from cooperative game theory and is a stable solution. This approach was acceptable among the forest companies. This was further extended in a two-stage process where the first identified volumes that make a contribution to the collaboration. Then the EPM was applied to these identified volumes.

As a result of the case study, in 2008 three companies started a collaboration where monthly coordinated planning was done (Figure 7). Ahead of each month, each company provided the information about supply and demand to a third party logistics (i.e. represented by the dotted area in Figure 7), in this case the Forestry Research Institute of Sweden (i.e. the leader of the collaboration). Then an integrated plan (i.e. common plan) was made and the result was given back to the forest companies for their own detailed transportation planning. The sharing principle was based on having the same relative savings applied to each company's own supply. In addition, there were some constraints assuring that each company was the main supplier for its own mills, and that pairwise exchange flows were the same. The latter was to avoid financial exchange between companies. Moreover, some core conditions were not included. With this revised model, it was not possible to guarantee a stable solution. The approach was tested during four months in 2008 and the potential savings were 5-15% each month.



Flow number	**Description**
1a,b,c	Each company sends to the coordination process the supply and demand volumes.
2a,b,c	The coordination process sends to each company the volume and the destination of the supply volume.
3a,b,c	Each company sends to their carriers the volume to transport
4a,b,c	Each company pays their carriers.

Figure 7 : Coordination mechanism 3 applied to the first case study.

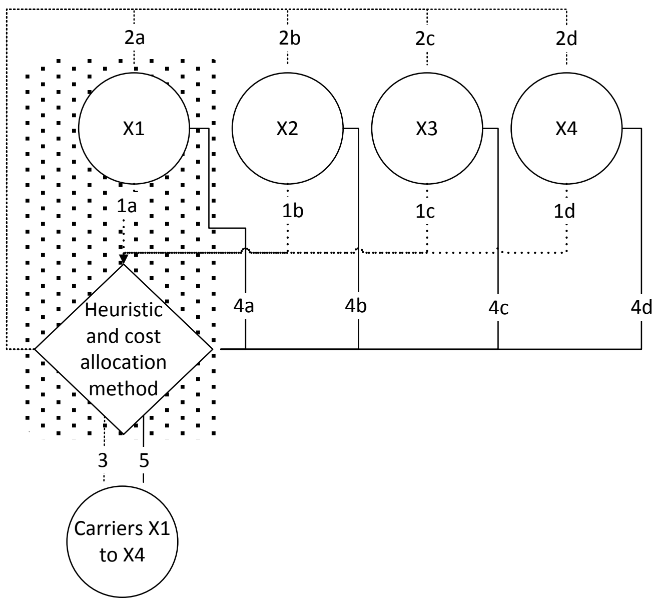
3.5.2 Outbound transportation collaboration

The second case study refers to the potential collaboration between four furniture manufacturers in Canada. The aim was to optimize collectively the outbound transportation of their products to the US. In Audy and D'Amours (2008), four different logistics scenarios were explored to establish the collaboration. Cost and delivery time reductions as well as gain in market geographical coverage were identified in each scenario. However, even though a scenario can provide substantial benefits for the group, each company needs to evaluate the scenario according to its own benefits. This individual evaluation can lead to a situation where the scenario with the highest cost-savings for the group (optimal cost-savings scenario) does not provide the individual highest cost-savings to some companies or worse, provides one or more negative benefits. As a result, without any modification, this optimal cost-savings scenario would be rejected in favour of another scenario that may not capture all the potential cost-savings and may exclude some of the companies.

Audy et al. (2008a) integrated in the optimal cost-savings scenario the modifications which satisfy the conditions allowing its establishment by the whole group. However, by doing so, the result in cost reductions goes from 21% to 12.9%. In other words, an additional cost of 8.1% was incurred in the collaborative plan to satisfy the heterogeneous requirements of some partners. Since some companies have more requirements than others and because the impact on cost increase between two requirements is almost never the same, this raises a new question: how the additional cost incurred to satisfy the special requirements should be shared between the companies? Using the solution concept of a cost allocation scheme called Alternative cost avoided method (see e.g. Tijs and Driessen, 1986), a new method was proposed and analyzed. This new method allowed a share according to the impact of the requirements of each partner on the cost of the collaborative plan. Thus, the partner who most increased the cost of the collaborative plan obtained the greatest part of the additional cost incurred to satisfy the requirements of all partners. The previous costs allocated to each partner were then considered as a fixed cost parameter in a sharing principle to determine the individual cost-savings of each company. The Equal Profit Method proposed by Frisk et al. (2010) was used as the sharing principle with two modifications: (i) to tackle the previous fixed cost parameter and two other fixed cost parameters typical to the furniture industry, and (ii) to ensure a minimum bottom-line cost-savings percentage for each partner.

As a result of the case study, a pilot project was initiated by companies with the support of their industrial association. As agreed by the four companies, one of them, designated as the leader, defined a business agreement to manage the collaboration in the pilot project (Figure 8). However, the definition of the business agreement by the leading company was delayed for many reasons and then, two of the three companies cancelled the agreement. One company declared bankruptcy, while the second was suspected by the other companies of opportunistically using the monetary-related parameters, inside the proposition of agreement, to renegotiate downward its current transportation rates with its carriers. The benefit with the two remaining companies was judged insufficient and the pilot project was suspended.

Nevertheless, the leading company has recently joined a local organization regrouping several companies from different industrial sectors, and collaborative transportation is one of the strategies that members want to evaluate.



Flow number	Description
1a,b,c,d	The producers send the shipments to the coordination process.
2a,b,c,d	The coordination process sends to producers the delivery plan as well as the value of the cost to pay to the coordination process.
3	The coordination process sends to the carriersthe route to execute.
4a,b,c,d	The producers pay the coordination process.
5	The coordination process pays the carriers.

Figure 8 : Coordination mechanism 2 applied to the second case study.

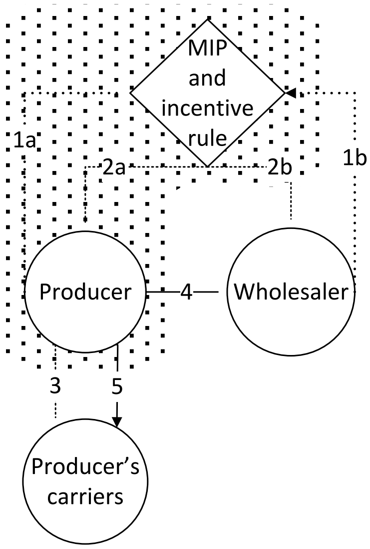
3.5.3 Collaboration approaches in the pulp and paper industry

The last case concerns a pulp and paper producer who decided to establish a partnership with one of its clients (vertical collaboration, see Lehoux et al., 2009c). Since the production capacity was limited, the producer had to plan operations in order to satisfy both the demand of the partner and that of other clients. The partner was a wholesaler, thus he bought products and sold them to consumers without transforming the merchandise. Even if each partner wanted to create a real partnership with mutual benefits, they made decisions based on their local costs rather than the global costs of the system. The producer planned operations in order to minimize production, distribution and inventory costs, while the wholesaler ordered products so as to minimize buying, ordering and inventory costs. For this context, the objective was to identify the collaborative approach to implement to ensure an efficient exchange of products and information as well as maximum benefits for the network and for each partner. Even though the wholesaler was a small company and, consequently, not one of the most important clients of the producer, a change in his order generally had a significant impact on production and distribution systems of the producer (small lot sizes that may not be produced or delivered economically). Therefore, the producer aimed to solve the problem by establishing collaboration with this wholesaler.

Four potential collaborative approaches were identified for the case study: a traditional system without any collaboration scheme, CR, VMI and CPFR. For each approach, decision models from the point of view of both the producer and the wholesaler were developed. Specifically, Mixed Integer Linear Programs (MILP) were used to take into consideration the costs, revenues and constraints involved in using each collaborative approach. Afterwards, models were tested and compared so as to find the most profitable approach for the network. Results showed that CPFR generated the greatest total system profit because of an efficient optimization of both transportation and inventory costs (CPFR inventory cost was up to 44% lower than inventory costs of other models). VMI was second best since the transportation cost was optimized. CR and the traditional system obtained the lowest total system profit.

After comparing each model using the system profit, the investigation was based on the profit of each partner. Specifically, the different collaborative approaches were compared to verify if the same approach could generate the highest profit for both the producer and the wholesaler. This analysis revealed that CPFR generated the greatest profit for the producer, while CR was the most beneficial for the wholesaler. For this reason, a method for sharing benefits was defined so as to obtain a CPFR collaboration profitable for each partner. The experiments showed that if the producer shared a part of the transportation savings with the wholesaler, the profit of the wholesaler was higher than the profit obtained with CR, and the producer obtained a higher profit than the one generated by the other approaches (Figure 9).

At present, partners work together using a CR technique (Lehoux et al., 2008) but ultimately they aim to implement a customized version of the CPFR technique. Therefore, as the leader of the collaboration, the producer will certainly have to share benefits with the wholesaler in order to maintain a win-win relationship. Otherwise, it is possible that the wholesaler may prefer to work with someone else.



Flow number	**Description**
1a	The producer sends its supply.
1b	The wholesaler sends its demand plan.
2a	The coordination process sends to the producer the delivery plan and the value of the financial incentive to transfer to the wholesaler.
2b	The coordination process sends to the wholesaler the delivery plan and the value of the financial incentive to receive from the producer.
3	The producer sends to its carriers the volume to transport.
4	The producer pays the financial incentive to the wholesaler.
5	The producer pays its carriers.

Figure 9 : Coordination mechanism 1 applied to the third case study.

3.6 Concluding remarks

This paper explores how to build and manage efficient logistics collaborations. We have first described why enterprises choose to work together, what challenges they are faced with, and what forms of potential collaboration they can implement. Next, we have explained how to manage collaborations in terms of responsibilities, leadership, and benefits sharing. Some mechanisms have been presented in order to illustrate the different ways for planning and coordinating logistics activities and sharing information and benefits among partners. The nature of the information to exchange, as well as the tools needed to support the relationship, have also been explored. Finally, we have examined three case studies which illustrate how enterprises have implemented logistics collaborations in practice.

Many Operational Research tools can be used to study inter-firm collaborations. While in some cases, economic models are applied to address costs and benefits sharing, in other cases, optimization models and simulations are used to plan operations and identify the costs to share. Moreover, collaborations can be analyzed at different planning levels: the design of the coalition, the strategies or the technology to implement to support the collaboration, the day-to-day activities to jointly execute the operations, etc. Collaborations can also be applied to different types of business contexts, from transportation activities to service companies.

Collaborations between supply chain entities are complex and many problems are still very difficult to deal with. These problems often call for interdisciplinary solutions and collaborative networks are emerging as a new discipline to study such collaborative issues (Camarinha-Matos and Afsarmanesh, 2005). In our case studies, the theoretical results showed important benefits and costs savings. However, partners were not necessarily ready to change their way of doing business, to share their knowledge, or to collaborate with other stakeholders to achieve these benefits. In the second case study, the collaboration failed because of non-cooperation between partners. In the third case, the producer wanted to implement VMI but the wholesaler was afraid to lose control over operations and not necessarily ready to shift some responsibilities.

Another important question is competition: in the process of building the coalition, some entities may be strong competitors. In such a case, trust and policies for sensitive information sharing may play a significant role in the decision process. Legal issues are also very important. Many countries are concerned with potential collusive activities and therefore legislate to avoid them (e.g. antitrust laws). Additional financial services could also be required to allow secure financial flows among the entities, but the cost of such services may reduce the benefit of the collaboration. Benefits sharing, although theory supports the process, may require facing the need to deal with benefits that are difficult to evaluate. For example, suppose there is a collaborative logistics project which permits an entity to access high-value markets more easily, more rapidly, and therefore develop them at low costs. What is the value of the increased geographical coverage or the faster deliveries? Furthermore, in our case studies, we observed that partners had difficulty evaluating the fixed costs associated with the implementation of collaborations. This cost seemed complex to define and to anticipate, even though it represented a risk for partners. Finally, the collaboration is rarely fixed in time. The environment changes constantly as well as the parameters considered when designing the collaboration. How should this dynamic be considered upfront? How often should the terms of the collaboration be reviewed?

For the forest industry, collaboration between network members is a real challenge. Companies that are willing to share resources and information as well as risks and benefits undoubtedly stand to gain from working together. This will certainly capture practitioners' attention in the coming years.

3.7 Acknowledgements

The authors would like to acknowledge the financial support of the Natural Sciences and Engineering Research Council of Canada and the private and public partners of the FORAC Research Consortium.

3.8 References

Agarwal, R., Ergun, Ö., 2008a. Network design and allocation mechanisms for carrier alliances in liner shipping. Forthcoming in Operations Research.

Agarwal, R., Ergun, Ö., 2008b. Mechanism design for a multicommodity flow game in service network alliances. Operations Research Letters. 36(5): 520–524.

Agarwal, R., Ergun, O., Houghtalen, L., Ozener, O.O., 2009. Collaboration in cargo transportation. In: Chaovalitwongse, W., Furman, K.C., Pardalos, P.M. (Eds.). Optimization and Logistics Challenges in the Enterprise. Springer Optimization and Its Applications, Springer, New York, pp. 373-409.

Audy, J.-F., D'Amours, S., 2008. Impact of benefit sharing among companies in the implantation of a collaborative transportation system – An application in the furniture industry. IFIP International Federation for Information Processing, Pervasive Collaborative Networks, Springer, Boston, MA, pp. 519-532.

Audy, J.-F., D'Amours, S., Rousseau, L.-M., 2008a. Cost allocation in the establishment of a collaborative transportation agreement - An application in the furniture industry. Journal of the Operational Research Society, doi: 10.1057/jors.2010.53.

Audy, J.-F., D'Amours, S., Rousseau, L.-M., Favreau, J., Marier, P., 2008b. Virtual transportation manager: a web-based system for transportation optimization in a network of business units. 3rd Forest Engineering Conference, October 1-4, Mont-Tremblant, Canada.

Audy, J.-F., D'Amours, S., Lehoux, N., Rönnqvist, M., 2009a. A review on collaborative logistics. International Conference on Industrial Engineering and Systems Management, May 13-15, Montreal, Canada.

Audy, J.-F., D'Amours, S., Rönnqvist, M., 2009b. An empirical study on coalition formation and cost/savings allocation. Forthcoming in International Journal Production Economics.

Bagchi, P. K., Skjoett-Larsen, T., 2005. Supply chain integration: a European survey. International Journal of Logistics Management, 16(2): 275-294.

Bailey, K., Francis, M., 2008. Managing information flows for improved value chain performance. International Journal of Production Economics, 111(1): 2-12.

Barratt M., 2004. Understanding the meaning of collaboration in the supply chain. Supply Chain Management: An International Journal, 9(1): 30-42.

Beaudoin, D., LeBel, L., Frayret, J.-M., 2007. Tactical supply chain planning in the forest products industry through optimization and scenario-based analysis. Canadian Journal of Forest Research, 37(1): 128-140.

Bhatt G. D., 2001. Business process improvement through electronic data interchange (EDI) systems: an empirical study. Supply chain Management: An International Review, 6(2): 60-74.

Burer, S., Jones, P.C., Lowe, T.J., 2008. Coordinating the supply chain in the agricultural seed industry. European Journal of Operational Research, 185(1): 354-377.

Cachon G. P., 2003. Supply Chain Coordination with Contracts. In de Kok, A.G., Graves, S.C. (Eds.), Handbooks in operations research and management science. Elsevier, Amsterdam, pp. 229-339.

Carlsson, D., Rönnqvist, M., 2007. Backhauling in forest transportation: models, methods, and practical usage. Canadian Journal of Forest Research, 37(12): 2612-2623.

Camarinha-Matos, L.M., Afsarmanesh, H., 2005. Collaborative networks: A new scientific discipline. Journal of Intelligent Manufacturing, 16 (4-5): 439-452.

Cederlund, J. P., Kohli, R., Sherer, S.A., Yao, Y., 2007. How Motorola put CPFR into action. Supply Chain Management Review, 11(7): 28-35.

Chambost, V., McNutt, J. Stuart, P.R., 2009. Partnerships for successful enterprise transformation of forest industry companies implementing the forest biorefinery. Pulp & Paper Canada, May/June 2009, 19-24.

Chen F., 2003. Information Sharing and Supply Chain Coordination. In de Kok, A.G., Graves, S.C. (Eds.), Handbooks in operations research and management science. Elsevier, Amsterdam, pp. 341-421.

Clifton, C., Iyer, A., Cho, R., Jiang, W., Kantarcioglu, M., Vaidya, J., 2008. An approach to securely identifying beneficial collaboration in decentralized logistics systems. Manufacturing & Service Operations Management, 10 (1): 108-125.

Corbett, C.J., Decroix, G.A., Ha, A.Y., 2005. Optimal shared-savings contracts in supply chains: Linear contracts and double moral hazard. European Journal of Operational Research, 163(3): 653-667.

Cruijssen, F., Borm, P., Fleuren, H., Hamers, H., 2005. Insinking: a methodology to exploit synergy in transport. CentER Discussion Paper 2005-121, Tilburg University, Netherlands.

Cruijssen, F., Borm, P., Dullaert, W., Hamers, H., 2007a. Joint hub network development. CentER Discussion Paper 2007-76, Tilburg University, Netherlands.

Cruijssen, F., Dullaert, W., Fleuren, H., 2007b. Horizontal cooperation in transport and logistics: a literature review. Transportation Journal, 46 (3): 22-39.

D'Amours, S., Frayret, J.-M., Rousseau, A., Harvey, S., Plamondon, P., Forget, P., 2006. Agent-based Supply Chain Planning in the Forest Products Industry. In Shen, W. (ed.) IFIP International Federation on Information Processing, Vol. 220, Springer, Boston, MA, pp.17-26.

Danese P. 2006. The extended VMI for coordinating the whole supply network. Journal of Manufacturing Technology Management, 17(7): 888-907.

De Toni, A. F., Zamolo, E., 2005. From a traditional replenishment system to vendor-managed inventory: A case study from the household electrical appliances sector. International Journal of Production Economics, 96(1): 63-79.

Dong, A. H., Wong, W. K., Chan, S. F., Yeung, P. K. W., 2006. Improve production balance for apparel supply chain adopting VMI replenishment strategy. Proceedings of the International Conference on Management of Innovation and Technology, June 21-23, Piscataway, NJ, pp. 848-852.

Durango-Cohen, E., Yano, C. A., 2006. Supplier commitment and production decisions under a forecast-commitment contract. Management Science, 52(1): 54-67.

Ergun, O., Kuyzu, G., Savelsbergh, M., 2007a. Reducing truckload transportation costs through collaboration. Transportation Science, 41(2): 206-221.

Ergun, O., Kuyzu, G., Savelsbergh, M., 2007b. Shipper collaboration. Computers & Operations Research, 34(6): 1551-1560.

Eriksson, J., Rönnqvist, M., 2003. Decision support system/tools: Transportation and route planning: Åkarweb – a web based planning system. 2nd Forest Engineering Conference. May 12-15, Växjö, Sweden.

Fawcett, S.E., Osterhaus, P., Magnan, G.M., Brau, J.C., McCarter, M., 2007. Information sharing and supply chain performance: the role of connectivity and willingness. Supply Chain Management: An International Journal, 12(5): 358–368.

Frayret, J.-M., D'Amours, F., D'Amours, S., 2003. Collaboration et outils collaboratifs pour la PME [Collaboration and collaborative tools for manufacturing SMEs]. CEFRIO Technical Report.

Frayret, J.-M., D'Amours, S., Montreuil, B., 2004. Co-ordination and control in distributed and agent-based manufacturing systems. Production Planning and Control, 15(1): 1-13.

Frisk, M., Jörnsten, K., Göthe-Lundgren, M., Rönnqvist, M., 2010. Cost allocation in collaborative forest transportation. European Journal of Operational Research 205(2): 448-458.

Frayret, J.-M., D'Amours, S., Rousseau, A., Harvey, S., Gaudreault, J., 2007. Agent-based supply chain planning in the forest products industry. International Journal of Flexible Manufacturing Systems, 19(4): 358-391.

Forsberg, M., Frisk, M., Rönnqvist, M., 2005. FlowOpt – a decision support tool for strategic and tactical transportation planning in forestry. International Journal of Forest Engineering, 16(2): 101-114.

Fugate, B. S., Davis-Sramek, B., Goldsby, T. J., 2009. Operational collaboration between shippers and carriers in the transportation industry. International Journal of Logistics Management, 20 (3): 425-447.

Guo, B.-c. Ding, H.-p., 2006. Information Sharing Value and Its Allotment in Multi-level Supply Chain. Proceedings of 13th International Conference on Management Science and Engineering, ICMSE'06, Lille, France, October 5-7, pp. 571-576.

Hu, L.-y., Chunyu, Y.-q., Jiang, Z.-s., 2007. Research on the coordination mechanism model of the three-level supply chain. Proceedings of the 14th International Conference on Management Science & Engineering, August 20-22, Piscataway, NJ, pp. 734-739.

Kang, K., Zhang, J., Xu, B., 2007. Optimizing the Selection of Partners in Collaborative Operation Networks. Proceedings of the 3rd International Conference on Intelligent Computing: Advanced Intelligent Computing Theories and Applications, August 21–24, Qingdao, China. pp. 836-850.

Kilger, C., Reuter, B., Stadtler, H., 2008. Collaborative Planning. In : Stadtler, H., Kilger, C., (Eds.). Supply Chain Management and Advanced Planning: Concepts, Models, Software, and Case Studies, Springer-Verlag, Berlin Heidelberg, pp. 263-284.

Lambert, D.M., Emmelhainz, M.A., Gardner, J.T., 1996. So you think you want a partner? Marketing Management. 5(2): 24-40.

Lee, H.L., Padmanabhan, V., Whang, S., 1997. Information Distortion in Supply Chain: the Bullwhip Effect. Management Science, 43(4): 546-558.

Lehoux, N., D'Amours, S., Langevin, A., 2008. A win-win collaboration approach for a two-echelon supply chain: a case study in the pulp and paper industry. Forthcoming in European Journal of Industrial Engineering.

Lehoux, N., Audy, J.-F., D'Amours, S., Rönnqvist, M., 2009a. Issues and experiences in logistics collaboration. In: Camarinha-Matos, L., Paraskakis, I., Afsarmanesh, H., (Eds.). Leveraging Knowledge for Innovation in Collaborative Networks, IFIP, Springer, Boston, MA, pp. 69–77.

Lehoux, N., D'Amours, S., Frein, Y., Langevin, A., Penz, B., 2009b. Collaboration for a two-echelon supply chain in the pulp and paper industry: the use of incentives to increase profit. Journal of Operational Research Society, doi: 10.1057/jors.2009.167.

Lehoux N., D'Amours, S., Langevin, A., 2009c. Collaboration and decision models for a two-echelon supply chain: a case study in the pulp and paper industry. Journal of Operations and Logistics, 2(4): VII.1-VII.17.

Leng, M., Parlar, M., 2005. Game theoretic applications in supply chain management: A review. Information Systems and Operational Research, 43 (3): 187-220.

Leng, M., Parlar, M., 2009. Allocation of Cost Savings in a Three-Level Supply Chain with Demand Information Sharing: A Cooperative-Game Approach. Operations Research, 57(1): 200-213.

Liu, D, Roberto Boër C., Sacco M., Fornasiero, R., 2006. A networked engineering portal to support distributed supply chain partnership. International Journal of Computer Integrated Manufacturing, 19(2): 91-103.

March, J. G., Simon, H.A., 1958. Organizations. John Wiley & Sons, New York.

Marshall, H., 2007. Log merchandizing model used in mechanical harvesting. In: Weintraub, A., Romero, C., Bjorndal, T., Epstein, R., (Eds.). Handbook of Operations Research in Natural Resources, International Series in Operations Research and Management Science, Kluwer Academic Publishers, New York, pp. 379-389.

Mason, R., Lalwani, C., Boughton, R., 2007. Combining vertical and horizontal collaboration. Supply Chain Management: An International Journal, 12(3): 187-199.

Montreuil, B., Frayret, J.M., D'Amours, S., 1999. A Strategic Framework for Networked Manufacturing. Computers in Industry 42(2-3): 299-317.

Moyaux, T., Chaib-draa, B., D'Amours, S., 2007. The impact of information sharing on the efficiency of an ordering approach in reducing the bullwhip effect. IEEE Transactions on Systems, Man, and Cybernetics. Part C. 37(3): 369-409.

Naesens, K., Gelders, L., Pintelon, L., 2007. A swift response tool for measuring the strategic fit for resource pooling: a case study. Management Decision, 45(3): 434-449.

Nagarajan, M., Sošic, G., 2008. Game-theoretic analysis of cooperation among supply chain agents: review and extensions. European Journal of Operational Research, 187(3): 719-745.

Özener, O.Ö., Ergun, Ö., 2008. Allocating costs in a collaborative transportation procurement network. Transportation Science, 42(2): 146-165.

Quélin B., 2002. Les frontières de la firme. Economica, Paris.

Ryu, I., So S., Koo, C., 2009. The role of partnership in supply chain performance. Industrial Management & Data Systems, 109(4): 496-514.

Shen, H., Pang, Z., 2004. Supply chain coordination via capacity options with uncertain demand and supply. Proceedings of the International Conference on Systems, Man and Cybernetics, IEEE, October 10-13, New York.

Simatupang, T.M., Sridharan, R., 2002. The collaborative supply chain. International Journal of Logistics Management, 13(1): 15-30.

Sirias, D., Mehra, S., 2005. Quantity discount versus lead time-dependent discount in a inter-organizational supply chain. International Journal of Production Research, 43(16): 3481-3496.

Sombattheera, C., Ghose, A., 2006. A distributed branch-and-bound algorithm for computing optimal coalition structures. In Antoniou, G., Potamias, G., Spyropoulos, C., Plexousakis, D. (eds) Lecture Notes in Computer Science. Springer-Verlag, Berlin.

Sreedharan, P., Vollmer, D.D., 2009. Partnerships for Sustainability: Past, Present, and Future. In: Vollmer, D. (ed.) Enhancing the Effectiveness of Sustainability Partnerships: Summary of a Workshop, National Academies Press, Washington.

Stadtler, H., 2009. A framework for collaborative planning and state-of-the-art. OR Spectrum, 31(1): 5-30.

Subramani, M., 2004. How do suppliers benefit from information technology use in supply chain relationships? MIS Quaterly, 28(1): 45-73.

Thron, T., Nagy, G., Wassan, N., 2005. The impact of various delivery prioritization strategies in heterogeneous supply chain environments. Proceedings of the 3rd International Industrial Simulation Conference, Eurosis-ETI, Ghent, June 9-11, pp. 262-268.

Tijs, S.H., Driessen, T.S.H., 1986. Game theory and cost allocation problems. Management Science, 32 (8): 1015-1058.

van der Vaart, T., van Donk, D. P., 2008. A critical review of survey-based research in supply chain integration. International Journal of Production Economics, 111(1): 42-55.

Xu, X.-s., Weng, M., 2007. Quantity flexibility contract design in supply chain under adverse selection. Proceedings of the 14th International Conference on Management Science & Engineering, August 20-22, Piscataway, NJ.

Yan, X., Zhang, M., Liu, K., 2010. A note on coordination in decentralized assembly systems with uncertain component yields. European Journal of Operational Research, 205(2): 469-478.

Young, H.P., 1985. Cost allocation: methods, principles, applications. North-Holland, Amsterdam.

4 Decision support system for collaborative transportation

This chapter presents the article entitled “Virtual Transportation Manager: A decision support system for collaborative forest transportation” which will be submitted shortly. Here is an abstract of the article in French.

4.1 Résumé

Les opérations de transport représentent une partie importante du coût d'approvisionnement en bois. Ces dernières années au Canada, des initiatives de recherche ont été consacrées aux méthodes de planification avancées du transport forestier comme un moyen de réaliser des réductions de coût. Parallèlement, la littérature sur le transport des marchandises a identifié la collaboration interentreprises dans la planification du transport comme un moyen d'atteindre des économies additionnelles. En général au Canada, de nombreux décideurs sont impliqués dans le transport forestier au niveau régional. Cet article présente un système d’aide à la décision soutenant la collaboration en transport entre ces décideurs. Plus précisément, la collaboration a lieu lors du routage des camions forestiers, à savoir lors de la détermination des itinéraires de livraison de demandes de transport spécifiés par les décideurs. Les principales composantes du système sont détaillées ainsi que la façon dont la collaboration est organisée avec le système. Le problème de routage étudié et la méthode de planification proposée sont également décrits. Une étude de cas industriel dans laquelle le système a été testé est présentée avec les résultats obtenus. Des détails sur les retombées de l'étude de cas termine la discussion.

Virtual Transportation Manager: A decision support system for collaborative forest transportation

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Abstract. Transportation operations account for a significant part of wood procurement costs. In recent years in Canada, a number of research initiatives have been devoted to forest transportation planning methods as a means of achieving cost reduction. Moreover, literature on freight transportation identifies inter-firm collaboration in transportation planning as a way to attain further cost-savings. Typically in Canada, many decision makers are involved in forest transportation at the regional level. This article presents a decision support system supporting collaborative transportation among these decision makers. More precisely, collaboration takes place in the routing of forest trucks, i.e. the determination of the set of routes to deliver transportation requests specified by the decision makers. The main components of the system as well as how transportation collaboration is organized with the system are detailed. The routing problem addressed and the solution method proposed are described. An industrial case study in which the

system was tested is presented with the results obtained. Details about the actual outcome of the case study complete the discussion.

Keywords: Transportation; Collaboration, Decision support system; Forest products industry

4.2 Introduction

Transportation activities from harvest areas to industries represent an average of 36% of the operational costs of delivering timber to a Canadian mill (Michaelsen, 2012). With an average of 155 million cubic metres harvested annually from 2005-2010 (CCFM, 2012), transportation represents an expense of at least two billion Canadian dollars a year for Canadian forest companies. With all this money spent on transportation, even a small cost reduction can lead to substantial savings (Palmgren et al., 2004). Therefore, in recent years in Canada, a number of research initiatives have been devoted to computer-based transportation planning methods as a means of achieving cost reduction through enhanced transportation activities efficiency, Gingras et al. (2007); El Hachemi et al. (2009, 2011, 2013); Audy et al. (2011b); Rix et al. (2011). Different benefits, including potential/real cost-savings of 0.8-35%, from computer-based planning methods in forest transportation have already been reported in several countries such as Chile, Finland, New Zealand, Sweden and US. Moreover, to allow decision makers (DM) in forest transportation to use computer-based planning methods, decision support systems (DSSs) embedding planning methods have been developed and deployed in the industry.

In the research field on freight transportation planning, collaboration among companies has been identified as a way to attain a further increase in transportation activities efficiency and, in turn, provide additional cost-savings to collaborating companies. We refer interested readers to e.g. le Blanc et al. (2007), Cruijssen et al. (2007b), Ergun et al. (2007), Özener and Ergun (2008), Krajewska et al. (2007), Clifton et al. (2008), Audy et al. (2011a) and Dai and Chen (2012). Case studies with cost-savings through collaborative planning have also been reported in the literature on forest transportation. For instance, Marier et al. (2009) and Lehoux et al. (2009) report a savings of 1.2% and 8.7% with collaborative planning in their respective case studies. These savings from collaboration account for a proportion of 23.8% and 61.3% of the total cost reduction obtained by the computer-based planning method. Therefore, forest companies must be aware that continuing further with collaborative transportation planning could provide significant additional cost-savings.

In Canada, many DMs are typically involved in the management of the wood fibre flow at the regional level. This regional wood fibre flow includes flow from the forest to industries as well as between industries. In this article, we present a DSS to support inter-firm collaboration in forest transportation in Canada. Collaboration occurs through the planning of a Vehicle Routing Problem (VRP): the determination of the delivery routes to be performed by a fleet of forest trucks to transport wood fibre (e.g. logs, sawdust, wood chips) from origin sites (e.g. harvest area, intermediate terminal, industry) to destination sites (e.g. intermediate terminal, industry). By enabling centralized organization of the delivery routes, the DSS makes collaboration possible among these DMs. Called VTM (abbreviation of ‘Virtual Transportation Manager’), the DSS was jointly developed from 2003-2007 by researchers at FORAC Research Consortium (Université Laval) and FPInnovations (formerly Forest Engineering Research Institute of Canada), and with the cooperation of a number of Canadian forest companies.

The main research contribution of our article is twofold. First, we give a description of a DSS for forest truck routing that is explicitly designed to address an inter-firm collaboration context. Second, through the presentation of an industrial case study where the system use is illustrated, we provide a description of the VRP addressed and the planning method proposed.

The article is organized as follows. In Section 4.3, we introduce preliminary concepts supporting the article; we introduce transportation planning and the collaboration opportunities in forest transportation, we discuss a number of existing DSSs in forest transportation and finally, we review a number of planning methods for VRP in forest transportation. In Section 4.4, we introduce the developed DSS and provide an overview of its main components. How transportation collaboration is organized on the system is described in Section 4.5. This description covers the VRP addressed and the planning method proposed. In Section 4.6, we detail the industrial case study in which the system was tested and report numerical results. Discussion about the actual outcome of the case study and further initiatives to transfer the system to the Canadian forest industry are given in Section 4.7. Finally, we make concluding remarks in Section 4.8.

4.3 Preliminary concepts

4.3.1 Planning and collaboration opportunities in forest transportation

Transportation planning in forestry operations involves many decisions commonly managed according to four time-perspective horizons [i.e. strategic (up to five years), tactical (six months to one year), operational (one to 180 days), and real-time (<one day)] where the exact planning horizons used by transportation decision makers are related to their context. 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 of transportation infrastructures (e.g. primary road network, terminal) and the selection of transportation modes (e.g. deployment of train, ship or heavy-load truck multimodal system with the acquiring of associated transportation equipment). 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 aggregated utilization level (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.

Strategic and tactical transportation-related decisions are often planned simultaneously with other decisions related to wood procurement (e.g. silviculture, harvesting) and mill production. Consequently, companies are generally reluctant to engage in transportation collaboration on these levels even with high expected returns (Audy et al. 2006). This is particularly true for the construction of major transportation infrastructures (e.g. train terminals). In contrast to strategic/tactical decisions, operational decisions provide interesting conditions (i.e. high-moderate expected return, low risk and non-core activity) for collaboration among many companies (Audy et al. 2006). Depending on the operational decisions, the savings with collaboration in transportation planning derive from several collaboration opportunities. We identify three main collaboration opportunities when companies collaborate in their transportation planning at the operational/real-time level: *raw material exchange* (operational level), *common back-haulage tour* (operational level) and *common route* (operational and real-time levels).

In *raw material exchange*, volumes of certain supply points are exchanged between companies to reduce the total travelling distance as e.g. in Marier et al. (2009). To reduce the total travelling distance even more, the raw material exchange can be jointly planned with back-haulage tours as e.g. in Forsberg et al. (2005) and Frisk et al. (2010). Back-haulage tours are future potential routes schedules that combine the delivery of two or more truckloads (see the survey by Carlsson and Rönnqvist, 2007). Our second collaboration opportunity, designated as *common back-haulage tours* refers to tours in which the combined truckloads belong to different companies. The third collaboration opportunity, *common routes*, can occur at both the operational and real-time planning levels. At the operational level, it involves routing a fleet of trucks in which some route schedules are enhanced by realizing pick-up/delivery operations for several companies rather than only one. At the real-time level, enhanced truck routes by multi-company pick-ups/deliveries will also be obtained but through truck dispatching instead of truck routing. The *common routes* collaboration opportunity also involves sharing of transportation capacity among independent carriers as e.g. in the case study by Mendell et al. (2006). Typically, independent carriers rely on a fixed transportation capacity (e.g. in number of trucks and drivers) for a fluctuating workload. This leads to situations of excess or shortage in capacity depending on the average short (excess) or long (shortage) transportation distance from roadside inventory supply sites (for which they are responsible) to the industries. Sharing transportation capacity allows minimizing such situations by a transfer of capacity from the carriers in excess to the carriers in shortage.

Geographical distribution of the origin and destination sites, as well as a multi-directional and connected road network, has an important influence on the potential in savings from these collaboration opportunities. Moreover, not all the volumes to transport involve a collaboration opportunity. For instance, in the aformentioned case study in Marier et al. (2009), only 12% of the total transported volume involves raw material exchange. Furthermore, the collaboration opportunities as well as the potential in savings are not necessarily equally distributed among the volumes of each company. This means that the volume of some companies provides, either absolutely or relatively, more potential in savings than the volume of other collaborating companies, as found in the case study with eight collaborating companies by Frisk et al. (2010).

The second column in Table 7 reports a number of papers on solutions methods for forest transportation planning at the operational/real-time level. The selected papers focus on timber transportation and thus planning methods for other wood fibre are excluded (e.g. forest fuel transportation in Acuna et al., 2011 and Flisberg et al., 2012). The papers are classified according to the main planning decision addressed by the solution method they propose. For the planning decision on timber truck routing, the solution methods are further classified in two subsets depending on whether they also involve allocation decisions (i.e. subset titled ‘many-to-many structure’) or not (i.e. subset titled ‘one-to-one structure’). More details on this classification are provided in Section 4.3.3.

Modifications to a method can be required in a context of collaborative planning among forest companies and/or their carriers. These modifications are usually expressed as additional constraints to the models behind the planning methods. For instance, in a case study of raw material exchange, Forsberg et al. (2005) report additional constraints to their allocation model according to different exchange scenarios (e.g. a limit on the total volume that could be exchanged between the companies). In another case study with raw material exchange on a monthly basis, Lehoux et al. (2009) report two constraints: each company must remain the main supplier for its own mills (specified by a minimum percentage), and raw material exchanges must be pairwise equal (i.e. a company must supply each collaborator with the volume equivalent to that received from that specific collaborator). This latter constraint is also mentioned in the case study in Bouchriha et al. (2009) and Marier et al. (2009). By adding constraints, the potential savings of the collaboration is usually reduced. For instance, the two modifications in the aforementioned case in Lehoux et al. (2009) systematically decrease by 1-2% the potential savings of each month, which are in the range of 5-20%. Many of the papers with case studies involving transportation collaboration (papers identified with an asterisk in Table 7) do not report modification to their planning method because of the transportation collaboration. Therefore, this suggests that the solution methods proposed for planning in a context without collaboration could be used without modification for collaborative planning. However, extra care must be taken to ensure that no modification is required to satisfy the collaboration context.

Table 7 : Planning methods and decision support systems classified per collaboration opportunity.

Collaboration opportunity **(planning decision)**		**Reference on planning method** **(papers identified with an asterisk involve case studies with collaboration)**	**Decision support system** **(reference)**
Raw material exchange (Supply and demand points allocation)		Williamson and Nieuwenhuis (1993); Bergdahl et al. (2003); Puodziunas et al. (2004)*; Forsberg et al. (2005)*; Palander and Väätäinen (2005)*; Carlgren et al. (2006)*; Frisk et al. (2010)*	Pulkki (1984); FlowOpt (Forsberg et al., 2005)
Common back-haulage tours (Design of truck back-haulage tours)		Eriksson and Rönnqvist (2003)*; Puodziunas et al. (2004)*; Forsberg et al. (2005)*; Palander and Väätäinen (2005)*; Carlgren et al. (2006)*; Carlsson and Rönnqvist (2007)*; Gingras et al. (2007); Frisk et al. (2010)*	Åkarweb (Eriksson and Rönnqvist, 2003); FlowOpt (Forsberg et al., 2005); MaxTour (Gingras et al., 2007);
Common routes	(Truck routing)	*Many-to-many structure:* Shen and Sessions (1989); Linnainmaa et al. (1995); Weintraub et al. (1996); Murphy (2003)*; Palmgren et al. (2003, 2004); El Hachemi et al. (2009, 2013); Flisberg et al. (2009)*; Rey et al. (2009); Rummukainen et al. (2009); Audy et al. (2011b); Hirsch (2011) *One-to-one structure:* McDonald et al. (2001a,b)*; Mendell et al. (2006)*; Gronalt and Hirsch (2007); El Hachemi et al. (2011); McDonald et al. (2010)*; Zazgornik et al. (2012)*	Tolkki and Koskelo (1993); EPO2 (Linnainmaa et al., 1995); ASICAM (Weintraub et al., 1996) ; KUORMA (Savola et al., 2004 ; Rummukainen et al., 2009) ; RuttOpt (Andersson et al., 2008) ; ORTEC (Kokenge, 2011); Blue Ox/FLO (Jacqmin, 2012)
	(Truck dispatching)	Rönnqvist and Ryan (1995); Rönnqvist et al. (1998)	CADIS (Rönnqvist and Ryan, 1995; Rönnqvist, 2012); Blue Ox/FLO (Jacqmin, 2012); ForesTruck (Soriano, 2012)

4.3.2 Decision support systems in forest transportation

How the transportation planning is done, by whom and to what level of detail varies significantly among companies (Rönnqvist et al., 2003). Some companies perform in-house transportation planning while others outsource it, entirely or partially, 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 its behalf, a set of asset-based transportation service providers (Selviaridis and Spring, 2007). Some companies also merge their wood procurement function in one independent and non-for-profit company responsible for supplying each of them and thus, overlapping transportation organizations are eliminated. As a result, there is a gradient in transportation planning from a decentralized approach to a centralized one.

There is a trend for transportation planning to become more centralized and for trucks to increase their working area (Epstein et al., 2007). Such a trend increases the relevance of computer-based planning methods like the ones reported in Table 7. Indeed, on larger and more complex transportation problems involved in centralized planning, they are more cost-effective than manual planning by a DM. Thus, to allow a DM in timber transportation to use computer-based planning methods, decision support systems (DSSs) embedding planning methods have been developed and deployed in the industry. To the best of the authors' knowledge, the first mention of a 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. Considerable effort has been expended on transportation-oriented DSSs in other industry sectors as reported by Zak (2010).

The third column in Table 7 reports a number of DSSs in timber transportation. They are classified according to the main planning decision they address. We provide an overview of them and we refer to the review by Audy et al. (2012b) for more details.

An earlier DSS in timber transportation is presented by Pulkki (1984). The system can be used to solve a number of transportation decisions, mainly at the tactical level (e.g. wood procurement areas, terminal service area), and also account for several transportation methods (e.g. road, rail, water channel, bundle floating) and inter-modal system. Improved versions of the system were implemented in timber transportation in Finland and Norway and in other industrial sectors (Pulkki, 1988).

Since its development in the early 1990's by researchers at the Universidad de Chile, ASICAM is used by several forest companies, mainly in South America (Epstein et al., 2007). It produces the daily working schedule for a fleet of more than 250 trucks and many loaders (Rey et al., 2009) and significant benefits are reported in Weintraub et al. (1996) and Epstein et al. (1999). More recently, the system has been redesigned to be used for real-time decisions in truck dispatching (Weintraub, 2012).

EPO2 is the truck 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. It produces the weekly working schedule for a fleet of about 20 trucks (Linnainmaa et al., 1995). Additional savings are anticipated with KUORMA, the second-generation DSS that replaced EPO in 2002 (Savola et al., 2004). KUORMA provides a few days' working schedule for the entire fleet (about 250 trucks) carrying for the forest company. Before its execution, the working schedule is validated by local DMs (Rummukainen, 2012).

CADIS was developed in the mid-1990s for truck dispatching in a New Zealand forest company. This system was successfully implemented to manage a fleet of more than 120 trucks for several years before the company went through a difficult period financially and abandoned the system in its reorganization (Rönnqvist, 2012).

Åkarweb is a web-based system developed by a major Swedish forest company from 1999-2001. It is used with 50 DMs and involves about 80 trucks (Andersson et al., 2008).This system identifies, on a daily basis, the best potential back-haulage tours for all the truckloads, each assigned to a specific DM. It is then up to each DM to schedule or not the proposed back-haulage tours and, for a back-haulage tour involving a truckload assigned to a different DM, collaborate or not to achieve it.

A first version of FlowOpt was developed from 2002-2004 by the Forestry Research Institute of Sweden. It makes the allocation decision of large supply areas (i.e. catchment areas) to demand points with the possibility of integrating inter-modal transportation (e.g. truck and train), back-haulage tours and, with collaborative planning, raw material exchanges. The DSS has been successfully used for Swedish and international forest companies (Flisberg et al., 2012) and, in particular, to update the whole transportation planning of a Swedish forest company after its supply areas were hit by a major storm (Broman et al., 2009).

RuttOpt was developed from 2003-2007 by the Forestry Research Institute of Sweden for log truck routing in the Swedish context (Andersson et al., 2008). It produces, for up to five days, the daily working schedule for a fleet of up to 110 trucks. Despite significant potential benefits in several case studies, the system faced implementation concerns and until now has mainly been used to perform analyses (Audy et al., 2011c). This system is currently being used to assess truck routing efficiency for 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 recent loads delivered by their fellows (Lidén, 2011).

Developed in the mid-2000s, MaxTour is the truck backhauling module within the forestry operations control platform FPSuite, developed by FPInnovations (Lepage, 2012). It provides back-haulage tours with the possibility of using multi-product truck trailers (e.g. timber and pulp chips) in addition to classic (mono-product) truck trailers. Multi-product trailers can increase the number of possibilities in back-haulage tours and, in turn, benefits (see e.g. case study in Gingras et al., 2007). The proposed back-haulage tours have been used by DMs in Canada to support their manual truck routing (Lepage, 2012).

The company ORTEC provides decision support software solutions for different industrial sectors. A tailored version of their truck routing system was implemented by a US Pacific Northwest forest company and provided, from 2005-2007, the daily working schedule for a fleet of up to 100 trucks. Despite significant benefits, the use of the system was suspended, especially because of the difficulty in changing the culture of the parties involved (Kokenge, 2011).

Forestruck is an information system for the operational planning, control and analysis of the entire wood supply chain activities that include a truck dispatching module. A first version of ForesTruck was developed in 2006 by West Ingeniería Ltda. It is used by Chilean forest companies to manage any size fleets up to reaching limits in technology capacities (e.g. hardware, Internet connection). Implementation of the system provides cost-savings according to two main factors: increased productivity of the equipment and lower fees for administration and required system use (Soriano, 2012).

A first version of FLO (formerly Blue Ox) was developed in 2009 by Trimble Forestry Automation. It 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). FLO can be configured to be used for truck routing or dispatching 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).

4.3.3 Planning methods for forest truck routing

The presented DSS focuses on one operational planning decision: how to determine the set of routes to be performed by a fleet of trucks to deliver wood fibre (e.g. logs, sawdust, wood chips) from origin sites (e.g. harvest area, intermediate terminal, industry) to destination sites (e.g. intermediate terminal, industry). In the literature, this planning problem is known as the Vehicle Routing Problem (VRP) and is one of the most important and well-studied combinatorial optimization problems (Toth and Vigo, 2002). The VRP in forest 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. Therefore, the PDP consists of constructing a set of vehicle routes according to a given objective and subject to a set of constraints. Often when time constraints are considered in vehicle routing, the problem is called vehicle scheduling (or vehicle routing and scheduling) and the vehicle route is usually called vehicle schedule. For a survey on planning 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).

An important dimension in PDP is the availability of information at planning time (Berbeglia et al., 2007). 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. Planning methods for both static (see papers on line 'Truck routing' in Table 7) and dynamic (see papers on line 'Truck dispatching' in Table 7) PDP in timber transportation have been proposed in the literature. A critical aspect in the planning method for a dynamic PDP is to be able to quickly adjust a current solution as new and/or updated information is obtained. In practice, a DSS designed to be used in a dynamic mode (i.e. therefore embedding a dynamic PDP) involves higher operational requirements than a DSS designed for use in static mode. For instance, a dynamic DSS requires human resources for continuous monitoring of the transportation operations and deployment of technology for information exchange in quasi real-time with scattered transportation actors (e.g. drivers, delivery facility at destination site). The presented DSS was designed to be used in a static mode (i.e. embedding a static PDP). Future redesign of the system for a dynamic mode remains an option as done by the aforementioned DSS ASICAM.

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. In Table 7, papers addressing a static PDP can be classified into two of them: the *many-to-many* structure (i.e. in which any site can serve as a source or as a destination for any commodity) and the *one-to-one* structure (in which a commodity has a given origin and a given destination). This means that in the many-to-many structure, the supply and demand points are unpaired and, therefore, the PDP includes allocation decisions in addition to the routing decisions. Allocation decisions are made before the presented DSS and thus the system addresses a static PDP with a one-to-one structure.

Static PDP in timber transportation has been studied in many countries (e.g. Austria, Canada, Chile, Finland, New Zealand, Sweden and US). Several planning methods have been proposed in the literature (see Table 7). Typically, planning methods for PDP with a many-to-many structure transform the many-to-many structure of their initial PDP into a one-to-one structure by making the allocation decisions first and then the routing ones. To make allocation decisions, the well-known *transportation model* in OR could be modified to deal with the notions of assortment and assortment group (see e.g. Epstein et al., 2007). We discuss a number of planning methods for static PDP in timber transportation and we refer to Audy et al. (2012b) for a complete review.

Linnainmaa et al. (1995) propose a three-phase approach using exact mathematical programming methods and heuristics to generate a preliminary weekly truck schedule that is then subject to validation by DMs. 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. McDonald et al. (2001a,b) and Mendell et al. (2006) also propose a simulation-based method to generate a daily route schedule and different rules to assign trucks to supply sites are tested.

A column generation method in which each column corresponds to one feasible route is proposed by Palmgren et al. (2003, 2004) and Rey et al. (2009) to generate a daily truck schedule. McDonald et al. (2010) propose a simulated annealing method in which each new solution (daily routes schedule) generated is evaluated according to four performance metrics.

Gronalt and Hirsch (2007) propose a Tabu Search (TS) method to generate a daily route schedule to deliver a set of requests. 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. The third phase in the three-phase method by Hirsch (2011) addresses a daily PDP and, based on Gronalt and Hirsch (2007), the author proposes a TS method and two modified TS strategies.

Flisberg et al. (2009) also propose an extended version of the UTSA in the second phase of their method generating routes schedules for up to five days. In the first phase, a two-step procedure generates *transportation nodes* (i.e. comparable to a request with a maximal volume of one full truckload) in which less-than-truckload (LTL) size requests with the same destination are, under certain conditions, allowed to be included in one request of full (or nearly) truckload size. Along with Rummukainen et al. (2009), Flisberg et al. (2009) propose the two planning methods that support the consolidation of less-than-truckload (LTL) size requests in a full (or nearly) truckload-size request. Rummukainen et al. (2009) propose a three-phase method embedding a mixed integer programming (MIP) model, a dynamic programming algorithm and two TS heuristics. It is in the first phase that a TS heuristic creates a full (or nearly) truckload-size request by splitting large volume at supply point or by consolidating LTL-size requests together.

El Hachemi et al. (2009) and El Hachemi et al. (2013) propose a two-phase method to solve consecutive daily PDPs from an initial weekly PDP. The first method embeds local search algorithms enhanced with a tabu component and a greedy heuristic. The second method embeds an MIP model and a constraint-based local search model with two solving approaches: an iterated local search algorithm and a hybrid algorithm combining previous iterated local search algorithm and constraint programming (CP). A hybrid method based on a CP model and an integer programming model is proposed by El Hachemi et al. (2011) to generate a daily route schedule.

4.4 Decision support system Virtual Transportation Manager

In Canada, many DMs are involved in managing wood fibre flows at the regional level, i.e. flow from the forest to the industries as well as between industries (e.g. the wood chips produced at a sawmill are used to supply a pulp mill). As reported in other countries (e.g. Sweden, US), the organization of transportation planning in Canada is typically decentralized: i.e., each DM performs his/her own transportation planning with no or limited collaboration with other DMs. However, a growing number of forest companies are aware that a number of their transportation contractors achieved some limited collaboration without disclosing it. Moreover, according to a number of experts and studies (Brown et al., 2003; Gingras et al., 2007), benefits could be achieved in Canadian regions through well-organized collaboration in transportation planning, especially through the use of multi-product truck trailers. Indeed, cases in the forest industry (Michaelsen, 1996; Webb, 2002; Michaelsen, 2009) demonstrated the benefits of replacing a number of tractor-trailers specialized in hauling only one type of product by multi-product tractor-trailers capable of hauling different types of product (e.g. bulk fibre and timber, bulk fibre and finished wood products). Despite such results, adoption by the Canadian forest industry of multi-product trailers remains limited up to now. One issue is the decentralized organization of transportation planning: the types of product that a multi-product trailer is capable of hauling are typically managed by distinct DMs with no or limited collaboration.

The DSS presented in this article was developed to capture the third aforementioned collaboration opportunity (i.e. common route) within the wood fibre flow in a region. DMs with transportation activities within the targeted region specified their transportation needs on the DSS through transportation requests. A transportation request is defined by a product type and attribute(s), an origin and a destination site, a volume, a weight and a transportation time window (i.e. an earliest pickup time at the origin and a latest delivery time at the destination). By enabling a centralized organization of the routes to deliver these transportation requests, the DSS allows collaboration among the DMs, i.e. to achieve a number of common routes. The novelty of the developed DSS lies in a number of attributes specifically designed to address an inter-firm collaboration context. More particularly, the DSS is designed to provide a logistics service to distinct DMs (belonging or not to the same company) and to manage transportation planning of different product types with the possibility of using multi-product trailers, while respecting data confidentiality and standardization issues.

4.4.1 System overview

Object-oriented modelling (OOM) was used to design the VTM. OOM is a modelling paradigm in which the data structure of software application is represented by ‘objects’ in an object-oriented model. In such a model, each object (e.g. transportation request, site) has potential mandatory or optional attributes (e.g. weight for object ‘transportation request’), methods (e.g. ‘GetByOriginSite’ returns the transportation requests at a given origin site) and relations with other objects (e.g. object ‘transportation request’ is linked with two objects ‘site’). We refer to e.g. Meyer (1997) for more details on OOM in the design of software application.

The VTM was developed as a web-based system. In contrast to the desktop DSS, a web-based DSS makes the system accessible via the Internet, typically using a web browser.

See Zahedi et al. (2008) for a review on web-based systems. One motivation for opting for a web-based DSS is the expected business model of the VTM: the Application Service Provider (ASP) model. In such a business model, the software application (here the VTM) is hosted and maintained by an ASP and Internet (or other wide area network) is used to provide online access to it on a rental basis (e.g. users billed on a per-seat basis or monthly/annual membership fee). This business model offers a number of benefits for the users (e.g. no hardware/software to maintain, small investment and risk), particularly for small to medium-size enterprises that are very present in the Canadian forest industry. More details on ASP model are found in Tao (2001).

A user of the system must perform one of the following three roles. First, there is a central DM role to perform, using the VTM, a centralized organization of the truck routing between the collaborating DMs. Second, there is a member role for each company with one to many DMs receiving the logistics service from the VTM. Third, the ASP has an administrator role to ensure proper system running and management of the user accounts on the VTM (e.g. once a company becomes a member of the VTM, a personalized user account is created for each of his DMs).

The main components involved in the VTM system are illustrated in Figure 10. They include: i) the transportation data from the DMs members of the VTM, ii) the core components constituting the VTM and, iii) the support components connected to the VTM. We describe each of them.

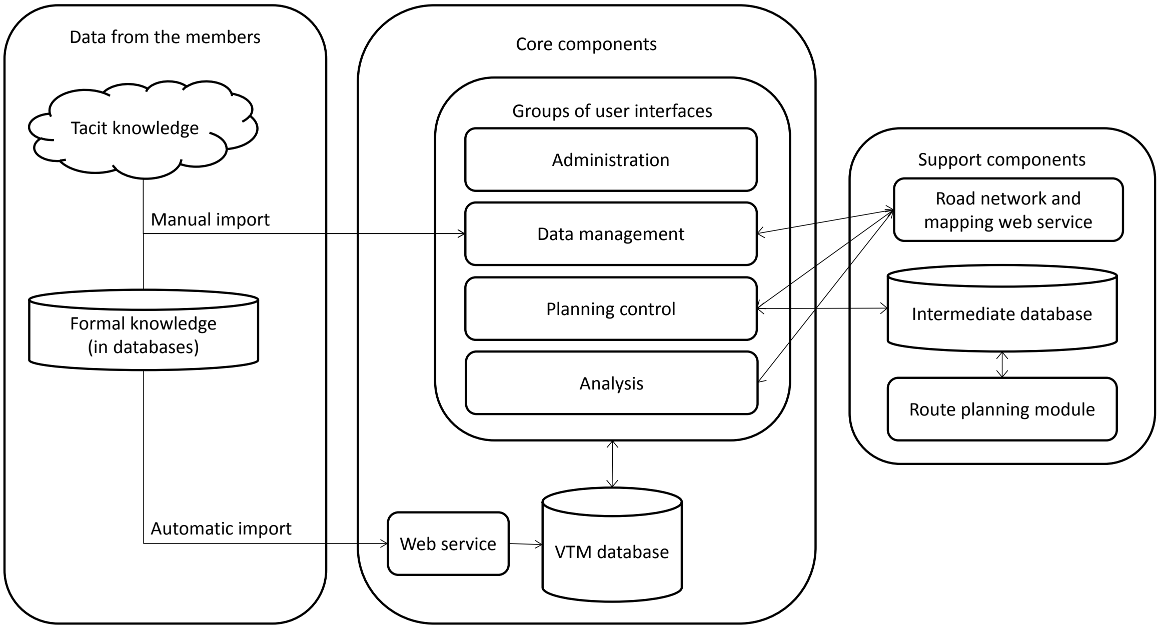


Figure 10 : Main components of the VTM system.

4.4.1.1 Transportation data from the members

The first component includes all the sources of transportation data available from each DM. These sources can be formal or tacit knowledge. With formal knowledge (i.e. already present in databases) it is possible to set up an automatic import of the transportation data from the database of a DM to the VTM database. This was implemented in the presented case study (see Section 4.6). This import is done using an Extensible Markup Language (XML) document and a web service. XML is a simple text-based format for representing and sharing structured information between programs, people and computers-people (W3C, 2012). The web service acts as a postal box to receive the XML documents (generated automatically from the DMs' databases) and triggers the update of the VTM database.

When such automatic import is not developed and/or to transfer tacit knowledge, a user interface in the VTM has been developed to allow DMs to manually import their transportation data to the VTM database. This import also uses XML documents that DMs generate on their own from their database (if formal knowledge) or (if tacit knowledge) by 'manually' generating the XML document, e.g. typing information in a provided database (Microsoft Access) embedding an XML document generator. As was done in the presented case study, in practice it is expected that most transfers of tacit knowledge to the VTM database will be handled by the central DM instead of individual DMs. Indeed, using different modes of communication (e.g. telephone, email), the central DM will gather the tacit knowledge from the individual DMs and achieve the required steps to import it to the VTM database.

Finally, we highlight the one-way flow of information from the individual DMs to the VTM database. At each new automatic or manual import, an update process is performed by the VTM to compare information already in the VTM database to the new imported information. For instance, new transportation requests in the import are added to the VTM database and transportation requests present in the VTM database but absent (with new parameters value) in the new import are removed from (modified in) the VTM database. Also, after each automatic or manual import by a user, a message (i.e. report on the import) is automatically generated and sent to the user by the VTM.

4.4.1.2 Core components

The core components constituting the VTM are: the groups of user interfaces, the VTM database (Microsoft SQL Server) and the aforementioned web service dealing with the automatic imports.

There are four groups of user interfaces grouped together by their main functionality: Administration, Data management, Planning control and Analysis. Access right to each user interface is according to the aforementioned roles (see Table 7). Moreover, some interfaces support the editing of the VTM database: i.e. they allow editing information directly in the interface. This editing right is also according to aforementioned roles (see Table 7). The administrator role has access and editing rights to all user interfaces but typically uses only its editing right on the interfaces related with the management of membership and the user accounts (i.e. interfaces in the Administration group). The central DM role has access and editing rights to all interfaces except the ones in the Administration group. Interfaces in the Data management group support preparation of the data required for the routes planning that are run by the central DM (using interfaces in the Planning group’s control), as well as the evaluation and implementation of the planned routes (using interfaces in the Analysis group). For the DMs of a member role, the access and editing right is limited to specific interfaces dedicated to data import (Data management group) or viewing (Data management and Analysis groups). In particular, an editing right is temporarily allowed when a DM imports a new site in the VTM database and only the information related to this new site can be edited. Details on a number of interfaces are given in Section 4.5. Finally, not reported in Table 8, there is an interface dedicated to each user of the VTM for the management of their personal account (e.g. change login password, update contact information).

Information displayed in an accessible user interface is subject to a confidentiality restriction for the member role while the central DM and administrator roles have complete visibility on all members' data. This restriction guarantees the confidentiality of members' private data between them while allowing private data visibility among the DMs of a same member. Data private to a member are the transportation requests imported by its DMs and, if any, specific site(s) requested to be kept private to the member. How the privacy on a site is managed on the VTM is detailed in Section 4.5.1.3.

Table 8 : Access and editing rights to the VTM interfaces per role.

			Role					
			Administrator		**Central DM**		**Member (1…n DMs)**	
Set of user interfaces	**Interface**		**Access**	**Editing**	**Access**	**Editing**	**Access**	**Editing**
Administration	Membership management		Y	Y	-	-	-	-
	User account management		Y	Y	-	-	-	-
Data management	Data import		Y	n.a.	Y	n.a.	Y	n.a.
	Product types		Y	Y	Y	Y	Y	-
	Product attributes		Y	Y	Y	Y	Y	-
	Distance and time matrix		Y	Y	Y	Y	-	-
	Sites	Detail	Y	Y	Y	Y	Y	Y when a new site is imported
		Mapping	Y	Y	Y	Y	Y	Y when a new site is imported
		Resource	Y	Y	Y	Y	Y	Y when a new site is imported
		Calendar	Y	Y	Y	Y	Y	Y when a new site is imported
		Visibility	Y	Y	Y	Y	Y when a new site is imported	Y when a new site is imported
		Approbation	Y	Y	Y	Y	-	-
	Resource types	Detail	Y	Y	Y	Y	Y	Y when a new site is imported
		Calendar	Y	Y	Y	Y	Y	Y when a new site is imported
	Truck types		Y	n.a.	Y	n.a.	-	-
	Truck fleet	Region definition	Y	Y	Y	Y	-	-
		Pseudo-depot mapping	Y	Y	Y	Y	-	-
		Capacity	Y	Y	Y	Y	-	-
		Calendar	Y	Y	Y	Y	-	-
Planning control	Planning	Parameters	Y	Y	Y	Y	-	-
		Start	Y	n.a.	Y	n.a.	-	-
Analysis	Route	Status management	Y	Y	Y	Y	-	-
		Statistics	Y	n.a.	Y	n.a.	-	-
		Segments	Y	n.a.	Y	n.a.	-	-
	Transportation requests	Query	Y	n.a.	Y	n.a.	Y	n.a.
		Map and table	Y	n.a.	Y	n.a.	Y	n.a.

Legend: Yes (Y); No (-); Not applicable (n.a.)

4.4.1.3 Support components

The support components used by the VTM are: a road network and mapping web service, an intermediate database and a route planning module.

To perform truck routing, travelling time and distance between each pair of sites are required. In some countries, this information is available in specialized national road databases, for example the Forestry National Road Database (SNVDB) in Sweden (Andersson et al., 2008). In Canada, this information is typically obtained from a company's geographic information system (GIS) or governmental or general road databases (e.g. Google Maps web service). The level of accuracy and coverage of the forest road network is variable. Therefore, the selected database(s) will mainly depend on which databases are available in the region(s) where the VTM must be implemented. The presented case study involves several regions and the planning of transportation activities travelling only on the public road network. Thus, a forest roads database was not required and a general one can be used; we selected the Map Point web service. More specifically, using a procedure of information exchange in Simple Object Access Protocol (SOAP), the VTM obtains the travelling time and distance information from the Map Point web service. Moreover, the Map Point web service is also used in a number of user interfaces requiring a roads network-based mapping display.

The two other support components (i.e. an intermediate database and a route planning module) are related with the computer-based planning method supporting the central DM in the organization of the transportation. The solution from the planning method provides a set of routes to deliver the transportation requests and, because the VTM has been designed to support collaboration in transportation planning, a number of these routes are enhanced with the aforementioned third collaboration opportunity (i.e. common route). The planning method was implemented and solved with the modelling environment ILOG OPL Studio 3.7. Information in input/output to/of the planning method is kept in an intermediate database (Microsoft SQL Server) generated from the VTM database/route planning module with queries in Structured Query Language (SQL).

4.5 Organization of transportation collaboration with the VTM

How the central DM uses the VTM to organize transportation collaboration can be summarized in three basic steps: i) gathering and organizing the transportation data for the planning, ii) performing the planning and iii) analyzing and implementing the solution. These steps are applied in a sequential routine each time the central DM triggers the process of organizing transportation collaboration. In the next subsections, we describe each of these steps followed by the central DM as well as their associated user interfaces. We also detail how (and on which interfaces) the DMs of each member use the VTM. As aforementioned, all the membership and user accounts must first be set by the administrator to allow the central DM and DMs of each member to use the VTM.

4.5.1 Gathering and organizing the transportation data

As discussed by Andersson et al. (2008), one complex factor when developing a DSS for timber truck routing is the need to obtain the detailed information required in input for the planning of the PDP. The main attributes of a PDP in timber transportation can be summarized by: the objective and planning horizon targeted, the time windows considered, the definition of the transportation requests (for a PDP with a one-to-one structure), the representation of the truck fleet, the driver and the depot (i.e. a site where the truck fleet is based) and, finally, the representation of the loader and its operator (Audy et al., 2012b). We follow a similar framework to describe what information is required in input to the static PDP addressed by the VTM and how this information is acquired in the VTM database.

4.5.1.1 Objective

The set of routes schedule delivering all requests at the total minimum transportation cost is the objective. We represent a route schedule as an ordered sequence of segments starting at a site and travelling towards another. In each segment, there are four potential operations (i.e. waiting, (un)loading, carrying and resting) and each of them involves a cost. In order to explicitly compute the number of fuel litres consumed by each route schedule, fuel cost is computed separately in the cost of each potential operation. The total transportation cost of a route schedule is the sum, in each segment, of the operation cost and the fuel cost.

The first three operations (i.e. waiting, (un)loading and carrying) involve the same hourly cost depending on the truck type selected. This hourly cost includes the driver's salary and a fraction of the annual expenses of the truck such as depreciation, license and insurance. Waiting time occurs when a truck arrives on a site before the beginning of a mandatory time window (e.g. opening hours of the site). Handling time is estimated according to: the handled volume, if it's for loading (slow) or unloading (fast), if it's performed by a truck type with (slower) or without (faster) a crane and finally, a short fixed time to represent various basic actions for pickup/delivery on a site such as travel within the site and load binding. The productivity values to enable handling time estimation are parameters setting by the central DM in interface 'Planning-Parameters'. Finally, the operation resting involves a fixed cost that corresponds to a compensation for the potential layover that the driver must take. Details on when a resting operation is required are found in Section 4.5.1.4.

Except during the resting operation (no fuel cost), fuel costs are calculated according to three different truck engine fuel consumption functions: idling, handling and on-road. The idling and handling functions are hourly fuel consumption applied on the duration of the waiting and (un)loading operation, respectively. For truck type without a crane, no additional power is demanded from the engine during the (un)loading operation, consequently the value of the hourly fuel consumption is the same for both idling and handling functions. The on-road function depends on the travelling distance and the total weight of the truck in the carrying operation. The class of route taken is usually another factor in such a function. However, virtually all roads belong to one class (i.e. paved route) in the case study, consequently this factor was not included (we use the function for paved route).

The cost and fuel consumption functions have been provided by FPInnovations which, in turn, are based on many studies conducted in the Canadian forest industry. This means that the computed costs on the VTM are not the transportation rates paid by the members of the VTM. There are indisputable issues (e.g. anti-trust laws) and well-founded resistance to the sharing of transportation rates among distinct companies. Consequently, the VTM uses a cost function representative of the operational cost of a truck (i.e. without the variable profit (or loss) percentage included in the rates table of a carrier). In the presented case study, computed costs on the VTM were compared with the average transportation rates paid by the different DMs for 8.5 months of deliveries at the main customer-mill. Results showed that the difference was plus or minus 4% for five of the six DMs (Charrouf, 2009). The cost and fuel consumption functions are embedded in the data on each type of truck (see 4.5.1.4) while the cost by fuel litre is a parameter setting by the central DM in interface 'Planning-Parameters'.

4.5.1.2 Time windows

Several time windows are used. A first time window is specified on each transportation request to advise the earliest (latest) pickup (delivery) time of the request at its origin (destination) site. Time windows on the availability of the trucking capacity can also be specified when e.g. no capacity is available during the weekend. How this could be achieved on the VTM is given in Section 4.5.1.4.

Time windows on a site consist of two forms: opening hours and on-site resource operation hours. The first indicates the site's opening hours during which a truck can perform a pickup/delivery, while the second indicates the hours during which a given on-site resource is in operation (e.g., on-site loader(s) are available for (un)loading operations, wood scaler on duty). Truck types without a crane must be scheduled inside two time windows: site opening hours and on-site loader(s) operation hours. Waiting time is allowed when a truck arrives on a site before the beginning of the mandatory time window(s). Time windows on a site are managed by the central DM using the interface 'Sites - Calendar' for site opening hours and 'Resource types – Detail/Calendar' for on-site resource loader(s) operations hours. When a site is a member's private site (see Section 4.5.1.3), this member is responsible for providing site information to the central DM.

General practices in place among the carriers involved in the presented case study, require the addition of a daily time window on the allowed starting time of a route. Indeed, as discussed in 4.6.1, night shifts for a driver are uncommon in the presented case study and thus, a route cannot start during the evening-night. This optional time window is a parameter that can be set by the central DM in interface 'Planning-Parameters'

4.5.1.3 Transportation request

As discussed in Section 4.4.1.1, each DM is a source of transportation data that are automatically and/or manually (using interface ‘Data import’) imported in the VTM database. The crucial data specified by each DM are their transportation requests. To allow the system to perform data consolidation, the members have to agree on a standard in defining their requests. More precisely, there must be a standard on the different product type (e.g. logs, wood chips), their attributes (e.g. firm-spruce chips, pine chips) and their unit (i.e. volume, weight and time). Adhering to this standard is crucial to respect the compatibility/incompatibility matrix associated with each product type and product attribute. Indeed, for each product type (product attribute) there is a set of compatible/ incompatible product types (product attributes) that can/cannot be hauled at the same time. Access right to the interfaces ‘Product types’ and ‘Product attributes’ allows the DMs to consult the standards to follow. Modification to the standards can only be made by the central DM (has an editing right on these two interfaces), for instance when a DM demands the addition of new product attributes.

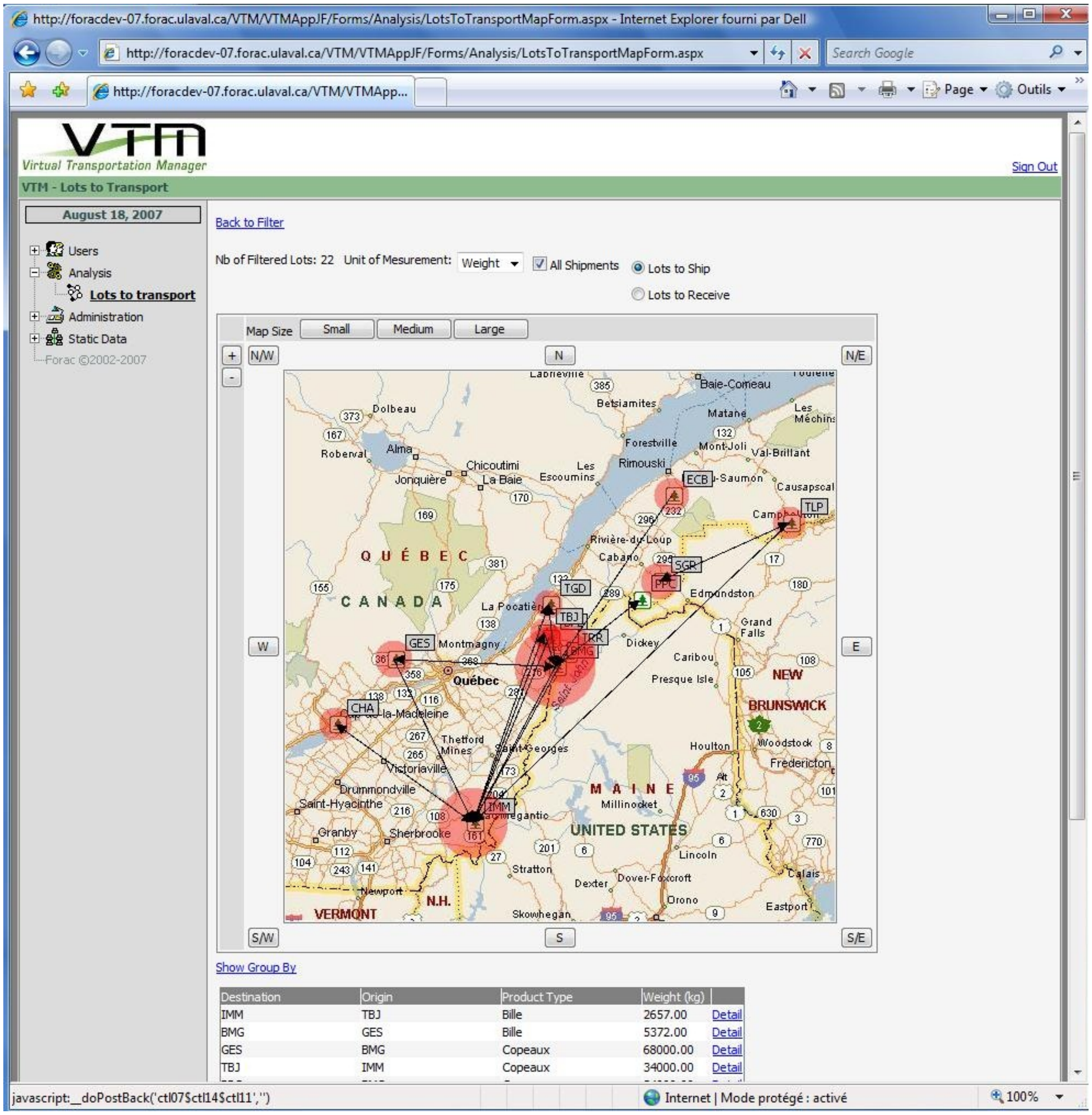
To allow the system to perform data consolidation, there is also a standard for the origin and destination site that must be indicated by the DM on each of their transport requests. Access right to the interfaces proving information on each site (i.e. interfaces ‘Site – Detail/Mapping/Resource/Calendar) allows the DMs to consult the standard to follow. However, display of the list of sites among the members is subject to confidentiality restrictions. Indeed, there are two kinds of status for a site: shared or private. Information on a shared site is displayed to all members while information on a private site is only displayed to a subset of the members established when a private status is attributed to a site. Private sites are only for particular business considerations (e.g. high competition between two or more members for a supplier recognizable by an origin site) and consequently, most sites on the VTM are expected to be shared.

The status of a site is attributed by the first DM who, by importing its transportation requests in the VTM database, imports a new site (i.e. not present in the VTM database). In the message received after each import, the DM will receive the notification to perform a few tasks related to its import of a new site. The purpose of these simple tasks is to collect basic information on the new site to enable its management by the central DM. Cooperation to achieve these tasks promptly is expected by the DM, considering that the collected information is required for organization of the transportation request(s) with this new site.

To complete the mandatory tasks, an editing right (limited to the new site information) is temporarily given to the DM on specific interfaces. The first task is to enter information related to the new site and, if any, on-site resource (using interfaces 'Sites – Detail/Resource/Calendar' and 'Resource types – Detail/Calendar') and then, to localize and validate the geographic position of the new site on a map (using interface 'Site - Mapping'). Finally, the DM attributes a shared or private status of the site, and if the status is private, indicates the member(s) (dis)allowed to see the site.

After the DM has completed these tasks, the central DM must approve the new site before the transportation request(s) with this new site can be planned (using interface 'Sites – Approbation'). Approbation involves a diligent review of the site information and the travelling time/distance between the new site and the sites already in the VTM database. As aformentioned, travelling time and distance values are obtained from the Map Point web service through an automatic procedure. Modification, if any, can be effected by the central DM on the interface 'Sites – Distance and time matrix'.

Transportation requests in the VTM database can be viewed in both an interactive map and a table format in the interface 'Transportation requests – Map and table'. The choice of the transportation requests displayed can be limited by product type with or without additional product attributes, origin site and/or destination site (using interface 'Transportation requests – Query'. Moreover, on the interface 'Transportation requests – Map and table', an additional filter may be applied on the transportation request displayed as well as how transportation requests are illustrated on the interactive map. For instance, scaled semi-transparent circles at origin (or destination) sites illustrate the total volume or weight in transportation request(s) to be picked up (delivered) on these sites and transportation flow are illustrated by arrows (see Figure 11). All members' data are completely visible to the central DM and administrator roles while each member can only view their transportation requests and, on the map, each private site is only displayed to the member(s) allowed to see it.



VTM - Lots to Transport

August 18, 2007

Nb of Filtered Lots: 22 Unit of Mesurement: Weight ☑ All Shipments ● Lots to Ship ○ Lots to Receive

Destination	Origin	Product Type	Weight (kg)	
IMM	TBJ	Bille	2657.00	Detail
BMG	GES	Bille	5372.00	Detail
GES	BMG	Copeaux	68000.00	Detail
TBJ	IMM	Copeaux	34000.00	Detail

javascript:__doPostBack('ctl07$ctl14$ctl11','')

Figure 11 : Screenshot of the interface ‘Transportation requests – Map and table’ displaying information on queried transportation requests.

4.5.1.4 Truck fleet, driver and depot

Typically, Canadian forest companies do not operate a private truck fleet, but sign one-to-many-year(s) contracts and/or maintain not-contracted business (i.e. without official agreement) with assets-based transportation service providers (i.e. independent or associated carriers). Forest truck fleet ownership is highly fragmented in Canada, mostly for timber trucks where approximately 80% of the whole fleet (i.e. about 2530 units) belongs to independent owner-operator truckers (Boutin, 2012). Forest companies usually prefer to do business with a limited number of carriers (that typically sub-contract a number of carriers) but this is not always possible, mainly in vast regions. Therefore, as in the presented case study, DMs have a precise-to-general knowledge of their available truck fleet and thus, there is a significant level of imprecision on the available truck fleet for the VTM. To manage such imprecision, we use an approach based on transportation regions with pseudo-depots instead of the standard representation of the truck fleet in a PDP: i.e., vehicles spread throughout a set of sites (multi-depot) or based in only one site (single depot).

A transportation region is defined by a subset of sites in which given trucking capacities are available. Transportation regions can overlap (i.e. a site can be included in more than one transportation region). Trucking capacity in a transportation region is aggregated by type of truck, each type having a unique set of transportation-relevant characteristics (e.g. volume/weight payload capacity, cost/fuel consumption function, with or without a crane, set of product types allowed to haul). Payload capacity is given in both volume and weight because on some truck types, the first capacity reached depends on the product type(s) hauled. Time windows could be added to the trucking capacity to represent: e.g., the trucks on duty the whole week and the ones on leave during the weekend.

Furthermore, each transportation region is linked with a site designated as its pseudo-depot and localized around the centre of the region. Transportation payment method in the Canadian forest industry is mainly based on a route that starts and finishes at the first pickup site (i.e., a loop). This rule is applied in the route planning module of the VTM with one exception related to our representation of the truck fleet using transportation regions with pseudo-depot. Each route is planned for a given type of truck. This type of truck is available through the aggregated trucking capacity of a transportation region. When no capacity is available in the transportation region(s) where the first pickup site of the route is located, capacity from a neighbouring transportation region should be sought. In this case, the pseudo-depot of the neighbour transportation region becomes the starting and ending site of the route in order to reflect the additional cost incurred by going back and forth to a neighbour transportation region.

This approach based on transportation regions with pseudo-depot also supports a transportation payment method based on a route starting and ending at a carrier's depot (i.e. garage) instead of the first pickup site. In such a case, only the site of the garage must be included in the transportation region and the garage must be defined as the pseudo-depot of the region. Usually, no pickup takes place at a garage. Therefore the first pickup site will be outside the transportation region and this will constrain the planning module to start and end the route at the pseudo-depot, which is the garage.

The definition and up-to-date care by the central DM of the transportation zones (interfaces 'Truck fleet - Region definition'), their pseudo-depot (interfaces 'Truck fleet – Pseudo-depot mapping') and their aggregated trucking capacities (interfaces 'Truck fleet – Capacity/Calendar') are based on regular discussions with the DMs. No regular modification is expected to the existing types of truck in Canada and thus, no editing right has been developed on the interface 'Truck types'. An XML document including average parameters of the most common truck types in Canada is available to the central DM for an import in the VTM database (interface 'Data management-Data import'). The value of the parameters is based on the many studies conducted by FPInnovations in the Canadian forest industry. XML is a text-based format that is human-readable, therefore modification to the types of truck (e.g. addition of a truck type, increase of a cost value) is easily done by manually editing the XML document and importing it back to the VTM database.

Routes must respect different time constraints and a number of them are related to official regulations for drivers as well as general practices in the forest trucking industry. Regulations and general practices that are in place are not homogeneous across Canada and thus, modification to the following ones could be required in other implementations of the VTM.

Regulations on working and driving hours for drivers of commercial carriers embrace many rules and exceptions. Most of them are managed by carriers (i.e. crew scheduling) but three rules may constrain route planning on the VTM: (i) maximum driving time allowed per working shift; (ii) maximum working time allowed per working shift (usually two additional hours to prior maximum driving time) and (iii) minimum daily layover time in which a given number of resting hours must be consecutive. In forest transportation, a typical working shift for a driver involves many sites to visit and, in turn, considerable working time not behind the steering wheel. Therefore, route duration is restricted by the second rule rather than the first one. The minimum daily layover time (third rule) is applied when the second rule is reached on a route. When a route involves more than one working shift, the driver is allowed to go on layover with a truck not fully unloaded (i.e. stay loaded overnight). General practices in the forest trucking industry try to return drivers home every day and, when impossible, to limit the number of nights away from home. Therefore, a maximum number of working shifts on a route is embedded in the data (i.e. XML document) on each type of truck.

4.5.1.5 Loader and operator

Any available loader on duty at a site is specified by the aforementioned time windows for on-site loader(s).

4.5.2 Performing routes planning

Procedures conducted in previous steps allow setting in the VTM database the detailed information required for the planning. Before launching the routes planning (using interface ‘Planning-Start’), a number of parameters can be edited by the central DM to control/influence the planning method (using interface ‘Planning-Parameters’). We have already reported the parameters’ fuel cost per litre, productivity values to enable handling time estimation and optional daily time window on the allowed starting time of a route. The other parameters are the duration (in days) and starting date of the planning horizon.

The planning module is a solution method implemented and solved with the modelling environment ILOG OPL Studio 3.7. The method embeds heuristics, a tabu list and three constraint programming (CP) models. The solution methodology is greedy (i.e. only the ‘best’ route is kept at each iteration) and adopts a two-phase approach to generate each route (i.e. perform the routing first and then the scheduling).

The main concept behind the methodology is to use a sequence of origin and destination sites as a support to perform the routing. This sequence is called ‘itinerary’. Relaxing time constraints, a route is built by a heuristic adding transportation request on the itinerary. Then, using a CP model, the route is scheduled to test its feasibility. At each iteration a number of itineraries are used to build a set of routes. From this set of routes, the best feasible one (i.e. scoring the higher performance metric) is kept in the solution base and a new iteration is started. But just before the new iteration, the ‘best’ route is duplicated as many times as possible in the solution base. When no feasible route is found in an iteration, specific transportation request(s) is(are) sent to a tabu list to prevent looping in the solution methodology.

The methodology starts with a set *S1* of pre-determined itineraries. *S1* is composed of back-haulage tours: i.e., a sequence of sites that combines delivery of two or more loads to reduce the total empty travelling distance. This set is generated by solving one of the backhauling planning methods reported in Table 7 on the medium-long-term forecast in wood flow and/or historical wood flow. It is also possible for the central DM to add its own hand-made itineraries. The methodology will use *S1* until all transportation requests are planned or all unplanned requests are in the tabu list. In the former, the tabu list is emptied and at each iteration, two new itineraries to be tested against unplanned requests are generated with the resolution of two sequential CP models.

The solution methodology is summarized in seven steps:

1. If all requests are planned, stop. If all unplanned request(s) are in the tabu list, empty tabu list and go to 4). Else, select itineraries from *S1*.

2. For each itinerary, generate testing pairs of ‘itinerary, truck type’ and, on each of them, run a route building heuristic and then a route scheduling model.

3. If a feasible route is found in 2), keep the ‘best’ route, try to duplicate it as many times as possible, and go to 1). Else, add specific request in tabu list and go to 1).

4. If all requests are planned, stop. If all unplanned request(s) are in the tabu list, empty tabu list and go to 7). Else, generate two new itineraries with two sequential CP models.

5. If no itinerary is found in 4), empty tabu list and go to 7). Else, for each itinerary, generate testing pairs of ‘itinerary, truck type’ and, on each of them, run a route building heuristic and then a route scheduling model.

6. If a feasible route is found in 5), keep the ‘best’ route, try to duplicate it as many times as possible, and go to 4). Else, add specific request in tabu list and go to 4).

7. Stop.

In the next subsections, we detail each step. Steps 2 and 5 as well as steps 3 and 6 are described together because they are identical from a methodological point of view.

4.5.2.1 Step 1: selection of the itineraries to test

Selection of the itineraries to test is made according to the following heuristic: rank by their weight all transportation requests not in the tabu list, pick the heaviest one (denoted *r'*) and select all itineraries in *S1* that visit both, and in precedence, the origin and destination sites of request *r'*.

4.5.2.2 Steps 2 and 5: generation of testing pairs, and route building heuristic and scheduling model

For each itinerary to test, generate a testing pair (<itinerary>, <truck type>) for each different type of truck with available capacity in the transportation region(s) of the starting site of the itinerary.

Then, on each testing pair, a route is built according to the following heuristic:

I- on a list, rank by their weight all transportation requests that could be delivered using the itinerary (i.e. must visit both, and with precedence, the origin and destination sites of the request) and the type of truck (e.g. truck type must be allowed to haul the product type of the request, origin and destination site of the request must have on-site loaders for truck types without a crane);

II- on the list, pick the heaviest one (denoted *r'*) and, on each segment of the itinerary from the origin to the destination site of request *r'*:

- compute the available payload capacity;
- if truck type can haul several types of product (i.e. multi-product trailer):
    - validate there is no incompatibility between the product attribute of request *r'* and the product attribute of all requests already on the route segment;

      (if there is incompatibility, remove request *r'* from the list and return to step II)

Else:

- validate that the type of product for request *r'* is the same (thus, no incompatibility) for all requests already on the route segment;

(if there is incompatibility, remove request *r'* from the list and return to step II)

iii- if the available payload capacity is over 5% on each segment of the itinerary from the origin to the destination site of request *r'*:

- add request r' to the route with a pickup of the minimum quantity between the lower available payload capacity and the unplanned quantity of request r';

Else:

- to avoid splitting the request into a very small quantity, do not add request r' on that itinerary and go to step IV);

IV- remove request *r'* from the list and return to step II until no more requests are on the list.

In building heuristics, time constraints are relaxed, therefore feasibility of the route is verified by solving a CP model to schedule the route. The objective of the CP model is twofold: minimize the duration of the route and start the route as early as possible on the planning horizon. In the objective function, a multiplier is applied on the route duration to make it three times more important than the starting time of the route. That feasibility verification is fast, as only scheduling decisions are made and previous routing decisions are input parameters (i.e., sequence of the sites to visit, pickup quantity of each request on the route, the type of truck in a transportation region that is used).

4.5.2.3 Steps 3 and 6: selection of the best route, duplication and tabu list

In the presented case study, requests are mainly less-than-truckload (LTL) size. In such a context, a relevant metric to evaluate the performance of a route is the cost paid per quantity delivered per distance travelled. This metric is computed on each feasible route and the 'best' one has the lower metric. The 'best' route is kept in the solution base and the input data for a new iteration are adjusted (e.g., quantity delivered on the 'best' route, trucking capacity use on the 'best' route).

Furthermore, before launching a new iteration, the ‘best’ route is duplicated as many times as possible. More precisely, to duplicate a route, there must remain an unplanned quantity to pick up in each request on the route and availability in the regional trucking capacity used.

When no feasible route has been found, specific request(s) are added to the tabu list to prevent looping in the solution methodology. In step 3, transportation request denoted *r’* in step 1 is added to the tabu list while in step 6, all transportation requests added on a route in step 5 are added to the tabu list.

4.5.2.4 Step 4: generate new itineraries with two CP models

At this stage of the methodology, the main part of the transportation requests has been planned using the itineraries in set *S1* (i.e. back-haulage tours). The purpose of this step is to generate new itineraries personalized to the current unplanned requests by including a number of their origin and destination sites. To do so, two sequential CP models are used. The origin sites’ precedence over the destination sites are constraints considered in both models.

Before the resolution of the first CP model, the pair (<origin site>, <destination site>) of all unplanned transportation requests not in the tabu list is listed. The objective of the first CP model is to select a number of pairs and assemble them in an itinerary that maximizes the gain in travelling distance. The gain is computed by assuming that in the worst scenario, each of the pairs is travelled twice (i.e. back-and-forth) in an individual route.

If a solution is found, the second CP model is applied. The objective of the second CP model is also to assemble an itinerary that maximizes the gain in travelling distance. However, here the pair (<origin site>, <destination site>) to visit is imposed (i.e. the ones selected by the first CP model) but more than one origin can be visited before visiting a destination. This structure of how the sites can be visited on the itinerary can provide more efficient routes with many LTL-size requests to plan, as in the presented case study.

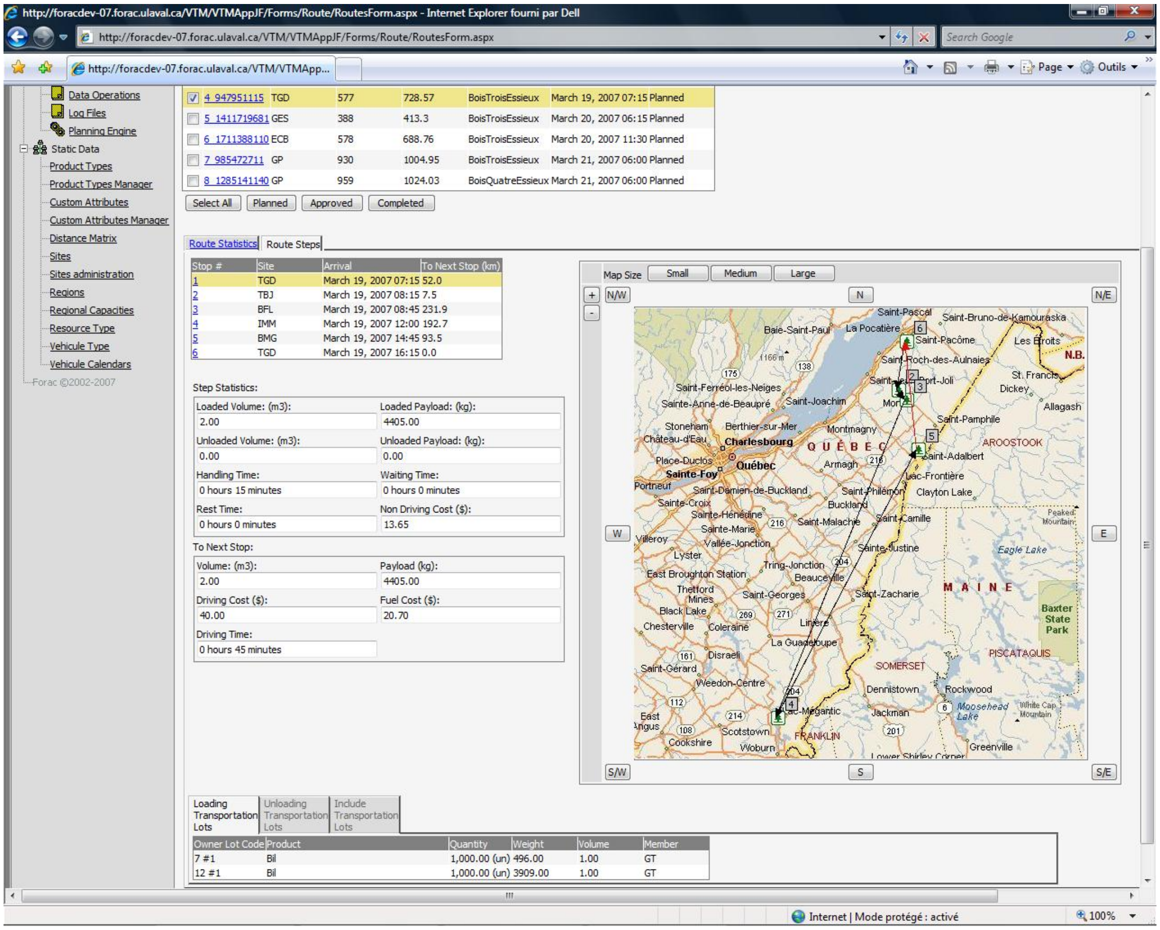
Moreover, this structure provides the building heuristic (4.5.2.2) with a higher level of flexibility in the routing of LTL-size requests compared to other planning methods in timber transportation that consider LTL-size requests (Flisberg et al., 2009; Rummukainen et al., 2009). In the former, only one to several pickups followed by one to several full deliveries (i.e. unloading of all loaded requests) is allowed. In the building heuristic, new pickup(s) are allowed after a partial delivery (i.e. truck not completely empty) has been made. Figure 14-B illustrates an example of this flexibility in the routing. The many loading compartments design of timber-trailer allow such routing flexibility while trailers in general LTL freight transport are usually constrained by a ‘First In, Last Out’ constraint (i.e. the sequence of deliveries is the reverse sequence of pickups/loading).

4.5.2.5 Step 7: Stop

The remaining requests are sent back unplanned to the VTM assuming that, in the worst scenario they will be delivered in a back-and-forth route. In a better scenario, their deliveries can be delayed until new requests are imported on the VTM and they are planned on a route with (some of) these new requests the next time the central DM launches the routes planning module.

4.5.3 Analyzing and implementing the routes

Once the planning module has been done, the central DM achieves an evaluation of each route proposed. Two interfaces support the central DM in its evaluation. First, interface ‘Route-Statistics’, which is composed of two sections: a first section reporting a number of time, costs, travelling distance and payload statistics for the route; and a second section reporting a number of key indicators for the route (e.g., cost per kilometre, percentage of kilometres in load). The second interface ‘Route-Segments’ illustrates on an interactive map all the segments and visited sites of the routes and, on each visited site, a table provides information on the pickup/delivery to perform (e.g. arrival time on the site, transportation request to load/unload) as well as a short selection of previous statistics but on the segment instead of the whole route (Figure 12). Layout of the interface ‘Route-Segments’ includes work instructions for the truck driver.



☑ 4 947951115	TGD	577	728.57	BoisTroisEssieux	March 19, 2007 07:15	Planned
☐ 5 1411719681	GES	388	413.3	BoisTroisEssieux	March 20, 2007 06:15	Planned
☐ 6 1711388110	ECB	578	688.76	BoisTroisEssieux	March 20, 2007 11:30	Planned
☐ 7 985472711	GP	930	1004.95	BoisTroisEssieux	March 21, 2007 06:00	Planned
☐ 8 1285141140	GP	959	1024.03	BoisQuatreEssieux	March 21, 2007 06:00	Planned

Stop #	Site	Arrival	To Next Stop (km)
1	TGD	March 19, 2007 07:15	52.0
2	TBJ	March 19, 2007 08:15	7.5
3	BFL	March 19, 2007 08:45	231.9
4	IMM	March 19, 2007 12:00	192.7
5	BMG	March 19, 2007 14:45	93.5
6	TGD	March 19, 2007 16:15	0.0

Step Statistics:

Loaded Volume: (m3): 2.00
Loaded Payload: (kg): 4405.00
Unloaded Volume: (m3): 0.00
Unloaded Payload: (kg): 0.00
Handling Time: 0 hours 15 minutes
Waiting Time: 0 hours 0 minutes
Rest Time: 0 hours 0 minutes
Non Driving Cost ($): 13.65

To Next Stop:

Volume: (m3): 2.00
Payload (kg): 4405.00
Driving Cost ($): 40.00
Fuel Cost ($): 20.70
Driving Time: 0 hours 45 minutes

Owner Lot Code	Product	Quantity	Weight	Volume	Member
7 #1	Bil	1,000.00 (un)	496.00	1.00	GT
12 #1	Bil	1,000.00 (un)	3909.00	1.00	GT

Figure 12 : Screenshot of the interface ‘Route –Segments’ detailing one route’s segment.

Each route has a status: 1) planned, 2) approved or 3) completed. The status planned is the default status of a route: i.e., the status attributed to each route in output of the planning module. When the evaluation of a route satisfies the central DM, the status approved is attributed to the route (using interface ‘Route – Status management’). A route with a status different than planned allows keeping the route in the VTM database when a new planning is being performed. On the other hand, a route with a status planned is removed from the VTM database and therefore, the transportation requests that were planned on this route could be planned on new routes. The status approved is also used when the central DM has proposed the route to a carrier or if a carrier has accepted the route (reservation). If the carrier refuses the proposed route or later on cancels its reservation, the status approved (as the other status) can be modified with no restriction. Finally, the status completed is attributed to a route that was carried out by a carrier.

Tendering of the routes to carriers could be done in several ways (e.g. auction, area-based assignment). The same apply to the control of their execution. Therefore, processes specific to members of the VTM are expected to be developed and integrated to the VTM. In the presented case study, a number of routes were analyzed with the participating company and evaluated as satisfying enough to be executed by their carriers. Therefore, the implementation of the planned route was not considered in the presented case study.

4.6 Case study

The VTM system was implemented in a case study to simulate its utilization over almost one year of historic transportation data. This section provides a description of the case study and then the results of the simulation. A discussion about the actual outcome of the case study and the issues faced in further initiatives to transfer the system to the Canadian forest industry complete the section.

4.6.1 Description of the case study

The case study involves a wood supplier specialized in high-value logs, Groupe Transforêt (GT). This company buys logs from thousands of occasional-to-regular suppliers, classifies them, and finally, resells them in a network of around 20 customer-mills. Its business activities take place in eastern Ontario, southern Quebec and northern New Brunswick in Canada. This wide territory is separated into regions, each being the responsibility of one coordinator in charge of purchasing the logs and organizing their transportation. Figure 13 illustrates the coordinators' regions and business network (i.e. intermediate sites, supplier-mills and customer-mills) of the company.

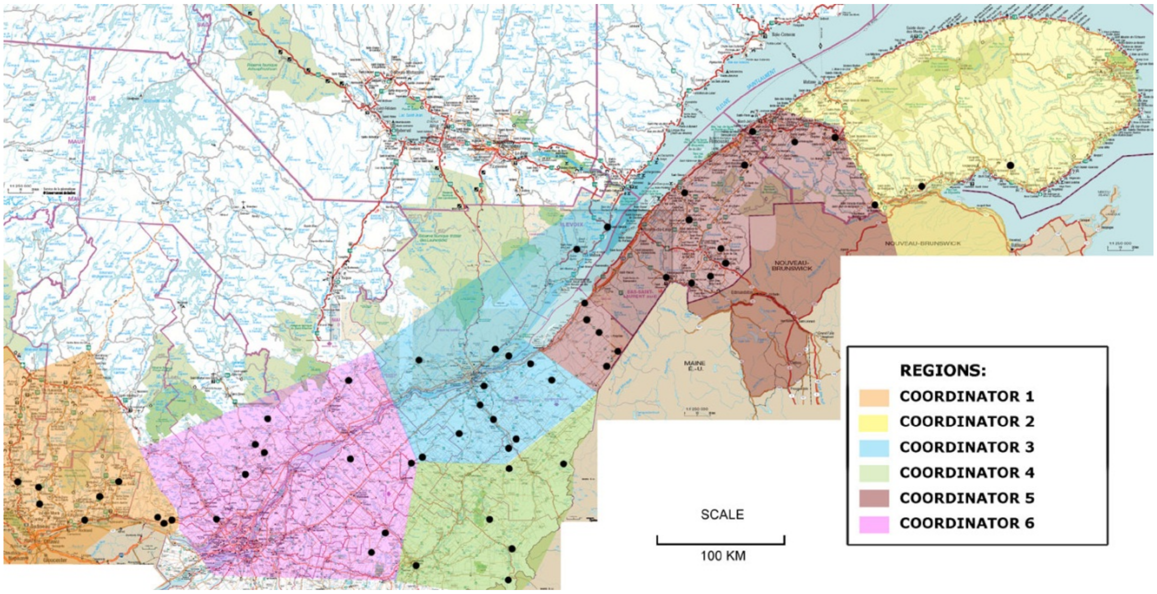


Figure 13 : Coordinators' regions and business network of Groupe Transforêt.

GT signs supply agreements with customer-mills based on log 'species and grades' pairs. When a coordinator purchases a log, these supply agreements require the measuring and classification of the log according to a specific 'species-grade' pair. All regional coordinators are licenced wood scaler members of a professional association. Sixteen species are purchased, all hardwood species except three. For one species, up to nine grades are possible among many lengths and diameter classes. For example, for yellow birch, there exist nine possible grades in nine lengths and eight classes of diameter. Purchase and resale prices are different between the species (or a group of species) and also between the grades of one species. For example, the slicing grade of yellow birch can reach up to three times the price of its low veneer grade, five times the price of its medium saw grade and 10 times the price of its poor saw grade. All supply agreements can be roughly divided into two categories:

- supply agreement on the higher value species-grades which are signed with only one or two customer-mills in the whole business network of GT. Logs belonging to this category are thus almost always delivered outside the region of the coordinator who purchases it. This leads to high one-way delivery distances (i.e. can be up to 700 km) compared to the 140-150 km average one-way delivery in Canada (Michaelsen, 2012).

- supply agreements on all other values species-grades which are signed with several customer-mills under the general rule of one species-grade customer-mill inside each or two coordinator regions. Thus, the one-way delivery distances are much lower than in the previous agreements (usually from 50 km up to 250 km).

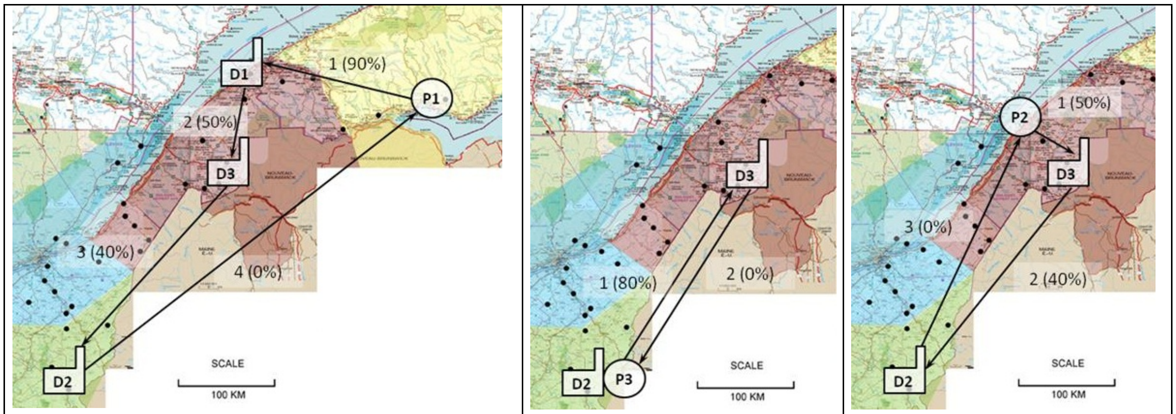
The supply agreements guide the coordinators in the allocation to a customer-mill of each purchase log. A plastic log tag of a specific colour - including a unique barcode and identification number per tag - is associated to each major GT customer-mill. Code-based identification information in spray paint is used for the other customer-mills. Such visual information on each log is useful to the truck drivers (e.g., pickup/delivery of the right 'colour' of logs) and customer-mills (e.g., perform random quality control on purchased logs). When the coordinator hammers the colored plastic tag (or spray-paints the identification code) on a log at purchasing time, the allocation decision is made and cannot be changed.

Each coordinator uses a hand-held computer to register all purchased logs directly in the field, print an invoice and give a copy to the supplier. A company's web-based system is used to transfer purchasing information from each coordinator to the finance department. Typically, coordinators perform the transfer on a daily basis to allow a very fast payment to the suppliers (i.e. a few business days). In the system, the finance department has a complete view of all purchased volume but each coordinator views only his/her own purchased volume. The information is shown in a query-table without any map support.

Coordinators purchase logs from among a network of thousands of wood producers and dozens of supplier-mills. Volume purchased from a wood producer can represent as few as a dozen logs, while volume purchased at supplier-mills is larger, sometimes over a full truckload size. Coordinators organize their transportation using a hub and spoke network where intermediate site(s) between the origins (supplier sites) and destinations (customer-mills) sites receive the logs, sort them, consolidate them and ship them to the customer-mills. Therefore, most logs are carried twice (i.e. upstream to an intermediate site and downstream to an intermediate site). In some situations (e.g. when logs are purchased at a supplier-mill where an intermediate site is located), upstream transport is avoided. Potential time in inventory at an intermediate site is limited by different factors (e.g. wood deterioration with hot weather, customer demand to satisfy, internal cash flow). Despite this effort for consolidation, most transportation requests are less-than-truckload size. Therefore, coordinators will typically plan a route starting at an intermediate site (with many pickups of transportation request) and then deliver transportation requests to more than one customer-mill (see the route of coordinator 2 or 5 in forthcoming Figure 14-A).

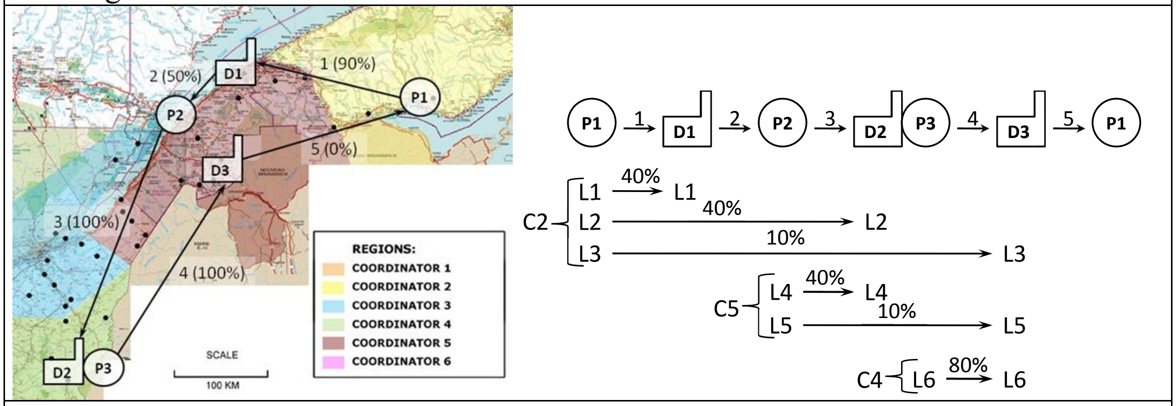
Each coordinator is responsible for organizing the transportation of the logs he/she purchased. To do so, in almost all regions coordinators can use five different types of truck with 13.5, 31.5, 34.5, 37.5 and 41 t capacities on average. The two smaller truck types are equipped with a crane. GT has no exclusivity agreement with any carrier but each coordinator has preferred carriers with regular business. Typical carriers are small companies with one to three trucks. In accordance with current practice with these carriers, they are on leave during the weekend (i.e. Monday-to-Friday working time windows) and drivers can be away from home two nights maximum (except for 13.5 t capacity trucks restricted to one working shift). Also, night shifts for a driver are uncommon and thus a route cannot start during the evening-night. The transportation regions were equivalent to the coordinator's regions with a pseudo-depot located around the centre of the region and the aggregated trucking capacity was estimated with GT.

Overall profitability of GT can be roughly summarized by the resale price of a log minus its purchase price and the operation costs to deliver the log to the customer-mill. Transportation costs account for a significant proportion of these operation costs. In current governing mode, transportation is organized regionally with no or rare collaboration between the coordinators while a large proportion of the purchased logs is delivered outside their purchasing region. Collaboration between the coordinators would lead to increased truck routing efficiency which, in turn, reduces transportation costs and increases overall profitability of GT. Figure 14 illustrates an example of the collaboration opportunity 'common route' in the case study. Collaboration between coordinators 2, 4 and 5 modifies three individual routes (Figure 14-A) in one common route (Figure 14-B) that results in shorter travelling distance to deliver the same volume.



Coordinator 2 (C2) Coordinator 4 (C4) Coordinator 5 (C5)

Individual route with numbered pick-up (P) or delivery (D) and loading percentage on each segment



Common route with numbered pick-up (P) or delivery (D) and loading percentage on each segment

Figure 14 : Individual (A) and common (B) route.

4.6.2 Numerical results

To assess the potential savings of the collaboration opportunity 'common route', the VTM system was implemented at GT and its utilization was simulated during 10 months of historical transportation data (from July 2006 to April 2007). The VTM system was responsible for organizing the transportation activities downstream the intermediate site while transportation organization upstream the intermediate sites remained in the hands of the coordinators. To handle the VTM system, new employees will be hired by GT. This new way of organizing transportation was the one planned by the company in case of system deployment. Among the different analyses conducted on the historical transportation data of GT, one of the findings was the over-average weighted transportation cost (i.e. transportation rate paid by delivered volume and travelled distance) of some coordinators (Charrouf, 2009). Poor transportation planning skill was one of the main reasons identified. This new organization avoids a large part of this concern by focusing the job of the coordinators on the purchase of logs rather than on their transportation planning.

In the literature on freight transportation, several case studies exist where companies obtain savings with collaboration in road transport planning (le Blanc et al. 2007; Cruijssen et al. 2007b; Ergun et al. 2007; Özener and Ergun 2008; Krajewska et al. 2007; Clifton et al. 2008; Audy et al. 2011a). In these case studies, the potential savings (additional profit) of the collaboration are defined as the difference between the cost (profit) of the collaborative transportation plan (i.e. transportation planning of all companies together) compared to the sum of the cost (profit) of each individual transportation plan (i.e. transportation planning of each company alone). This is also the approach used in some case studies in forest transportation in Table 7 (e.g. Forsberg et al., 2005; Frisk et al., 2010). It was impossible to retrace with confidence the routes achieved during the simulation period. Therefore, as in the aforementioned case studies, we defined the potential savings as the difference between the cost of the collaborative routing plan with the volume of all coordinators compared to the sum of the cost of the individual routing plan of the volume of each coordinator.

Logs are stored individually in the GT inventory system because a number of operations (e.g. purchasing, selling) are performed at this level. However, with thousands of logs to deliver, a procedure to consolidate logs in transportation requests was required for transportation planning. Consolidation was done with the following procedure: logs located at the same origin and that should be delivered to the same destination are grouped together in the same transportation request. For the volume and estimated weight (a volume to weight conversion factor by species is used) associated to the transportation request, these parameters on each log are summed up. For the time window associated to the transportation request, the more restrictive one is selected: latest pickup time and earlier delivery time among the grouped logs.

We generate the set *S1* by running the aforementioned DSS MaxTour on aggregated wood flow of the transportation requests in the testing period. Description of the planning method in MaxTour is found in Gingras et al. (2007). Back-haulage tours found with MaxTour can only provide an itinerary including a sequence of pairs of origin and destination sites. As discussed in 4.5.2.3, in a context involving many LTL-size requests, an itinerary with one to several origin(s) followed by one to several destination(s) can provide a more efficient route. Therefore, on each back-haulage tour obtained from MaxTour, a procedure was applied to allow the addition of new site(s) that imply a minimal detour between two consecutive sites visited on the backhaulage tour.

Considering the limited number of transportation requests to deliver, planning was performed every two weeks during the simulation period. With carriers on leave during the weekend, a Monday to Friday planning horizon was set. At each instance, the VTM provided seven routing plans (i.e., one collaborative plan and six individual plans for each of the six coordinators). A number of routing plans were analyzed with GT and evaluated as satisfying enough to be accepted by their carriers. However, one minor issue was found on a limited number of routes; it involved over three pickup stops before a delivery stop. Drivers typically prefer routes with a small number of sites to visit. In other words, they prefer driving rather than visiting sites for loading. GT points out that payment of compensation for each additional pickup stop will be required. The impact of this additional cost on the whole transportation cost is insignificant and was thus not considered in the simulation.

Harvesting operations and, in turn, purchasing and transportation activities, are subject to seasonality where the business activities of GT take place. A question that arose was to see if this seasonality has an impact on the results. Therefore, three periods have been identified by GT. Including 5 (7) instances and an average of 17 (20) transportation requests to deliver, period 1 (period 2) occurs during the higher (lower) level of purchasing and transportation activities at GT. Period 3 is the buffer and includes 9 instances and an average of 20 transportation requests to deliver.

Table 9 presents average results (with the standard deviation) per period. For each period, the average results (with the standard deviation) reported are from the solutions (i.e. seven routing plans) obtained in each instance included in the period. The illustrated results are the average solution time and average percentage of reduction in cost, fuel consumption and travelling distance.

Table 9 : Results from the case study.

Period	Solution time (second)	Reduction		
		Cost ($)	Fuel (L)	Distance (km)
1	543.6 ± 233.5	9.8% ± 4.7%	7.1% ± 3.5%	13.0% ± 5.6%
2	647.3 ± 234.0	7.3% ± 3.8%	4.3% ± 4.6%	11.1% ± 4.6%
3	620.4 ± 149.2	10.5% ± 4.2%	8.3% ± 3.1%	12.1% ± 4.3%

Average cost-saving opportunities in the range of 7.3-10.5% exist in the collaboration of the six coordinators. Seasonality has a mitigating effect on the results. At the least, we can observe that the period with the lower level of business activity in general shows a few percentage points less in cost reduction.

4.7 Outcomes and discussion

Since the start of the system development and its utilization simulation at GT, the hardwood processing industry has entered a major crisis in the province of Quebec. The production of hardwood lumber fell by 40% between 2004 and 2008 (MRNF, 2009). A large number of hardwood industries shut down temporarily or permanently, including GT wood customers. Therefore, in less than two years, GT lost a major part of its business volume built up over nearly a decade. The annual transportation cost dropped to under 1 million Canadian dollars when the decision to move forward with the deployment of the system could be made. With this low level of transportation expense, for GT this meant that the expected annual savings with the system use was nearly equal to the estimated system operation fees (e.g., salary of an employee dedicated to the system, plus IT fee to host the system). Consequently, despite the expected benefits of the VTM, the system deployment decision was postponed until better business conditions would prevail. Another reason for avoiding important changes to the key process of transportation was to maintain GT staff priority on keeping the company in operation. Less than a year later, faced with a continuing negative business perspective, GT first suspended its operation temporarily and then, permanently.

Different benefits from DSS in timber transportation are reported in the literature, including potential/real cost-savings of 0.8-35%. Despite such results, the adoption of DSS by forest companies worldwide has been limited up to now, with one notable exception (i.e., mostly in Chile with aforementioned DSSs ASICAM and ForesTruck). Different issues relevant to their adoption are reported by Audy et al. (2011c), Kokenge (2011) and Rönnqvist (2012). For instance there are problems associated with planning based on inaccurate/erroneous information, unreliable communication, myopic planning, complexity of the set-up parameters that influence the planning method, resistance to sharing of sensitive information, lack of trust between the transport stakeholders, opportunistic behaviour, software non-interoperability, and paying for the DSS and sharing the savings. Further initiatives to transfer the developed DSS to the Canadian forest industry also face similar concerns.

Typically, Canadian forest companies outsource their timber truck routing decisions to assets-based transportation service providers (i.e. independent or associated carriers). Implementing the VTM among a set of forest companies modifies current transportation organizations. The central DM plays the role of a logistics service provider (LSP) that makes, on behalf of the forest companies, the collaborative routing decisions that are then executed by their transportation service providers. Although very common in several other industries, to the best of the authors' knowledge, LSPs are fairly rare in forestry. One example of an LSP in forestry is Asset Forestry Logistics that provides a transportation planning and execution control service for several forestry companies in New Zealand (Ludbrook, 2011). Introducing an LSP represents a major change to the traditional business model of the Canadian forest industry which, as in many countries, has a culture usually known to be conservative. Implementation of the VTM by other actors already involved in forest transportation may represent a more suitable alternative for the Canadian industry. Audy et al. (2012a) identify four alternatives with examples in the international forest industry. Moreover, there are also a number of practical aspects to be addressed in the implementation of transportation collaboration: see e.g. discussion by Frisk et al. (2006) and Audy et al. (2012a) for a case study involving eight forest companies and the literature review on collaboration in logistics and transportation by Cruijssen et al. (2007b).

Results of recent research projects aiming the VTM simulation among five forest companies tend to suggest that Canadian forest companies are reluctant to engage in inter-firm collaboration in transportation. Indeed, the project obtains mixed results due to the low and hesitant participation of most of them (Marier, 2012). However, all participating forest companies show great interest in improving the planning of their transportation activities through the use of a DSS embedding an advanced planning method. This interest also exists in another on-going project to simulate VTM utilization in a wood procurement organization (see Dorval et al., 2012) and, for transportation-oriented DSSs in general, in a large number of Canadian forest companies. For instance, during recent years, a number of analyses with the aforementioned DSS MaxTour have been conducted on historical transportation data of Canadian forest companies and, in the six most exhaustive cases, potential cost savings (travelling time reduction) between 4-7% (5-9%) have been identified (Lepage, 2012).

Despite the potential cost savings revealed through historical data analysis, the adoption by the Canadian forest industry of truck routing DSSs, such as the VTM, has not been successful up to now. As discussed by Andersson et al. (2008) for the Swedish forest industry, one complex aspect when developing a DSS for timber truck routing is the need to obtain the detailed information required in input to the planning problem. Typically in Canadian forest companies, such detailed information is diffused among several databases held by different transportation actors and databases have variable levels of accuracy and unstandardized formats (e.g. different units of measure). In comparison, part of the required information is already in centralized databases in some countries: e.g., the Forestry National Road Database in Sweden (Andersson et al., 2008). Moreover, typically in Canadian forest companies, part of the required information is tacit knowledge: i.e., not recorded in any database and only available through discussion with DMs. Therefore, considerable effort must be devoted to gathering this detailed information and removing error in the data. Furthermore, additional effort will be required to maintain the detailed information up-to-date while transportation is taking place.

Another issue faced in the initiatives to transfer the developed DSS into the Canadian forest industry was the specialization of the developed planning method to the transportation problem encountered in the case study. Typical transportation problems in the Canadian forest industry involve large volumes composed of dozens of full-truckloads instead of small volumes of less-than-truckload. A joint project between FORAC Research Consortium at Université Laval and FPInnovations, is ongoing to develop a more generic planning method and preliminary results on real instances from the Canadian forest industry were obtained (Marier, 2012).

4.8 Conclusion

In this paper, we presented a DSS supporting inter-firm collaboration in forest transportation. Collaboration occurs through a centralized organization of the routes to deliver transportation requests specified by DMs. The main components of the system are described and are: i) the transportation data, in formal or tacit knowledge, from the DMs; ii) the core components of the system made up of user interfaces, a database and a web service for automatic data import; and iii) the support components connected to the VTM that include a road network and mapping web service, an intermediate database and a route planning module. Users of the system belong to one of the three roles (i.e. central DM, member and administrator), and access/editing rights to the user interfaces are accorded to them.

How the system enables the organization of transportation collaboration is detailed in three steps, in which the forest truck routing problem addressed and the planning method developed are highlighted. By capturing a number of collaboration opportunities for ‘common routes’, the system allows transportation efficiency enhancements and, in turn, benefits for the collaborating DMs. An industrial case study is presented and simulation over almost one year of the system usage results in potential cost-savings of 7.3-10.5%. Details about the actual outcome of the case study and further initiatives to transfer the system to the Canadian forest industry complete the discussion.

There are many research directions that can be pursued in the future on DSS in forest transportation in Canada and other forested countries such as such as Chile, Finland, New Zealand, Sweden and US. We mention a number of them in addition to the ones raised in the discussion (Section 4.7). One research direction concerns truck waiting time (i.e. queuing), mainly at the destination sites. Reserved short-time slot for pickup/delivery or enhanced coordination between the truck routing and the scheduling of on-site resources are possibilities to study for queuing time reduction. To better tackle stochastic events intrinsic to forest transportation (e.g. mill reception closure, equipment breakage), insights from the “(…) increasing body of research on dynamic VRPs” (Berbeglia et al., 2010;

Pillac et al., 2011) must be investigated. Another research direction concerns revision of the transportation payment methods currently used by the industry that mostly do not foster organization of transportation efficiencies among the transportation actors. Recently, a method has been proposed by Frisk et al. (2010) but other payment methods providing all transportation actors with a fair and sustainable financial incentive to achieve transportation efficiencies could be developed.

4.9 Acknowledgements

The authors wish to thank the many contributors to the system development and test, in particular Alain Rousseau, Line Simoneau and Philippe Marier from the FORAC Research Consortium at Université Laval, Jan Michaelsen and Jean Favreau from FPInnovations and Pierre Courtemanche from Groupe Transforêt. The authors would also like to acknowledge the financial support of the Canadian Forest Service - Natural Resources Canada, and the private and public partners of the FORAC Research Consortium.

4.10 References

Acuna, M., Brown, M., Mirowski, L., 2011. Improving forestry transport efficiency through truck schedule optimization: a case study and software tool for the Australian industry. Austro 2011 & FORMEC 2011, October 9-12, Graz and Rein, Austria.

Andersson, G., Flisberg, P., Lidén, B., Rönnqvist, M., 2008. RuttOpt: a decision support system for routing of logging trucks. Canadian Journal of Forest Research, 38(7): 1784-1796.

Audy, J.-F., D'Amours, S., Rönnqvist, M., 2006. Business models for collaborative planning in transportation: an application to wood products. In: Maula, M., Hannula, M., Seppä, M., Tommila, J., (Eds.). International Conference on Electronic Business and Research Forum to Understand Business in Knowledge Society, November 28 - December 2, Tampere, Finland. Tampere: Tampere University of Technology and University of Tampere. 533-539.

Audy, J.-F., D'Amours, S., Rousseau, L.-M. 2011a. Cost allocation in the establishment of a collaborative transportation agreement - An application in the furniture industry. Journal of the Operational Research Society, 62 (6), 960-970.

Audy, J.-F., El Hachemi, N., Michel, L., Rousseau, L.-M., 2011b. Solving a combined routing and scheduling problem in forestry. International Conference on Industrial Engineering and Systems Management, May 25-27, Metz, France.

Audy, J.-F., Lidén, B., Favreau, J., 2011c. Issues and solutions for implementing operational decision support system – An application in timber truck routing system. In:

Ackerman, P., Ham, H., Gleasure, E., (Eds.). 4th Forest Engineering Conference, April 5-7, White River, South Africa. Stellenbosch University, 94-97.

Audy, J.-F., D'Amours, S., Rönnqvist, M., 2012a. An empirical study on coalition formation and cost/savings allocation. International Journal Production Economics, 136(1): 13-27.

Audy, J.-F., D'Amours, S., Rönnqvist, M., 2012b. Planning methods and decision support systems in vehicle routing problems for timber transportation: a review. CIRRELT Research Paper 2012-38, CIRRELT, Canada.

Barnhart, C., Laporte, G. (Eds.). 2007. Transportation, Handbooks in Operations Research and Management Science, Volume 14. Amsterdam: North-Holland.

Berbeglia, G, Cordeau, J.-F., Gribkovskaia, I, Laporte, G., 2007. Static pickup and delivery problems: A classification scheme and survey. TOP, 15(1): 1–31.

Berbeglia, G, Cordeau, J.-F., Laporte, G., 2010. Dynamic pickup and delivery problems. European Journal of Operational Research, 202(1): 8-15.

Bergdahl, A., Örtendahl, A., Fjeld, D., 2003. The economic potential for optimal destination of roundwood in North Sweden – Effects of planning horizon and delivery precision. International Journal of Forest Engineering, 14(1): 81-88.

Bouchriha, H., D'Amours, S., Mammou, M.A., Alouane, A.B.H., 2009. Chips supply optimization for a network of pulp mills. Journal of Operation and Logistics, 2(1): IV.1-IV.14.

Boutin, F., FPInnovations, personal communication, September and December 2012.

Broman, H., Frisk, M., Rönnqvist, M., 2009. Supply chain planning of harvest operations and transportation after the storm Gudrun. Information Systems and Operational Research, 47(3): 235-245.

Brown, M., Michaelsen, J., Hickman, A., Provencher, Y., 2003. Potential for multi-use trailers in the Canadian forest industry. CR-0196-1, Forest Engineering Research Institute of Canada, Canada.

Carlgren, C.-G., Carlsson, D., Rönnqvist, M., 2006. Log sorting in forest harvest areas integrated with transportation planning using backhauling. Scandinavian Journal of Forest Research, 21(3): 260-271.

Carlsson, D., Rönnqvist, M., 2007. Backhauling in forest transportation: models, methods, and practical usage. Canadian Journal of Forest Research, 37(12): 2612-2623.

CCFM (Canadian Council of Forest Ministers), 2012. National Forestry Database. http://nfdp.ccfm.org/data/graphs/graph_21_a_e.php [On-line]: 12-04-19.

Charrouf, B., 2009. Implantation et test d'un outil de gestion et de planification du transport routier [Implementation and testing of a tool for planning and management of road transportation]. Master of Business Administration thesis, Faculty of Business Administration, Université Laval, Canada.

Clifton, C., Iyer, A., Cho, R., Jiang, W., Kantarcioglu, M., Vaidya, J., 2008. An approach to securely identifying beneficial collaboration in decentralized logistics systems. Manufacturing & Service Operations Management, 10 (1), 108-125.

Cordeau, J.-F., Laporte, G., Mercier, A., 2001. A unified tabu search heuristic for vehicle routing problems with time windows. Journal of the Operational Research Society, 52(8): 928–936.

Cruijssen, F., Bräysy, O., Dullaeert, W., Fleuren, H., Salomon, M., 2007a. Joint route planning under varying market conditions. International Journal of Physical Distribution and Logistics Management, 37(4), 287-304.

Cruijssen, F., Dullaert, W., Fleuren, H., 2007b. Horizontal cooperation in transport and logistics: a literature review. Transportation Journal 46(3) : 22–39.

Dai, B., Chen, H., 2012. Profit allocation mechanisms for carrier collaboration in pickup and delivery service. Computers & Industrial Engineering, 62 (2): 633-643.

D'Amours, S., Rönnqvist, M., Weintraub, A., 2008. Using operational research for supply chain planning in the forest products industry. Information Systems and Operational Research, 46(4): 265-281.

Dorval, J.S., Lehoux, N., Gaudreault, J., Marier, P., 2012. Collaboration in transportation management – Case study for the forest industry. In: 4th International Conference on Information Systems, Logistics and Supply Chain, August 26-29, Quebec City, Canada.

El Hachemi, N., Gendreau, M, Rousseau, L.-M., 2009. A heuristic to solve the weekly log-truck scheduling problem. In: International Conference on Industrial Engineering and Systems Management, May 13-15, Montreal, Canada.

El Hachemi, N., Gendreau, M, Rousseau, L.-M., 2011. A hybrid constraint programming approach to the log-truck scheduling problem. Annals of Operational Research, 184(1): 163-178.

El Hachemi, N., Gendreau, M, Rousseau, L.-M., 2013. A heuristic to solve the weekly log-truck scheduling problem. Computers and Operations Research, 40(3): 666-673.

Epstein, R., Morales, R., Serón, J., Weintraub, A., 1999. Use of OR systems in the Chilean forest industries. Interfaces, 29(1): 7-29.

Epstein, R., Karlsson, J., Rönnqvist, M., Weintraub, A., 2007. Forest transportation. In: Weintraub, A., Romero, C., Bjorndal, T., Epstein, R., (Eds.). Handbook of Operations Research in Natural Resources, International Series in Operations Research and Management Science, Vol. 99, Chapter 20. New York: Kluwer Academic Publishers. 391-403.

Ergun, O., Kuyzu, G., Savelsbergh, M., 2007. Reducing truckload transportation costs through collaboration. Transportation Science, 41 (2), 206-221.

Eriksson, J., Rönnqvist, M., 2003. Transportation and route planning: Åkarweb - a web-based planning system. In: Iwarsson Wide, M., Hallberg, I., (Eds.). 2nd Forest Engineering Conference, May 12-15, Växjö, Sweden. Uppsala: SkogForsk. 48-57.

Flisberg, P., Lidén, B., Rönnqvist, M., 2009. A hybrid method based on linear programming and tabu search for routing of logging trucks. Computers and Operations Research, 36(4): 1122-1144.

Flisberg, P., Frisk, M., Rönnqvist, M., 2012. FuelOpt -A decision support system for forest fuel logistics. Journal of the Operational Research Society, doi: 10.1057/jors.2011.157.

Forsberg, M., Frisk, M., Rönnqvist, M., 2005. FlowOpt: a decision support tool for strategic and tactical transportation planning in forestry. International Journal of Forest Engineering, 16(2): 101-114.

Frisk, M., Göthe-Lundgren, M., Jörnsten, K., Rönnqvist, M., 2006. Cost allocation in collaborative forest transportation. Discussion Paper 2006-15, Norwegian School of Economics and Business Administration, Norway.

Frisk, M., Jörnsten, K., Göthe-Lundgren, M., Rönnqvist, M., 2010. Cost allocation in collaborative forest transportation. European Journal of Operational Research, 205(2), 448-458.

Gingras, C., Cordeau, J.-F., Laporte, G., 2007. Un algorithme de minimisation du transport à vide appliqué à l'industrie forestière [An algorithm for minimizing unloaded transportation applied to the forest industry]. Information Systems and Operational Research, 45(1): 41-47.

Golden, B., Raghavan, S., Wasil, E., (Eds.), 2008. The Vehicle Routing Problem – Latest Advances and New Challenges. New York: Springer Science+Business Media.

Gronalt, M., Hirsch, P., 2007. Log-truck scheduling with a tabu search strategy. In: Doerner, K.F., Gendreau, M., Greistorfer, P., Gutjahr, W.J., Hartl, R.F., Reimann, M. (Eds.). Metaheuristics - Progress in Complex Systems Optimization. New York: Springer. 65-88.

Hirsch, P., 2011. Minimizing empty truck loads in round timber transport with tabu search strategies. International Journal of Information Systems and Supply Chain Management, 4(2): 15-41.

Jacqmin, F., Trimble Forestry Automation, personal communication, April 2011 and February-March 2012.

Krajewska, M.A., Kopfer, H., Laporte, G., Ropke, S., Zaccour, G., 2007. Horizontal cooperation among freight carriers: request allocation and profit sharing. Journal of the Operational Research Society, 59(11): 1483-1491.

Kokenge. K.S., 2011. Opportunities and challenges for decision support systems in log truck scheduling and dispatching. Master thesis, Oregon State University, US.

Lehoux, N., Audy, J.-F., D'Amours, S., Rönnqvist, M., 2009. Issues and experiences in logistics collaboration. In: Camarinha-Matos, L., Paraskakis, I., Afsarmanesh, H., (Eds.). IFIP International Federation for Information Processing, Volume 307, Leveraging knowledge for innovation in Collaborative Networks. PRO-VE 2009- 10th IFIP Working Conference on Virtual Enterprises, October 7-9, Thessaloniki, Greece. Boston: Springer, 69-77.

le Blanc, H.M., Cruijssen, F., Fleuren, H. A., de Koster, M.B.M., 2007. Factory gate pricing: an analysis of the Dutch retail distribution. European Journal of Operational Research, 174(3): 1950-1967.

Lepage, D., FPInnovations, personal communication, March and August 2012.

Lidén, B., Forestry Research Institute of Sweden, personal communication, December 2011.

Linnainmaa, S., Savola, J., Jokinen, O., 1995. EPO: A knowledge based system for wood procurement management. In: Aikins, J,m Shrobe, H., (Eds.). 7th Conference on Innovative Applications of Artificial Intelligence, August 20-23, Montreal, Canada. Menlo Park: AAAI Press. 107-113.

Ludbrook, M., Asset Forestry Logistics, personal communication, August 2011.

Marier, P., Gaudreault, J., D'Amours, S., 2009. Network collaboration and optimization: chip supply in an integrated pulp and paper company. 14th Annual International Conference on Industrial Engineering Theory, Applications & Practice, October 18-21, Anaheim, United-States.

Marier, P., FORAC Research Consortium at Université Laval. personal communication, July 2012.

McDonald, T., Taylor, S., Rummer, R.B., Valenzuela, J., 2001a. Information needs for increasing log transport efficiency. In: 1st International Precision Forestry Cooperative Symposium, June 17-20, Seattle, United-States. Seattle: College of Forest Resources. 181-184.

McDonald, T., Taylor, S., Valenzuela, J., 2001b. Potential for shared log transport services. In: Wang, J., Wolford, M., McNeel, J., (Eds.). 24th Annual COFE Meeting, July 15-19 Snowshoe, United-States. Corvallis: Council on Forest Engineering. 115-120.

McDonald, T., Haridass, K., Valenzuela, J., 2010. Mileage savings from optimization of coordinated trucking. 33rd Annual COFE Meeting, June 6-9, Auburn, United-States.

Mendell, B. C., Haber, J. A., Sydor, T., 2006. Evaluating the potential for shared log truck resources in middle Georgia. Southern Journal of Applied Forestry, 30 (2): 86-91.

Meyer, B., 1997 Object-Oriented Software Construction, second edition. Prentice Hall.

Michaelsen, J., 1996. A new Temisko multipurpose trailer for tree-length logs and chips. FPInnovations-FERIC, Communication technique – Chargement et camionnage 50.

Michaelsen, J., 2009. Reduction of energy intensity by the use of a multipurpose semi-trailer, FPInnovations-FERIC, Advantage 11(9).

Michaelsen, J., FPInnovations, personal communication, March, April and June, 2012.

MRNF (Ministère des Ressources naturelles et de la Faune), 2009. Ressources et industries forestières - portrait statistique. Quebec Governement.

Murphy, G., 2003. Reducing trucks on the road through optimal route scheduling and shared log transport services. Southern Journal of Applied Forestry, 27(3): 198-205.

Özener, O.Ö., Ergun, Ö., 2008. Allocating costs in a collaborative transportation procurement network. Transportation Science, 42 (2), 146-165.

Palander, T., Väätäinen, J., 2005. Impacts of interenterprise collaboration and backhauling on wood procurement in Finland. Scandinavian Journal of Forest Research, 20(2): 177-183.

Palmgren, M., Rönnqvist, M., Varbrand, P., 2003. A solution approach for log truck scheduling based on composite pricing and branch and bound. International Transactions in Operations Research. 10(5): 433-447.

Palmgren, M., Rönnqvist, M., Varbrand, P., 2004. A near-exact method to solve the log-truck scheduling problem. International Transactions in Operations Research. 11(4): 447-464.

Parragh, S.N., Doerner, K.F., Hartl, R.F., 2008. A survey on pickup and delivery problems - Part II: Tansportation between pickup and delivery locations. Journal für Betriebswirtschaft, 58(2): 81-117.

Pillac, V., Gendreau, M., Guéret, C., Medaglia, A.L., 2011. A review of dynamic vehicle routing problems. CIRRELT Research Paper 2011-62, CIRRELT, Canada.

Pulkki, R., 1984. A spatial database – heuristic programming system for aiding decision-making in long-distance transport of wood. Acta Forestalia Fennica, 188.

Pulkki, R., 1988. Use of spatial databases and heuristic programming for transport planning. In: Sutton, P. (Ed.). 7th International Transport Symposium. Transport and Handling in the Pulp and Paper Industry, Vol. 7. Chapter 10, 74-81.

Puodziunas, M., Rönnqvist, M. Fjeld, D., 2004. The potential of improvement for tactical planning of roundwood transport in Lithuanian state forest enterprises. Baltic Forestry, 10(1):79-88.

Rey, P.A., Muñoz, J.A., Weintraub, A., 2009. A column generation model for truck routing in the Chilean forest industry. Information Systems and Operational Research, 47(3): 215-221.

Rix, G., Rousseau, L.M., Pesant, G., 2012. Solving a multi-period log-truck scheduling problem with column generation. 34th Council of Forest Engineering Conference, June 12-15, Quebec City, Canada.

Robinson, T.F., 1994. Tour generation for log truck scheduling. In: 30th Annual Conference of the Operational Research Society of New Zealand, August 31- September 1, Palmerston-North, New Zealand. 166–171.

Rönnqvist, M., Ryan, D., 1995. Solving truck despatch problems in real time. In: 31th Annual Conference of the Operational Research Society of New Zealand, August 31-September 1, Wellington, New Zealand. 165–172.

Rönnqvist, M., Sahlin, H., Carlsson, D., 1998. Operative planning and dispatching of forestry transportation. Research paper LiTH-MAT-R-1998-18, Linköping University, Sweden.

Rönnqvist, M., 2003. Optimization in forestry. Mathematical Programming, 97(1-2) : 267-284.

Rönnqvist, M., 2012. OR challenges and experiences from solving industrial applications. International Transactions in Operational Research, 19(1-2): 227-251.

Rummukainen, T., Kinnari, T., Laakso, M., 2009. Optimization of wood transportation. Papermaking Research Symposium, June 1-4, Kuopio, Finland.

Rummukainen, H., VTT Technical Research Centre of Finland, personal communication, April 2012.

Savola, J., Rummukainen, H., Jokinen, O., 2004. KUORMA: A collection of APS-algorithms for forest industry wood transport. ERCIM News, 56: 29-31.

Shen, Z., Sessions, J., 1989. Log truck scheduling by network programming. Forest Products Journal, 39(10): 47-50.

Selviaridis, K., Spring, M., 2007. Third party logistics: a literature review and research agenda. International Journal of Logistics Management, 18(1): 125-150.

Soriano, H.O., West Ingeniería Ltda, personal communication, April-June 2012.

Tao, L., 2001. Shifting paradigms with the application service provider model. Computer, 34(10): 32-39.

Tolkki, S., Koskelo, I., 1993. Seeing the trees through the forest: GPS streamlines Finish logging operation. GPS World, October, 21-27.

Toth, P., Vigo, D. (Eds.), 2002. The Vehicle Routing Problem, SIAM Monographs on Discrete Mathematics and Applications. Philadelphia: Society for Industrial and Applied Mathematics.

W3C (World Wide Web Consortium), 2012. XML Essentials. http://www.w3.org/standards/xml/core [On-line]: 12-07-23.

Webb, C.R., 2002. Log/chip B-train: a new concept in two-way hauling. FPInnovations-FERIC, Advantage 3(8).

Weintraub, A., Epstein, R., Morales, R., Seron, J., Traverso, P., 1996. A truck scheduling system improves efficiency in the forest industries. Interfaces, 26(4): 1-12.

Weintraub, A., Universidad de Chile, personal communication, March 2012.

Williamson, G., Nieuwenhuis, M., 1993. Integrated timber allocation and transportation planning in Ireland. Journal of Forest Engineering, 5(1): 7-15

Zahedi, F. M., Song, J., Jarupathirun, S., 2008. Web-based decision support. In: Burstein, F., Holsapple, C.W., (Eds.). Handbook on Decision Support Systems 1, International Handbook on Information Systems, Chapter 16. Springer. 315-338.

Zak, J., 2010. Decision support systems in transportation. In: Jain, L.C., Lim, C.P., (Eds.). Handbook on Decision Making, ISRL 4, Chapter 11. Springer. 249-294.

Zazgornik, J., Gronalt, M., Hirsch, P., 2012. A comprehensive approach to planning the deployment of transportation assets in distributing forest products. International Journal of Revenue Management, 6(1/2): 45-61.

5 Cost allocation in collaborative transportation

This chapter presents the article entitled "Cost allocation in the establishment of a collaborative transportation agreement – An application in the furniture industry" which was published in Journal of the Operational Research Society, 62(6): 960-970, 2011. Here is an abstract of the article in French.

5.1 Résumé

Le transport est un élément important de la chaîne d'approvisionnement de l'industrie canadienne des fabricants de meubles. Même si plusieurs fabricants expédients sur les mêmes marchés, la coordination entre fabricants est rare. Récemment, des réductions potentielles en coût et délai de livraison ont été identifiés grâce à la collaboration en transport. Dans cet article, nous proposons et testons, dans le cadre d'une étude de cas avec quatre fabricants de meubles, un scénario logistique qui permet la collaboration de transport. De plus, nous abordons la question clé du partage des économies, en particulier lorsque les exigences hétérogènes de chaque entreprise participante ont un impact sur la valeur des économies. Pour ce faire, nous proposons une nouvelle méthode d'allocation du coût qui est validé par l'étude de cas. Une analyse de la sensibilité de la nouvelle méthode et des détails sur les retombées de l'étude de cas termine la discussion.

Cost allocation in the establishment of a collaborative transportation agreement – An application in the furniture industry

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Abstract. Transportation is an important part of the Canadian furniture industry supply chain. Even though there are often several manufacturers shipping in the same market region, coordination between two or more manufacturers is rare. Recently, important potential cost-savings and delivery time reduction have been identified through transportation collaboration. In this paper, we propose and test, on a case study involving four furniture companies, a logistics scenario that allows transportation collaboration. Moreover, we address the key issue of cost-savings sharing, especially when heterogeneous requirements by each collaborating company impact the cost-savings. To do so, we propose a new cost allocation method that is validated through a case study. Sensitivity analysis and details about the actual outcome of the case study complete the discussion.

Keywords: Collaboration; Cost allocation; Furniture industry; Game theory; Horizontal cooperation; Road transport

5.2 Introduction

The main export market of the Canadian furniture industry is the United States, with 95-96% of the total export value over the last decade (IC, 2008). Canada and the US being neighbouring countries, most deliveries are made by truck over long distances. Increased competition from countries with low production costs, mainly China, together with escalating fuel prices, US customs security and environmental concerns have created the need to improve transportation efficiency. The appreciation of the Canadian dollar against the US dollar in recent years, as well as the request by furniture retailers to reduce delivery time have also put extra pressure on the Canadian furniture industry supply chain. Efficiency, speed and agility in transportation operations are essential elements that constitute the furniture manufacturer of the future as described by Archambault et al. (2006). Moreover, regardless of the three 2016 scenarios expected by the Furniture Foresight Centre (CEFFOR) for the furniture industry in high production costs countries such as Canada, the search for efficiency to cut costs will become an everyday issue (CEFFOR, 2008).

However, even when different furniture companies located in the same region ship to the same market regions, the same cities and/or the same furniture retailers, coordination in the transportation operations between two or more companies is rare. Two recent internal studies (Audy and D'Amours, 2008) demonstrating significant potential benefits for the industry have led to increasing interest in transportation coordination through collaborative planning. By exploring different collaborative logistics scenarios among a group of furniture companies, these studies identify cost and delivery time reductions as well as gain in coverage of regional markets.

However, even though a collaboration logistics scenario can provide substantial benefits for the group, each company needs to evaluate the scenario according to its own benefits. This individual evaluation can lead to a situation where the logistics scenario with the highest cost-savings for the group, named the optimal cost-savings scenario, does not provide the individual highest cost-savings to some companies or worse, provides one or more negative benefits. As a result, without any modifications, this optimal cost-savings scenario would be rejected in favour of another scenario that may not capture all the potential cost-savings and may eventually exclude some of the companies. This situation was reported by Audy and D'Amours (2008) in their case study involving four furniture manufacturers in the province of Quebec.

In this paper, we integrate in the optimal cost-savings scenario the modifications which satisfy the conditions allowing its establishment by the whole group. Moreover, since the establishment of this scenario relies on a negotiated collaboration agreement among the future partners, we study the key issue of cost-savings sharing. More specifically, we study how cost-savings should be shared to the satisfaction of all companies when heterogeneous requirements among the partners impact the total cost of the optimal cost-savings scenario and need to be taken into account. Based on two methods existing in the literature, we propose and compute a new method to achieve these goals. We then analyze the impact of different sharing strategies according to different results in the negotiation of the collaboration agreement.

The paper is organized as follows. First, we introduce the transportation operation modes and planning problem studied in the context of the Canadian furniture industry in Section 5.3. Then, in Section 5.4 we discuss the benefits of collaborative transportation planning and, in Section 5.5, we present a logistics scenario allowing an implementation of collaborative transportation planning in an industrial case study with four furniture companies. In Section 5.6 we discuss how to share cost-savings and how to share a reduction to these cost-savings. In both cases, we present a modified method to do so. In Section 5.7, numerical results of the two modified methods are illustrated and discussed using the case study as well as an impact analysis on two parameters in the negotiation. Finally, details about the actual outcome of the case study and concluding remarks are provided in Sections 5.8 and 5.9, respectively.

5.3 Transportation operation modes

In the Quebec furniture industry, most furniture retailers' (i.e. the customers) orders are less-than-truckload size shipments and are delivered by truck to the US. To execute their transportation activities, furniture companies rely on carriers that operate mainly according to one of the two following modes.

The first mode is multiple-stop truckload (TL) operations. The TL carrier delivers a trailer to the shipping dock of the furniture company, who loads the trailer with many shipments. Occasionally, only one shipment will fill the trailer, but on average, nine to 21 shipments are needed. Soon after the trailer is loaded, a TL carrier driver will leave for the delivery destination of its first customer. Since the shipments are not handled again before their delivery to the customer, loading of the trailer must respect the ‘First In, Last Out’ constraint.

Thus, loading decisions are tightly linked to truck routing decisions. Efficient truck routing is a key issue for short delivery time and reduced cost. This planning is commonly done on a weekly basis by the furniture company. Each planned delivery trip must respect operational constraints such as the truck capacity limit, the driver's hours of service regulations (i.e. working/driving time daily limits and minimum daily rest time) and the business hours of the customers. The cost of a delivery trip is proportional to the total one-way travelling distance with specific travelling distance rates according to the state of the last customer delivery. A cost by intermediate stop, a cost for customs documents preparation and a fuel surcharge is also charged on each delivery trip.

The second mode is less-than-truckload (LTL) operations. The LTL carrier always keeps a trailer at the furniture company in order to allow the company to load its shipment as it becomes ready. Each day or so, the LTL carrier comes with a new trailer and leaves with the previous one to collect these shipments and bring them to its terminal. The LTL carrier handles these transportation/consolidation operations with many furniture companies in order to consolidate a large number of shipments at its terminal and to achieve truck routing several times a week and dispatch drivers regularly. After a shipment has been collected at the company, the LTL carrier guarantees its delivery inside a specific time range by destination zone.

The furniture company is charged on each of its shipments rather than on a delivery trip basis. The cost is proportional to the shipment volume, with specific rates by volume range and destination state. The cost of shipment is subject to a minimum charge in addition to a fuel surcharge.

When it is really cost-effective, a furniture company operating with the first mode could use a regional LTL carrier located in the US (e.g. the terminals network of carrier USF). In this case, rather than planning the shipment delivery up to customer location, the delivery is planned up to one of the regional LTL carrier terminals who offers the service to the customer. The cost charged by a regional LTL carrier is usually proportional to the shipment weight and subject to a minimum charge in addition to a fuel surcharge.

5.4 Cost savings with collaboration

Currently, the companies in the case study carry out their transportation operations with the carrier/mode they judge to be most beneficial for them. Caputo et al. (2005) report that although different criteria may influence the selection of a carrier, cost is often the most important as is the case for the four companies. Therefore, the case study focuses on the cost reduction benefit, although delivery time is also measured. Meeting delivery time is a critical criterion for the companies.

According to Cruijssen et al. (2007a), identifying and exploiting win-win situations among companies at the same level of the supply chain in order to increase their performance is about horizontal cooperation. Group purchasing organizations are a typical example of horizontal cooperation among buyers. Our case study can be considered as an example of horizontal cooperation. The literature provides interesting case studies where companies obtain savings with horizontal cooperation in road transport planning, e.g. Bahrami (2002); Cruijssen et al. (2005) ; Forsberg et al. (2005) ; Palander and Väätäinen (2005); le Blanc et al. (2007) ; Cruijssen et al. (2007b) ; Ergun et al. (2007) ; Krajewska et al. (2007); Mason et al. (2007); Frisk et al. (2010). In this paper, when the companies accomplish collaborative planning, cost-savings derive from two coordination opportunities: improved delivery trips and better transportation rates.

By planning the delivery trips of the four companies' shipments together, improvements in efficiency can be achieved, such as reduction in travelling distance and increase in the loading rate of the trailer. A savings of 5% by such improved efficiencies with multi-stop delivery trips among half a dozen manufacturing plants are reported by Brown and Ronen

(1997). Cruijssen et al. (2007b) report a 30.7% savings in a case study involving the planning of multi-stop delivery trips among three collaborating entities. Moreover, according to a sensitivity analysis on average order size, Cruijssen et al. (2007b) report that collaborative planning appears to be more profitable in sectors where orders are small (i.e. less-than-truckload size shipments) than in sectors where the average order is large (i.e. truckload or close size shipments).

By negotiating their transportation rates with the carrier together rather than individually, companies obtain, at the least, better transportation rates among the four actual rates of the companies. Kuo and Soflarsky (2003) report discounts in the range of 20-45% by negotiating with several carriers, with up to 70% discount from some large firms. The existence of discounts, but in lower percentages, has been confirmed in our case study by a comparison of the actual rates of the four companies as well as a quotation study done by a consulting firm among several LTL and TL carriers operating in Quebec.

5.5 Establishment of the collaboration

In the study by Audy and D'Amours (2008), collaborative planning was explored in four different logistics scenarios. For each scenario, Table 10 identifies the service provider to which the coalition outsources their operations of i) transportation upstream to the terminal, ii) consolidation-warehousing at the terminal, and iii) transportation downstream from the terminal. Note that the only difference between scenarios #3 and #4 is the location of the terminal, which has an impact on the total travelling distance and, consequently, the total cost.

Table 10 : The service provider of the logistics scenario #1-5.

Logistics scenario	**Service provider**		
	Transportation upstream to the terminal	**Consolidation and warehousing at the terminal**	**Transportation downstream from the terminal**
1	LTL carrier		
2	TL carrier	Company A	TL carrier
3 and 4	LTL carrier		TL carrier
5	LTL carrier (Only the shipments that will have a delivery time delayed by more than two days)		
	TL carrier	Company A	TL carrier

Scenarios #2-4 result in more cost-savings than scenario #1. However, even though they reduce the average delivery time of the group, these three scenarios increase the average delivery time of two of the four companies, while this was not the case with scenario #1. For some shipments, this increase means a delivery time delayed by three days or more, which is not acceptable for almost all customers of the four companies. However, scenario #1 leads to the exclusion of company A from the transportation coalition (i.e. obtains a negative saving) and, consequently, a logistics scenario #5 is proposed.

Scenario #5 combines a carrier of both the TL and LTL operation modes. Caputo et al. (2005) report attractive benefits by using both modes. We will thus assign to an LTL operation mode all the shipments that will have a delivery time delayed by more than two days in a TL operation mode. By outsourcing these shipments to an LTL carrier directly from the shipping dock of the companies, we ensure that the customers' delivery time expectations are respected. The other shipments, which represent the majority, are assigned to a TL carrier. Among the three scenarios #2, 3 and 4, scenario #2 results in the highest cost-savings and consequently, in scenario #5, the terminal is located in the factory of company A. In fact, scenario #5 should not be considered as a totally new scenario but as the optimal cost-savings scenario (i.e. the name of scenario #2 in the introduction) to which more flexibility in the transportation operation is allowed in order to meet the requirements in delivery times of each company.

To avoid possible conflict of interest, the truck routing from the terminal is done by a computer application and company A must follow the transport plan obtained. In a discussion on inter-organizational systems, Kumar and van Dissel (1996) identify possible risks of conflict and strategies for minimizing the likelihood of such conflicts. In practice, possible conflict of interest or the appearance of such still remains. Companies B, C and D must accept this risk, since company A must be considered as a kind of third party logistics (3PL) provider of consolidation-warehousing, truck routing and logistics services. Indeed, the offer of multiple and bundled services from an asset-based company, rather than just single and isolated transportation or warehousing service, refers to a 3PL provider in the literature, see Selviaridis and Spring (2007) for a review. For its services, company A charges companies B, C and D a cubic foot flat rate on their total volume of shipments that transit by the terminal. This type of rate reflects how a service is charged in this industry.

Other types of rate are reported in the literature. For instance, in Cruijssen et al. (2005) the 3PL levy a pre-determined percentage of the cost-savings obtained through the cooperation in transportation.

Transportation operations upstream/downstream to/from the terminal are outsourced to a TL carrier. The shipments of companies B, C and D are delivered separately for each company to the terminal during the week using only full truckload delivery, except when a partial delivery is necessary on Friday afternoons to clear the shipments inventory at a company. During the weekends, trucks are routed and start their delivery trips from the terminal at company A. Note that the TL carrier in the scenario should not be considered only as a transportation service provider operating alone. The carrier could belong to a group of collaborating carriers such as World Wide Logistics, an ongoing founding organization of six specialized furniture carriers (Thomas, 2008).

Finally, furniture companies B, C and D request another modification to the initial delivery trips planning. Indeed, if these companies grant the delivery to a regional LTL, this means that some of their shipments will be handled three times instead of twice, thus increasing the risk of potential damage. However, with some of their customers, furniture companies B, C and D have delivery agreements that specifically do not allow more than one transit operation, with the precise aim of reducing the risk of damage as well as problems caused by damage. Thus, to meet the requirements of some of the customers of furniture companies B, C and D, the use of regional LTL carriers is prohibited on all the shipments specified by these companies.

5.6 Sharing the cost savings of the collaboration

Collaboration brings up the following question. How should the cost-savings obtained through collaboration among a group of companies be shared between the companies? To address this problem, cooperative game theory provides a natural framework.

In cooperative game theory, a situation in which a group of companies, through cooperation, can obtain a certain benefit (such as a cost-savings) that can be divided without loss between them, can be described in an n-person game with transferable utility. Moreover, in such a game, a company is named a player, and a group of companies, a coalition. As mentioned by Hadjdukavá (2006), there are two fundamental questions that need to be answered in such a game: (1) which coalitions can be expected to be formed; and (2) how will the players of coalitions that are actually formed apportion their joint benefit?

By studying a situation in which we aim to implement logistics scenario #5, we address the first question in a very restricted way. Indeed, we limit to one the number of coalitions that can be formed, namely the grand coalition, which includes all players. This limitation must be taken into account in studying the second question in order to guarantee that no player or subset of players will obtain a higher cost-savings by acting outside the grand coalition. A coalition whose sharing of the cost-savings satisfies this condition is said to be stable.

Instead of splitting the savings of the coalition among the players, we address the second question by using a cost allocation method in which the cost of the collaborative planning is split between the players. Several cost allocation methods exist in the literature, an extensive list of papers and applications on cost allocation methods, which are partly based on cooperative game theory such as the Shapley value and the nucleolus, can be found in Tijs and Driessen (1986) and in Young (1985, 1994). In his literature survey on cost allocation, Young (1994) indicates that cost allocation is a practical problem in which the salience of the solution depends on contextual and institutional details and there are various ways of modelling a cost allocation situation.

In a case study involving cooperation in transportation, the Shapley value was used as a cost allocation method by certain authors, e.g. Cruijssen et al. (2005) and Krajewska et al. (2007). More recently, Frisk et al. (2010) propose a new cost allocation method called Equal Profit Method (EPM). This method aims at finding a stable allocation, such that the maximum difference in relative savings between all pairs of two players is minimized. A linear programming model (LP) must be solved to find this stable allocation. The authors propose this new cost allocation principle because, in their case study involving eight companies, they found certain disadvantages with most well-known allocation models in the literature when it came to the acceptance of the cost allocation among the companies. They report that it was difficult to not show that all companies had a similar relative cost-savings compared to the stand alone cost. Thus, they suggest that in a negotiation situation, it would be beneficial to have an initial allocation where the relative savings are as similar as possible for all players. Since in our case study the companies will reach a collaboration agreement after a negotiation based on a proposition elaborated by company A, the EPM is meaningful and was computed. However, according to our business context and how transportation operations are performed in the furniture industry, two modifications to the EPM have been necessary.

The first modification was the introduction of a minimum bottom-line cost-savings percentage in the EPM. The business logic behind such a modification is that participation in a coalition must be profitable for each collaborating player. An allocation method ensuring that each player receives a strictly positive benefit from collaborating referred to the positive benefits propriety (Agarwal et al., 2009). Such propriety has recently been introduced by some authors in case studies involving cooperation in transportation (Özener and Ergun, 2008; Perea et al., 2008). However, how much must the minimum savings percentage be to convince each player to join the coalition? At the lowest, the percentage must be greater than zero; in other words the cost allocated to a player must be less than its stand alone cost. However, in practice this issue is much more complex and it is based on negotiation between the companies that goes beyond the scope of this paper, see Nagarajan and Sošić (2008) for a review of cooperative bargaining models in supply chain management.

The second modification was the introduction in the EPM of three non-transferable costs for each company. As previously mentioned, for its services, company A charges companies B, C and D a cubic foot flat rate on their total volume and this is the first non-transferable cost. The second non-transferable cost concerns the additional cost incurred in the collaborative planning to satisfy all the special requirements of a specific company. A special requirement is about the respect of tight delivery time and/or the prohibition on using a regional LTL carrier on a specific shipment, both of which are the modifications integrated in scenario #5. To calculate the value of these additional costs for each company, a method is proposed in the following section. The last and third non-transferable cost is for the transportation upstream to the terminal: i.e., the transportation from the company to the terminal of its shipment assigned to a TL operation mode.

The notation used in the LP model to solve the modified EPM is defined in Table 11.

Table 11 : Indexes, sets, parameters and decision variable in the modified EPM.

Sets	
N	: the set of players, $N = \{\text{A, B, C, D}\}$
S_N	: all subsets (i.e. coalitions) of N, $S_N = \{\{\text{A}\}, \{\text{AB}\}, \{\text{AC}\}, \{\text{AD}\}, \{\text{ABC}\}, \{\text{ABD}\}, \{\text{ACD}\}, \{\text{ABCD}\}, \{\text{B}\}, \{\text{BC}\}, \{\text{BD}\}, \{\text{BCD}\}, \{\text{C}\}, \{\text{CD}\}, \{\text{D}\}\}$
Parameters	
A_i	: non-transferable cost of player $i \in N$ for all its special requirements
B_i	: non-transferable cost of player $i \in N$ for its transport upstream to the terminal
$C^{sa}(i)$	: stand-alone cost of player $i \in N$
$C(s)$	: cost of collaborative planning for player(s) in $s \in S_N$ without any special requirement
$C_R(s)$	: cost of collaborative planning for player(s) in $s \in S_N$ with the special requirement of all player $i \in R,\ R \subseteq s$
P	: minimum savings percentage for all players
T	: volume flat rate charges at the terminal
V_i	: total volume in shipment of player $i \in N$ who transit by the terminal
Decision variable	
z_i	: cost allocated to player $i \in N$

The modified EPM is formulated in the following LP model:

`min` f

s.t.

$$f \geq \frac{z_i}{C^{sa}(i)} - \frac{z_j}{C^{sa}(j)} \quad \forall i, j \in N \mid i \neq j \qquad (1)$$

$$\sum_{i \in s} \left[z_i + T \times V_i + A_i + B_i \right] \leq C_{\{s\}}(s) \quad \forall s \in S_{N \setminus \{A\}} \qquad (2)$$

$$\sum_{i \in N} z_i = C(N) \qquad (3)$$

$$\frac{\left[C^{sa}(i) - \left(z_i + T \times V_i + A_i + B_i \right) \right]}{C^{sa}(i)} \geq P, \quad \forall i \in N \qquad (4)$$

The first constraint set is to measure the difference in savings between all pairs of players. The variable f is used in the objective function to minimize the largest difference. The second constraint set allows for an allocation ensuring a stable coalition, that is, no company or subset of companies will obtain a higher cost-savings by acting outside the grand coalition. Company A is excluded from all these partial coalitions because company A aims to bring all companies into its coalition. The third constraint is to obtain an efficient allocation (also referred to in the literature as the budget balance propriety): i.e., the total cost of the collaborative planning is divided among the players. Finally, the fourth constraint set allows company A to grant each company the minimum saving percentage agreed upon during the negotiation.

5.6.1 Sharing the additional cost incurred to satisfy special requirements

By modifying the collaborative planning in order to respect the special requirements of the companies, the cost of the collaborative plan increases. Since some companies have more requirements than others and the impact on the cost increase between two requirements is almost never the same, this raises a new question: how should the additional cost incurred to satisfy the special requirements be shared between the companies?

To address this question, we modified the Alternative Cost Avoided Method (ACAM) presented in Tijs and Driessen (1986). In the ACAM, the total cost to be allocated is divided into two parts: the separable and the non-separable costs. The method first allocates to each player his separable cost and then distributes the residual part of the total cost, i.e. the non-separable cost, among the participants according to given weights. The separable cost of each player is the marginal cost increase obtained when player $i \in N$ joins the coalition $S_{N\setminus\{i\}}$. The non-separable cost is then allocated using the weights expressing the marginal savings that are made by each player by joining the grand coalition instead of operating alone.

In the modified ACAM, we allocate the additional cost incurred in collaborative planning to satisfy the special requirements instead of the total cost. Specifically, we allocate the difference between the cost of the collaborative planning satisfying the special requirements and the cost of the collaborative planning without the special requirements. The cost of the collaborative planning without the special requirements is allocated among the players with the modified EPM described previously.

The modified ACAM aims to allocate the greatest part of the additional cost incurred in collaborative planning to the company with the most expensive requirements. The business logic behind this allocation modulated by the impact of the individual requirements of each company is to make each company aware that, in general, the more numerous and restrictive their requirements are, the more this has an impact on collaborative planning and, in turn, on the increase in the additional transportation cost. Thus, the modified ACAM encourages each company to keep the number and degree of restrictions of their transportation requirements to a strict minimum. As in the original ACAM, the modified ACAM first allocates its separable cost to each player and then distributes the non-separable cost. The decision variables used in the following detailed step by step description of the modified ACAM are defined in Table 12.

Table 12 : Decision variables in the modified ACAM.

Decision variables	
t	: non-separable cost to allocate among all players in the grand coalition
r_i	: marginal cost increase when player $i \in N$ joins the coalition.
w_i	: relative weight of player $i \in N$
x_i	: non-transferable cost of player $i \in N$ for all its special requirements (becomes the parameter A_i in the modified EPM)
y_i	: separable cost of player $i \in N$

Step 1: the separable cost of each player $i \in N$ must be calculated with:

$$y_i = C_{\{i\}}(N) - C(N) \quad \forall i \in N \tag{5}$$

Step 2: the non-separable cost must be calculated with:

$$t = C_{\{N\}}(N) - C(N) - \sum_{i \in N} y_i \tag{6}$$

Step 3: the relative weights to distribute the non-separable cost among the players must be calculated with one of these two equations:

$$t \geq 0 \quad w_i = C_{\{N\}}(N) - C_{\{N \setminus \{i\}\}}(N) \quad \forall i \in N \tag{7}$$

$$\begin{gathered} t<0 \quad r_i = C_{\{N\}}(N) - C_{\{N \setminus \{i\}\}}(N) \quad \forall i \in N \\ w_i = \begin{cases} r_i = 0 & w_i = 0 \\ r_i > 0 & \sum_{j \in N} r_j - r_i \end{cases} \quad \forall i \in N \end{gathered} \tag{8}$$

When the non-separable cost is negative, equation (8) becomes necessary to respect the cost allocation principle of the modified ACAM: i.e., allocate to the company with the most expensive requirements the greatest part of the additional cost incurred in the collaborative planning. Indeed, with equation (8), the method distributes to the players with the lowest marginal cost increase the greatest reductions on their non-separable cost, while on the other hand, the player with the highest marginal cost increase receives the lowest reductions.

Step 4: the non-transferable cost of each player $i \in N$ for its special requirements must be calculated with:

$$x_i = y_i + \frac{w_i}{\sum_{j \in N} w_j} t \quad \forall i \in N \tag{9}$$

5.6.1.1 An illustrative numerical example

In order to illustrate the modified ACAM, we consider a small example including three players. The cost of collaborative planning of the grand coalition N without any special requirement, $C(N)$ = 20, while the cost of the grand coalition with all special requirements, $C_{\{1,2,3\}}(N)$ = 30. The cost of collaborative planning with only the special requirements of player 1, $C_{\{1\}}(N)$ = 21, player 2, $C_{\{2\}}(N)$ = 22, and, finally, player 3, $C_{\{3\}}(N)$ = 24. The cost of collaborative planning with the special requirement of all players except player 1, $C_{\{2,3\}}(N)$ = 28, player 2, $C_{\{1,3\}}(N)$ = 26, and, finally, player 3, $C_{\{1,2\}}(N)$ = 24.

Step 1: the separable cost of player 1, y_1, is calculated by $C_{\{1\}}(N)-C(N)$ = 21 -20 = 1, while y_2 = 2 and y_3 = 4.

Step 2: the non-separable cost, t, is calculated by $C_{\{1,2,3\}}(N)-C(N)-(y_1+y_2+y_3)$ = 30 – 20 – (1 + 2 + 4) = 3

Step 3: the non-separable cost being greater than zero, the relative weights of player 1, w_1, is calculated by equation (7): $C_{\{1,2,3\}}(N)-C_{\{2,3\}}(N)$ = 30 – 28 = 2, while w_2 = 4 and w_3 = 6.

Step 4: the non-transferable cost of player 1 for its special requirements, x_1, is calculated by $y_1+\frac{w_1}{(w_1+w_2+w_3)}t$ = $1+\frac{2}{(2+4+6)}\times 3$ = 1.5, while x_2 = 3 and x_3 = 5.5.

Once this non-transferable cost is calculated for each player, the modified EPM can now be used to allocate to players the $C(N)$ = 20: i.e., the cost of the collaborative planning of the grand coalition N without any special requirement.

5.7 Numerical results

The data used in the case study were collected weekly in the billing system of the four furniture companies during four consecutive weeks in 2008. The results are thus based on a comparison between the sum of the stand alone cost (delivery time) of each company and the cost (delivery time) of the collaborative transportation plan in the logistics scenario. Moreover, the cost-savings of each player is the difference between the player's stand alone cost and its allocated cost according to the modified EPM.

Two regions in the US have been targeted by the companies for collaborative planning of their shipments: first, the states on the West Coast (characterized by a wide territory, a small density road network and clustered customers); and second, the states bordering the

Great Lakes (characterized by a high density road network and a relatively homogeneous geographical distribution of the customers). The case represents a total of 363 shipments to 256 different customers for a percentage of 44.6% of the total volume shipped to the US The representation of the volume shipped during the simulation compared to the rest of the year has been validated (e.g. not in a seasonal peak or down). Companies shipped, respectively, 66.6%, 17.5%, 9.3% and 6.7%, of the total volume shipped while the distribution of the stand alone cost is 59.7%, 21.8%, 10.4% and 8.2%.

5.7.1 Cost allocation

For each of the four weeks, collaborative planning was performed eight times in order to compute the modified EPM; i.e., collaborative planning with the grand coalition and with the seven coalitions without company A, $\forall s \in S_{N\setminus\{A\}}$. The collaborative planning was done with a Microsoft Excel spreadsheet as well as the modified ACAM while the modified EPM was programmed using ILOG OPL. Road information (i.e. distance and time) was obtained with PC*MILER. Table 13 shows the provisional and final (i.e. respectively, without and with the three non-transferable costs) cost and savings per company according to the allocation by the modified EPM.

Table 13 : Provisional/final cost and savings per company according to the modified EPM.

Company	**Stand-alone cost ($CAD)**	**Provisional (only z_i)**		**Final ($z_i + T \times V_i + A_i + B_i$)**	
		Cost ($CAD)	**Savings (%)**	**Cost ($CAD)**	**Savings %**
A	71 695	58 817	18.0	58 817	18.0
B	26 149	15 394	41.1	25 111	4.0
C	12 445	8 133	34.6	10 853	12.8
D	9 806	7 221	26.3	9 806	0.0
Sum	120 095	89 565	25.4	104 587	12.9

We see first that company D goes from a provisional savings of 26.3% to a 0.0% final savings. The total cost of its three non-separable costs takes its entire provisional savings. By setting the minimum savings percentage parameter at greater than zero in the modified EPM, we can avoid this situation. Thus, we ensure that the allocation would provide not only a stable coalition (i.e., no company or subset of companies will obtain a higher cost-savings by acting outside the grand coalition) but also a profitable coalition (i.e., no company or subset of companies will obtain a higher or equal cost-savings by acting outside the grand coalition). Moreover, we ensure that the individual rationality condition is satisfied for each company (i.e. no company pays more than its stand-alone cost). According to the solution concepts in cooperative game theory, a cost allocation that satisfies the two previous conditions is said to be in the core.

Secondly, we see that the final cost and savings of company A remains unchanged. Obviously, company A does not charge itself a volume flat rate and has no transportation operations upstream the terminal adjacent to its factory. The zero non-transferable cost for special requirements is explained by the absence of special requirements by company A. As for companies B, C and D, they had special requirements, which increased the cost of the collaborative planning by 9 737 $CAD. To compute the modified ACAM that distributed this additional cost among the companies, collaborative planning of the grand coalition was performed according to nine variations of special requirements to satisfy. With a 7 811 $CAD allocated cost, Company B assumes the greatest part (80.2%) of the additional cost, which makes sense since company B is the company that has the largest number of shipments with special requirements and thus is more likely to affect the rise of the cost in the collaborative planning. Companies C and D assume the balance of the additional cost, with respectively a 749 $CAD (7.7%) and 1 177 $CAD (12.1%) allocated cost by the modified ACAM.

5.7.2 Comparison between the original and modified methods

Table 14 shows the results on both the modified EPM proposed in this paper and the original EPM proposed by Frisk et al. (2010). Note that in the modified EPM, the value of the minimum savings percentage was set to 1% in order to obtain not only a stable coalition but also a profitable coalition, as discussed in the previous subsection.

Table 14 : Comparison between the original and the modified EPM methods.

Company	**Modified EPM**		**Original EPM**		**Difference**	
	Cost ($CAD)	**Savings (%)**	**Cost ($CAD)**	**Savings (%)**	**Cost ($CAD)**	**Savings (%)**
A	58 817	18.0	62436	12.9	3 619	-5.1
B	25 111	4.0	22773	12.9	-2 338	8.9
C	10 951	12.0	10838	12.9	-113	0.9
D	9 708	1.0	8540	12.9	-1 168	11.9
Sum	104 587	12.9	104 587	12.9	0	0

The original EPM provides a similar cost-savings of 12.9% to the four companies and thus, results in a zero f value. Company A has the most to lose with the original EPM. Indeed, the savings increases of companies B (+8.9%), C (+0.9%) and D (+11.9%), are gained from the savings of company A (-5.1%), which is allocated a higher cost of 3 619$CAD by the original EPM. Companies B and D are the two companies that benefit most from the original EPM by massively transferring to company A the additional costs incurred by the group to meet their special requirements in the collaboration. Finally, note that without the addition of a minimum savings percentage in the modified EPM, company B would obtain a zero savings.

5.7.3 Influence of the minimum savings percentage on the cost allocation

As detailed in the following section, these research works led to a pilot project aiming to put simulated logistics scenario #5 into practice. To do so, companies must reach a negotiated collaborative business agreement that details the collaboration setting, especially all the monetary-related parameters. As the direct (i.e. consolidation-warehousing and logistics) or indirect (i.e. truck routing) services provider for the group, company A was mandated to first define an agreement proposition to negotiate. Before submitting its proposition of collaborative agreement to the other companies, it would be beneficial for company A to evaluate the impact on the allocation results of different values of the minimum savings percentage parameter on which the group could agree. Figure 15 shows the savings per company according to all the integer values the parameter may take.

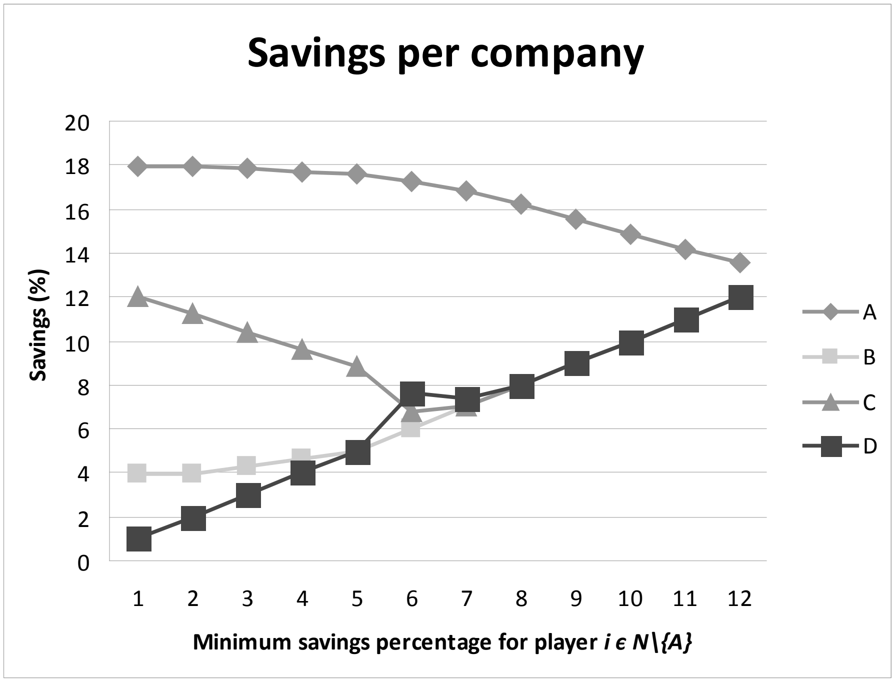

Figure 15 : Savings per company according to the minimum savings percentage.

We see that each increase of the minimum savings percentage is funded from the savings of companies A and C. It is therefore beneficial for companies A and C (except for company C if the group agrees to a minimum savings of 12%) that the group agree to a minimum savings percentage nearest to 1%. On the x axis, the values of the minimum savings percentage stop at 12%, since beyond this integer value of savings (or more precisely beyond 12.914%), the savings of company A will be less than the savings of companies B, C and D. Moreover, from an 8% minimum savings percentage (or more precisely from 7.1539%), companies B, C and D always obtain the same savings. However, an agreement by the group to 8% or more is contrary to the cost allocation principle of fairness embedded in the modified EPM and ACAM since the savings of companies B and D is funded by company A and C.

5.7.4 Influence of the volume flat rate on the savings of company A

Another monetary-related parameter that could be interesting to evaluate by company A before the negotiation is the impact on the allocation of both an increase and decrease of the volume flat rate. An increase of the cost could be the consequence of a significant decrease in the total volume shipped by the companies during a period of time while a decrease could be reached with an investment in the handling and warehousing equipment at the terminal. Company A estimates the cost of its 3PL provider services to a volume flat rate of 0.20 $CAD/cubic foot and this, with virtually nil profit. It is this volume rate that was used in the previous numerical results. Figure 16 shows the savings of company A according to the current volume flat rate and with both an increase and decrease of 0.05 $CAD/ft^3 to the current volume flat rate. Since the savings of the other companies remain unchanged they are not shown.

Figure 16 : Distribution of company A savings according to different volume flat rate.

Whatever the minimum savings percentage on which the group could agree, Figure 16 illustrates two crucial issues for company A. If the volume flat rate is more than the rate estimated, it is company A that assumes this difference by a reduction of its savings. Specifically, an increase by 0.05 $CAD/ ft^3 means a reduction of 1.0% of company A's savings. On the other hand, a decrease of 0.05 $CAD/ ft^3 means an increase of 1.0% of company A's savings. Consequently, this allows company A to evaluate further than the two regions and the periods of time of the study, the return on investment of any project: e.g., to renew handling or warehousing equipment.

5.8 Outcomes

Aiming at the implementation of logistics scenario #5 proposed in this paper, a pilot project was initiated by the companies with the support of their industrial association. To demonstrate some of the expected key issues in the pilot project, a simulation game, named the Cost Allocation Game, was played with the companies at the beginning of the project. This game, developed by two professors (Rönnqvist and D'Amours, 2008), is based on the industrial case study involving horizontal cooperation in transportation that is reported in Frisk et al. (2010). The purpose of the academic game is the creation of the grand coalition with a cost allocation method agreed on by each participant. The grand coalition is the coalition leading to the maximum benefit in this game (i.e. cost-savings). In a pre-determined number of rounds in which asymmetric information on the potential cost-savings of some coalitions is individually and confidentially revealed to each participant, negotiation takes place between the participants to form or break coalition(s) and define, in each coalition, a cost allocation method to agree on. The key issues relevant for the pilot project demonstrated with the simulation game were: i) the difficulty of defining a cost allocation method that is agreed on by all participants of a coalition; ii) the difficulty of sharing individual information in the negotiation; iii) the large gap in the collaboration synergy (mainly, cost-savings) obtainable between different participant(s); iv) the merger of two disjoint coalitions is always profitable (i.e. super-additive propriety); and v) the loss in cost-savings if the grand coalition is not formed (i.e. non constant-sum propriety).

As mentioned in Section 5.7.3, to put logistics scenario #5 into practice the companies must reach a collaborative business agreement that details the collaboration setting and, as the services provider, company A was mandated to define a first proposition of agreement to negotiate. Company A was highly involved and motivated by the pilot project, mainly for two reasons. First, the additional volume from the three other companies will allow company A to serve again the entire US on a weekly basis. The gradual decrease in demand (and therefore the volumes shipped) has, in some regions, forced delayed shipments in order to maintain competitive transportation costs. This has been done by moving to a fortnightly service in these regions. Second, as was agreed by the four companies at the beginning of the pilot project, company A projected, in a second phase, recruiting new collaborating companies to the limit of its internal capacities (i.e. warehousing and reception/shipping docks). This additional volume would increase (or at the least, maintain) the cost-savings, the delivery time and the future transportation rate negotiation power position of the furniture companies against the carriers.

The definition of the agreement by company A was delayed for many reasons (e.g. US customs security approbation, renewal of the employees' collective agreement at company A). When companies B, C and D received the proposition of agreement, company B left the negotiation early. Company B was suspected, by the other companies, of opportunistically using the monetary-related parameters inside the proposition of agreement to renegotiate downward its current transportation rates with its carriers. The negotiations between the three other companies were slowed down but continued. In growing financial difficulty, company C delayed its commitment to the pilot project and later on declared bankruptcy. Since the shipping volume of companies B and C represented 80% of the volume brought to company A for the collaboration, the sole volume of companies A and D did not provide enough coordination opportunities and the pilot project was suspended.

Since then, several factors (e.g. reduction of the fuel surcharge by the decrease of the record fuel prices, and transportation rates discounts due to competition between carriers on the reduced shipping volume in the slowdown economic period) have reduced the pressure of transportation expenses on companies' profitability. This in turn reduces the priority of any effort (such as the pilot project) deployed by the companies and their industrial association to reduce transportation expenses. Nevertheless, company A has recently joined an ongoing founded local organization grouping together several companies from different industrial sectors. The feasibility of transportation collaboration is one of the avenues the members want to evaluate. Moreover, more recently, motivated by the request of some of his major shippers-members, the Quebec Furniture Manufacturers' Association has launched a new initiative to improve outbound transportation through collaboration in transportation among its members (Michaud, 2012).

5.9 Concluding remarks

Using a case study of four Canadian furniture companies shipping to the US, it has been demonstrated that collaboration in transportation can provide cost-savings as well as delivery time reduction. To establish a collaboration meeting companies' requirements on certain shipments (i.e. tight delivery time and/or prohibition of the use of regional LTL carrier), a logistics scenario with more flexibility in the transportation operations has been proposed and tested. The result obtained in this improved logistics scenario satisfies the requirements of the furniture companies and thus, makes the collaboration with this logistics scenario acceptable to all companies.

We also studied one of the key issues in a collaboration agreement among the companies: how cost-savings should be shared among them. Based on two cost allocation methods in the literature, the Equal Profit Method and the Alternative Cost Avoided Method, we propose a new method embedding modifications for the business context of the case study. We first introduce in a modified EPM the presence of three non-transferable costs: (i) volume flat rate for 3PL provider services; (ii) special requirements cost; and (iii) transport cost for transportation upstream to the terminal. As for the second cost, we propose a modified ACAM to determine the non-transferable cost allocated to each of these companies. This modified ACAM aims to allocate to the company with the most expensive requirements the greatest part of the additional cost incurred in the collaborative planning with the special requirements. Secondly, to ensure an allocation providing a stable and profitable coalition, we introduce in the modified EPM the notion of having to guarantee a minimum savings percentage to all companies. We computed a set of values that can take this percentage to show the impact on the allocation among the companies. We also evaluated the impact on the cost-savings of company A in an increase or decrease of its volume flat rate as 3PL service provider in the collaboration. Details about the actual outcome of the case study complete the discussion.

There are many research directions that can be pursued in the future. For instance, in the case study, considerable geographical coverage benefit could be achieved by a company through the collaboration, raising the question of how much this access to new markets is worth. A way to study this question could be found by considering the coverage benefit in the cost allocation method. This could be a challenging problem also for other benefits from collaboration, see e.g. Cruijssen et al. (2007a) for a review of papers identifying different benefits revealed with collaboration.

Typically, the decision on the savings distribution among the companies is determined simultaneously with the decision on which coalitions can be expected to form (Greenberg, 1994). In the paper, the approach chosen to address these two concerns simultaneously is static: i.e., we expected that the grand coalition would be formed according to the negotiated minimum savings percentage and remain unchanged. This approach is justifiable considering the high transaction costs of implementing such a collaboration. Macho-Stadler et al. (2006) note that the transaction costs seem to increase with the number of companies involved. However, these two issues should be addressed using a more dynamic approach allowing modifications to the coalition as time goes by.

In the case study, company A wants to bring all companies into its coalition and, in further steps, other companies as well. However, the issues on the optimal size of the coalition, for all players of the coalition or only a subset, should be addressed. Moreover, in a context of transportation such as in the case study, this issue should be addressed according to delivery regions instead of on a company basis only. For instance, this geographical perspective would allow adding the shipments of a new company to the collaborative planning only in regions with transport capacity to fulfil.

Economics does provide a rich understanding of the fundamentals behind these issues, the next step is to validate the knowledge in field work.

5.10 Acknowledgments

The authors wish to thank Philippe Marier, FORAC, Charles Doucet, QFMA and the project leaders in the participating companies. Also, the authors wish to acknowledge the financial support of the NSERC and the private and public partners of FORAC Research Consortium.

5.11 References

Agarwal, R., Ergun, Ö., Houghtalen, L. and O.Ö. Ozener, (2009). Collaboration in cargo transportation. In: Chaovalitwongse, W., Furman, K.C. and Pardalos, P.M. (eds). Optimization and Logistics Challenges in the Enterprise. Springer: New York, pp 373-409.

Archambault, G., Carle, D., Caron. M. and R. Vézina (2006). The furniture manufacturer of the future, executive summary [In French]. FPInnovations-Forintek, Canada.

Audy, J.-F. and S. D'Amours (2008). Impact of benefit sharing among companies in the implantation of a collaborative transportation system – An application in the furniture industry. In: Camarinha-Matos, L. and Picard, W., (eds). IFIP International Federation for Information Processing, Volume 283, Pervasive Collaborative Networks. Springer: Boston, pp 519-532.

Bahrami, K. (2002). Improving supply chain productivity through horizonal cooperation – the case of cusumer goods manufacturers. In: Seuring, S. and Goldbach, M. (eds). Cost Management in Supply Chains. Physica Verlag: New York, pp 213-232.

Brown, G.G. and D. Ronen (1997). Consolidation of customer orders into truckloads at a large manufacturer. The Journal of the Operational Research Society, 48(8): 779-785.

Caputo, A.C., Fratocchi, L. and P.M. Pelagagge (2005). A framework for analyzing long-range direct shipping logistics. Industrial Management and Data Systems, 105(7): 876-899.

CEFFOR (2008). The furniture industry in 2016 – Competitive scenarios: strategic trends and implications, executive summary. Furniture Foresight Centre, Spain.

Cruijssen, F., Borm, P., Fleuren, H. and H. Hamers (2005). Insinking: a methodology to exploit synergy in transport, Center Discussion Paper 2005-121, Tilburg University, Netherlands.

Cruijssen, F., Dullaert, W. and H. Fleuren (2007a). Horizontal cooperation in transport and logistics: a literature review. Transportation Journal, 46(3): 22-39.

Cruijssen, F., Bräysy, O., Dullaeert, W., Fleuren, H. and M. Salomon (2007b). Joint route planning under varying market conditions. International Journal of Physical Distribution and Logistics Management, 37(4): 287-304.

Ergun, O., Kuyzu, G., and M. Savelsbergh (2007). Reducing truckload transportation costs through collaboration. Transportation Science, 41(2): 206-221.

Forsberg, M., Frisk, M. and M. Rönnqvist (2005). FlowOpt: a decision support tool for strategic and tactical transportation planning in forestry. International Journal of Forest Engineering, 16(2): 101-114.

Frisk, M., Jörnsten, K., Göthe-Lundgren, M. and M. Rönnqvist (2010). Cost allocation in collaborative forest transportation. European Journal of Operational Research, 205(2): 448-458.

Greenberg, J (1994). Coalition structures. In: Aumann, R.J. and Hart, S. (eds). Handbook of Game Theory with Economic Applications. North-Holland: Amsterdam, pp 1305-1337.

Hadjdukavá, J. (2006). Coalition formation games: a survey. International Game Theory Review, 8(4): 613-641.

IC (2008). Trade Data Online, requests on NAICS based code #337. Industry Canada, Government of Canada. Available from: http://www.ic.gc.ca/, accessed 25 January 2008.

Krajewska, M.A., Kopfer, H., Laporte, G., Ropke, S. and G. Zaccour (2007). Horizontal cooperation among freight carriers: request allocation and profit sharing. Journal of the Operational Research Society, 59(11): 1483-1491.

Kumar K and van Dissel H G (1996). Sustainable collaboration: Managing conflict and cooperation in interorganizational systems. MIS Quarterly, 20(3): 279-300.

Kuo, C.-C. and F. Soflarsky (2003). An automated system for motor carrier selection, Industrial Management and Data Systems, 103(7): 533-539.

le Blanc, H. M., Cruijssen, F., Fleuren, H. A. and M.B.M. de Koster (2007). Factory gate pricing: an analysis of the Dutch retail distribution. European Journal of Operational Research, 174(3): 1950-1967.

Macho-Stadler, I., Pérez-Castrillo, D. and N. Porteiro (2006). Sequential formation of coalitions through bilateral agreements in a Cournot setting. International Journal of Game Theory, 34(2): 207-228.

Mason, R., Lalwani, L. and R. Boughton (2007). Combining vertical and horizontal collaboration for transport optimisation. Supply Chain Management: An International Journal, 12(3): 187-199.

Michaud, J.F., Quebec Furniture Manufacturers' Association, personal communication, April and November 2012.

Nagarajan, M. and G. Sošić (2008). Game-theoretic analysis of cooperation among supply chain agents: review and extensions. European Journal of Operational Research, 187(3): 719-745.

Özener, O.Ö. and Ö. Ergun (2008). Allocating costs in a collaborative transportation procurement network. Transportation Science, 42(2): 146-165.

Palander, T. and J. Väätäinen (2005). Impacts of interenterprise collaboration and backhauling on wood procurement in Finland. Scandinavian Journal of Forest Research, 20(2): 177-183.

Perea, F., Puerto, J. and F.R. Fernández (2008). Modeling cooperation on a class of distribution problems. European Journal of Operational Research, 198(3): 726-733.

Rönnqvist, M. and S. D'Amours (2008). Cost allocation game. 5th CEMS Research Seminar: Supply Chain Management – Recent Trends and Future Perspectives, January 23-27 2008, Riezlern, Autria.

Selviaridis, K. and M. Spring (2007). Third party logistics: a literature review and research agenda. International Journal of Logistics Management, 18(1): 125-150.

Thomas, L. (2008). Six furniture trucking firms to merge. Furniture Today. Available from: http://www.furnituretoday.com/, accessed 30 April 2008.

Tijs, S. H. and T. S. H. Driessen (1986). Game theory and cost allocation problems. Management Science, 32(8): 1015-1058.

Young, H.P. (1985). Cost allocation: methods, principles, applications. North-Holland: Amsterdam.

Young, H.P. (1994). Cost allocation. In: Aumann, R.J. and Hart, S. (eds). Handbook of Game Theory with Economic Applications. North-Holland: Amsterdam, pp 1193-1235.

6 Coalition formation in collaborative transportation

This chapter presents the article entitled “An empirical study on coalition formation and cost/savings allocation” which was published in International Journal Production Economics, 136(1): 13-27, 2012. Here is an abstract of the article in French.

6.1 Résumé

Récemment, des économies potentielles ont été identifiées grâce à une planification collaborative dans les opérations logistiques. Même si des économies substantielles peuvent être réalisées, deux questions clés subsistes: (i) comment partager les économies potentielles entre les entreprises qui collaborent et (ii) à partir d’un ensemble d’entreprises pouvant collaborer, comment le ou les groupes d’entreprises collaboratrices sont formés? Ces deux questions sont étudiées dans un contexte spécifique: dans un ensemble d’entreprises pouvant collaborer, un sous-ensemble (désigné les entreprises dirigeantes) initie la formation d’un groupe d’entreprises collaboratrices et réalise la planification collaborative pour les entreprises au sein du groupe. Nous utilisons le concept de modèle d’affaires pour décrire ce contexte d’étude. En recourant à la littérature sur la formation d'un réseau où les économies sont modélisées par un jeu coopératif, quatre modèles d'affaires différents sont explorés avec quatre sous-ensembles différents d’entreprises dirigeantes. Nous proposons un modèle réseau comme méthode pour déterminer quel sera le groupe d’entreprises collaboratrices dans chaque expérience. Une étude de cas avec huit compagnies forestières est décrite et analysée. Les résultats montrent que des caractéristiques de solution très différentes peuvent être obtenues en fonction du modèle d'affaires choisi.

An empirical study on coalition formation and cost/savings allocation

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Abstract. Interest has been raised by the recent identification of potential savings through collaborative planning in logistics operations. Even though substantial savings can be realized, two key questions exist: (i) how should potential savings be divided among a group of collaborating companies; and (ii) among potential collaborating companies, how should collaborating group(s) be formed? These two questions are studied in a specific context: among potential collaborating companies, a subset (denoted the leading companies) performs collaborative planning on behalf of the others and together, they initiate formation of a collaborating group. We use the concept of a business model to detail such context. Based on the literature on network formation where potential savings are modelled by a cooperative game, four business models are explored in four different subsets of leading companies. We propose a network model as a method to determine the stable collaborating group in each computation. A case study including eight forest companies is described and analyzed. Results show that very different solution characteristics can be achieved depending on the business model selected.

Keywords: Game theory, OR in forestry, Transportation, Graph theory, Collaboration

6.2 Introduction

Transportation operations account for a significant expense in the wood products value chain. In forest operations (i.e. wood raw material procurement), large volumes and relatively long transport distances together with increasing fuel prices and environmental concerns create the need to improve transportation efficiency. Typically, several forest companies operate in the same region. However, coordination of wood flows between two or more companies is rare even if coordination can improve transportation efficiency, which in turn leads to cost savings. Potential cost savings of 5-15% are reported in case studies by Forsberg et al. (2005) and Frisk et al. (2010). However, coordination is conditional on collaboration between companies in transportation planning. As pointed out by Frisk et al. (2010), including coordination in planning raises the following questions: (a) how can potential savings from coordination of wood flows among a set of collaborating companies be computed; and (b) how should potential cost savings be divided among collaborating companies? In this article, we also add: (c) among potential collaborating companies, how should collaborating group(s) be formed? We conduct an empirical study addressing these three questions using an industrial case study with eight forest companies embedding potential cost savings with coordination of wood flows.

To address question (a), we examine the literature on horizontal cooperation (see Cruijssen et al. (2007a) for a survey of this field). The European Union (2001) defines horizontal cooperation as “(…) an agreement or concerted practice (...) between companies operating at the same level(s) in the market.” The cooperating companies can be competitors or not but they should perform the same type of activities and/or services rather than complementary activities and/or services, which is related to vertical cooperation. See Simatupang and Sridharan (2002) and Arun Kanda and Deshmukh (2008) for an in-depth discussion on vertical cooperation and Mason et al. (2007) on lateral cooperation, which is the combination of both horizontal and vertical cooperation. Moreover, the notion of 'company' should not be considered too restrictively; Barratt (2004) notes that horizontal cooperation can also be conducted among business units (e.g. departments, divisions) inside a sole company that work as if they themselves were a company. Cruijssen et al. (2007a) provide a more logistics-oriented definition of horizontal cooperation which "(…) is about identifying and exploiting win-win situations among companies that are active at the same level of the supply chain in order to increase performance". In this article, the latter definition is more relevant to address question (a). Indeed, in addition to the case studies in Forsberg et al. (2005) and Frisk et al. (2010), there exist several other case studies in the literature where companies obtain savings with horizontal cooperation in road transport planning (see, e.g. Zäpfel and Wasner (2002), Hageback and Segerstedt (2004), le Blanc et al. (2007), Ergun et al. (2007a,b) and Krajewska et al. (2007)).

Cooperative game theory addresses both questions (b) and (c) in the study of *cooperative game with transferable utility* (TU-games). Any situation in which a group of companies, through cooperation (such as a collaboration in the transportation planning), can obtain a certain benefit (such as a savings in transportation cost) which can be divided without loss between them is described in such a TU-game. Moreover, as in a TU-game, a company is named a *player* and a group of cooperating companies a *coalition*. Also, the coalition with all players is called the *grand coalition* and a coalition with only one player is a *singleton coalition*. For a survey of concepts and applications of game theory in the field of supply chain management, we refer to Leng and Parlar (2005), Cachon and Netessine (2006) and Nagarajan and Sošic (2008). In this article, the case study embedding potential savings with coordination of the wood flows among forest companies is described as a TU-game. However, given the requirement that coordination of wood flows should be included in planning, the TU-game is studied according to a specific context: among the eight companies, a subset denoted the *leading companies* (LC) performs planning on behalf of the others, denoted the *non-leading companies* (NLC), and builds together a collaborating group. Working jointly as a unique entity, the LC "(...) initiates and drives the collaborative planning process", while the NLC are the "(...) followers who support the process" (Kilger et al., 2008). This context of leadership by one unique entity involves some modifications to the study of the TU-game. We use the concept of a *business model* to describe these modifications. A business model involves restrictions on question (b): distribution of the benefit, and question (c): formation of coalition(s). To respect such restrictions in the study of the TU-game, we examine the literature on network formation where potential cooperating savings are modelled by a TU-game. By combining graph theory and both cooperative and non-cooperative game theory, the literature on network formation is well suited to address questions (b) and (c).

We explore four different business models, each evaluated according to four *leadership scenarios* in which one, two or four companies constitute the LC, working jointly as a unique entity. Restrictions on formation of coalition(s) are the same among the four business models, however there is a difference in the distribution of the benefits. Two business models follow a *savings allocation rule* to split common savings among collaborating companies while the two others follow a *cost allocation rule* to split common cost among collaborating companies. Moreover, in both the cost and the savings approaches, the allocation rule is customized according to a plausible altruistic or opportunistic behaviour by the LC. By adopting an opportunistic behaviour instead of an altruistic one, the LC aims to obtain additional benefit at the expense of the NLC when they build their collaborating group. Thus, the comparison of the two business models within the same approach allows us to evaluate: (1) how much additional benefit the LC can obtain by adopting an opportunistic behaviour instead of an altruistic one; (2) whether or not the sequence in which the NLCs are recruited in the collaborating group led by the LC has an impact on LC benefit; and (3) whether the final collaborating group that has been formed is the same or not. Another interesting point raised by this empirical study is (4) whether the grand coalition is always the final collaborating group that has been formed considering restrictions imposed by our business model concept. Points (1) and (2) are directly linked to question (b) while points (3) and (4) are linked to question (c).

The research contribution of our article is twofold. First, by including practical business considerations in our study of questions (b) and (c), we analyze both questions according to the self-interested objective of a subset of the players (i.e. the LC, rather than all players), and we demonstrate the impacts (e.g. the grand coalition is not always formed) of such an objective on the results of both questions. Second, we propose a network model as a method to determine the stable coalition(s) required by our analysis in the first contribution. The literature on horizontal cooperation in transportation almost never pays attention to the formation of stable coalition(s). Rather, most of the literature presumes that the coalition with the highest benefit (i.e. the grand coalition) always forms, while in practice the players, in making their coalition formation decisions, can face limitations, such as the ones raised by our business models.

The article is organized as follows. In Section 6.3, we introduce preliminary concepts supporting the article; we introduce transportation planning in forestry, define the foundations of our game and finally, we describe our game through the literature on network formation. In Section 6.4, we discuss the allocation rules used for benefit sharing. In Section 6.5, we provide a network representation of our game to determine the stable coalition(s). The industrial case study is detailed in Section 6.6. In Section 6.7, we analyze the numerical results and, in Section 6.8, we discuss a number of practical aspects considering the proposed model. Finally, we make concluding remarks in Section 6.9.

6.3 Preliminary concepts

6.3.1 Transportation planning

Transportation planning in forestry is performed in several steps and is commonly managed according to four time-perspective horizons: strategic, tactical, operational and real-time. Decisions at the strategic level deal with the construction of transportation infrastructures and the selection of transportation modes. Tactical decisions mainly address planning issues from a month to year basis (e.g. budget planning). On an annual basis, transportation is often integrated with harvesting planning, deciding on the catchment areas to supply the mills with the right wood assortments (defined by, e.g. species, dimension and quality) at the lowest cost. To reduce transportation cost even more, decisions on catchment areas can be jointly planned with back-haulage tours. A back-haulage tour combines delivery of two or more full truckloads into one potential future route schedule to reduce the total unloaded travelling distance. By including back-haulage tours, we always get a solution that is as good or better than without including them (see survey in Carlsson and Rönnqvist (2007)). Operational decisions set the routing for each individual truck for one or many days. Real-time decisions dispatch the next trip (or part of a route) to one truck in the present situation (e.g. when a truck completes a delivery). There exist many articles and case studies on different Operational Research (OR) problems occurring in transportation planning in forestry (see review articles such as Rönnqvist (2003), Epstein et al. (2007) and D'Amours et al. (2008)). In order to allow companies to deal with such OR problems, many decision support systems have also been developed: e.g. ASICAM, Weintraub et al. (1996); Åkarweb, Eriksson and Rönnqvist (2003); MaxTour, Gingras et al. (2007); VTM, Audy et al. (2007); and RuttOpt, Andersson et al. (2008).

The case study in this article is based on a classical OR problem, the transportation problem, with modifications for the forestry context and to allow back-haulage tours. We denote this OR problem as the *forest transportation problem*. Specifically, the forest transportation problem consists in determining which supply point(s) should deliver to which demand point(s) in what volume at the lowest total cost, without transportation capacity constraints. A complete description of the forest transportation problem is found in Forsberg et al. (2005). By concurrently planning supply and demand points of all collaborating companies, we obtain a *common solution* which provides the cost-effective wood bartering volumes and common back-haulage tours among collaborating companies. Wood bartering volume and common back-haulage tour are the two coordination opportunities that offer the savings provided by collaborative planning in the case study. Figure 17 illustrates the first coordination opportunity: wood bartering between two companies. Four mills (i.e. two mills for company 1 and two mills for company 2) and a set of supply areas are considered. In the left part, each company operates by itself, while in the right part both companies use all supply areas as a common resource. As a result, with wood bartering, volumes of some supply areas are exchanged between companies to reduce total travelling distance. In the second coordination opportunity, the common backhaul tours combine delivery of full truckloads from at least two different companies (see case study in Palander and Väätäinen (2005)).

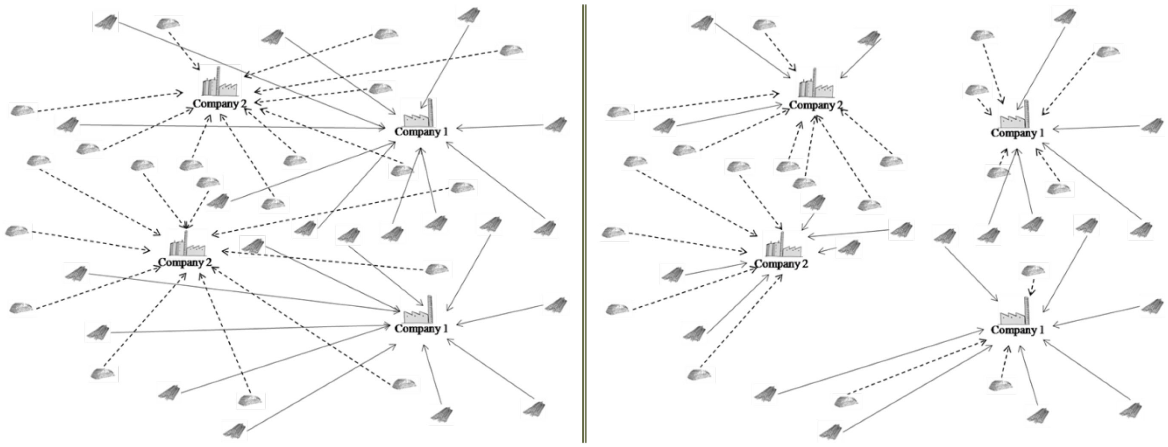

Figure 17 : Improvements in transportation efficiency using wood bartering between two companies (right) compared to two individual companies (left).

Forsberg et al. (2005) describe an OR-based decision support system (FlowOpt) that allows planning of these two coordination opportunities (i.e. provides the common solution). In addition, the system FlowOpt provides a *stand-alone solution* for each company by planning supply and demand points of each company individually. In turn, these solutions allow computing potential savings obtained through collaborative planning by any group of two to all eight forest companies of our case study. As in several aforementioned case studies involving horizontal cooperation in road transport planning, we define *savings* as the difference between the sum of the cost of each stand-alone solution and the cost of the common solution.

In this article, collaborating companies outsource planning of coordination opportunities to the LC. Thus, the LC acts as an organization that manages the collaboration by essentially, i) collecting information (e.g. supply, demand), ii) performing planning and, iii) providing each collaborating company with a *collaborative plan* to put into practice. This collaborative plan is specific to each company and is composed of two information parts. The first part advises the wood bartering and backhauling coordination opportunities within the supply and demand of the company and this information is extracted from the common solution. The second part concerns the monetary benefit obtained by the company in the collaboration. This information is computed with an allocation rule, using cost information from common and stand-alone solutions. More details on the allocation rule are provided in

Section 6.4. Our concept of a business model allows addressing both questions (b) and (c) according to the specific context of such a collaborative organization.

The question of how exactly the financial flows are performed among collaborating companies and the definition of exact information technology required by such a collaborative organization are beyond the scope of this article. However, different approaches exist in the literature on collaboration in logistics and transportation to tackle the first issue (see the review article by Audy et al., 2011b) while the second issue could be addressed by migrating the actual FlowOpt system to a web-based system.

6.3.2 Definition of the cooperative graph-restricted game

A TU-game is given by a pair (N,v), where $N=\{1,2,3...,n\}$ denotes a finite set of n players and v is the *characteristic function*, assigning to every coalition $S\subseteq N$ a *worth* $v(S)$, representing the total benefit of this coalition of players when they cooperate, without considering what other players do. A *coalition structure* is a partition of the n players into distinct coalitions (a player cooperates within only one coalition). A *payoff* represents the individual benefit of a player for cooperation on a coalition. In the literature, the notion of *n-person game with transferable utility* is also used to define a TU-game and the notion of *utility* is also used to define the worth of a coalition.

The worth of a coalition in the context of an OR problem with a minimization objective refers generally to savings, whereas with a maximization objective the worth refers to profit. The forest transportation model in the case study has a minimization objective. Its solution provides total transportation cost for the coalition while the worth of that coalition represents total savings in transportation cost obtained through collaboration. Thus, the value of the characteristic function is computed from the solutions of the FlowOpt system. Specifically, the cost of a given coalition S, $c(S)$, is obtained from the system as well as the cost of the singleton coalition $\{i\}$ of each company i in the coalition S, $c(\{i\})$. The worth of that coalition S is computed as follows:

$$v(S)=\sum_{i\in S}c(\{i\})-c(S) \qquad (1)$$

Obviously, $v(\varnothing)=0$ and $v(\{i\})=0$. Also, the worth of a coalition does not depend on non-member players (i.e. there is no externality between the coalitions), hence $v(S)$ denotes savings that members of coalition S can obtain on their own.

According to the solutions of the FlowOpt system on each coalition $S \subseteq N$ in the case study including eight players, we can state certain properties of the studied game. The studied game is *superadditive* since for every S and $i \notin S$ with $c(\{i\})>0$, $c(S \cup \{i\}) \leq c(S)+c(\{i\})$ and from which it follows that $v(S) \leq v(S \cup \{i\})$. In other words, a merger is always profitable (or at least not unprofitable). The studied game is a *non constant-sum* since $v(S)+v(\overline{S}) \neq v(N)$ for all complementary coalitions S and $\overline{S}$ due to loss of savings provided by wood flow coordination opportunities between players of two distinct coalitions. In other words, formation of two (or more) distinct coalitions instead of the grand coalition generates a loss in potential savings equal to the existing synergies in transportation between players in the two (or more) distinct coalitions.

In classical cooperative game theory, it is assumed that any and all coalitions can form. However, in many specific contexts, it is possible that some coalitions cannot form due to certain social, hierarchical, economic, communications or other restrictions (see van den Brink et al. (2007) for a list of articles addressing these restrictions). Introduced in cooperative game theory by Myerson (1977), graph theory provides a suitable tool for explicitly modelling these restrictions in the game. In Myerson graph theory formulation, a node represents a player and an undirected arc (i.e. link between two nodes) represents a potential to have a bilateral cooperative agreement between players i and j. Myerson defines a *cooperation structure* as all feasible links between potential agreeing players. Players connected on a non-directed graph *g* resulting from a given cooperation structure form a coalition. Even if two players do not have a direct bilateral agreement between each other, they may still be in the same coalition if they are connected through intermediate player(s). All resulting unconnected graphs (i.e. the network structure) furnish the set of distinct coalitions formed among N players (i.e. the coalition structure). Following the work of Myerson, directed graphs were then introduced in the literature. By using oriented arcs instead of undirected arcs, we can represent more complex restrictions: e.g., player i

can propose to player j to cooperate, whereas, player j cannot propose to player i to cooperate unless there exists an oriented arc from j to i. Our business model concept introduces such graph restrictions in the study of the TU-game. Specifically, we impose a cooperation structure where one central player i (representing the LC working jointly as a unique entity) is directly connected to every other NLC j by an oriented arc i to j and there are no other arcs. In the literature on network formation, this cooperative graph-restricted game without directed arcs is a special kind of cycle-free network called a 'star' in which there exists a node i, the centre of the star, such that every link in the network involves node i (Jackson, 2008). There are two consequences of such a cooperation structure. First, the LC is the only one that can propose a collaboration to an NLC. Second, only one coalition (involving more than one player) can form and this coalition must include the LC.

6.3.3 Description of the network formation game in extensive form

In classical cooperative game theory, the approach which is generally assumed during the coalition formation is that any number of players can simultaneously join or abandon a coalition. However, in other contexts, only bilateral agreements can occur and a player must maintain its previous agreement in any further bilateral agreement. For example, Macho-Stadler et al. (2006) study the sequential merger between two companies, two groups of already merged companies, and between a company and a group of already merged companies. Vidal-Puga (2007) studies a situation in which only one coalition is formed in the sequential inclusion of one new player. In a context similar to our case study, Cruijssen et al. (2005) study a procedure allowing a logistics service provider to form a grand coalition, with sequential offers to a set of potential collaborating shippers. Finally, Cruijssen et al. (2007b) study the development of a hub distribution network (i.e. a distribution network in which transhipment is allowed at specific intermediate facilities called hubs) by a step-wise procedure in which only one shipper at a time joins the coalition that jointly invests in a shared hub distribution network.

Our business model concept imposes such approaches with permanent and sequential bilateral agreement in the study of the TU-game (i.e. we have to study a TU-game in extensive form). Moreover, to respect the aforementioned cooperative graph-restricted game (i.e., the so-called ‘star’ with oriented arcs), the bilateral agreement can be proposed only by the LC and the unique coalition is formed through a sequence of bilateral agreements between the LC and the NLC. In order to tackle such a sequential, permanent and player-restricted bilateral agreement in the coalition formation, we draw on the literature on network formation where all the potential cooperating worth is modelled by a TU-game in extensive form.

The literature on network formation incorporates, among other matters, the graph theory formulation supporting the modelling of the cooperative graph-restricted game (see Demange and Wooders (2005) and Jackson (2008) for exhaustive surveys on the network formation literature). Thus, the set of the unconnected graph g resulting from the links formed in the cooperative graph-restricted game (i.e., the network structure) provides the coalition structure. The modelling by a TU-game of the worth obtained by each resulting coalition is based on which players are connected with one another within graph g and not on how exactly its players are connected within graph g (see van den Nouweland (2005) for a survey of articles based on this modelling approach). Finally, the study of the game in extensive form, rather than in normal/strategic form, allows being more explicit about the issue of timing in the study of the game. Indeed, games in extensive form allow studying sequential bilateral agreements over many time periods while games in normal/strategic form are limited to bilateral agreements in one time period.

Network formation games in extensive form were introduced in the article by Aumann and Myerson (1988) (see Bloch and Dutta (2008) for a survey of the literature on sequential models of network formation). In Aumann and Myerson’s game, an exogenous rule gives the sequence of pairs of players that have an opportunity to make a bilateral agreement (i.e., to form a link between them). Bilateral agreements cannot be broken once they have been made. All players observe which pairs of players made or not an agreement when they had the opportunity to do so (i.e., we are in a game with perfect information). Mutual agreement is required to form a link and each player makes its decision with a look-ahead perspective; in addition to considering whether or not he will be better off with this link, the player considers whether the formation of this link could end with a better or worse final payoff for him according to the further potential opportunities in links between other pairs of players. This look-ahead perspective is based on two assumptions in the game: first, players make their decision in a self-interested way to maximize their own individual final payoff; and second, the worth of each resulting coalition (modelling by a TU-game) will be divided among its players according to an exogenous allocation rule, the Myerson value (Myerson, 1977), which is an extension of the well-known Shapley value (Shapley, 1953). With this allocation rule, how the players in a coalition are connected is considered in determining the payoff.

The Aumann and Myerson game is finite in time; the game ends when, after the last link has been formed, all pairs of players without a bilateral agreement have, according to the sequence given by the exogenous rule, a last opportunity to make it, but do not agree. An equilibrium concept, the *subgame perfect Nash equilibrium* (SPNE), is applied to provide a prediction about the decision of each player at each opportunity, and thus makes a prediction about the ending network structure. An SPNE is a refinement of the well-known *Nash equilibrium* (Nash, 1951) for a finite game with perfect information in games in extensive form. The network structure supporting an SPNE, and by extension each resulting coalition, is said to be *stable* and *credible*. A network structure is stable when the prediction about the set of decisions by each player is the *best response* (i.e. allows the highest individual final payoff) against the sets of decisions of the other players and credible when these predictions hold at each *stage* of the game (i.e. at each opportunity to make a bilateral agreement). In a stable and credible network structure, no player, at any stage of the game, could benefit from a modification in its predicted set of decisions. Our concept of business model in the study of the TU-game imposes a similar approach with two main differences.

First, to respect the cooperative graph-restricted game, the sequence of pairs of players that have an opportunity to make a bilateral agreement is determined by the LC and each pair involves an LC. The maximum number of opportunities to make a bilateral agreement is equal to the number of NLCs because, if the LC decides to make a proposition to an NLC, the LC will do it only once. This maximum value means that we study a TU-game that is finite in time.

Second, we do not follow a two-step procedure in which the coalitions are formed and then the worth of each is divided among their players, rather, both are determined simultaneously. Thus, the proposition of bilateral agreement by the LC includes an immediate payoff for the NLC if this latter agrees and, in some business models, a description of the potential additional payoffs if other NLCs also agree on further propositions by the LC. We emphasize the word ‘potential’ since, in contrast to the immediate payoff, each of the additional payoffs for the NLC is conditional on the conclusion of a further bilateral agreement between the LC and other NLCs. The aforementioned procedure studied by Cruijssen et al. (2005) involves such an announcement of the potential for additional payoffs within the proposition to collaborate. The immediate payoff and, in some business models, the potential additional payoffs are computed with an allocation rule. Each of the four business models explored in this article uses a different allocation rule. Each rule is described in the following section. Moreover, to allow the description of the payoff(s) in the proposition of bilateral agreement and to put into practice the aforementioned coordination opportunities among the volumes belonging to several companies, the development stages of the coalition must be fully transparent between all companies. Each company is aware when an NLC receives a proposition of bilateral agreement and whether this bilateral agreement is concluded or not. This transparency means that we study a TU-game with perfect information.

6.4 Allocation rule of each business model

Several cost/savings allocation rules exist in practice in the industry and in the field of cooperative game theory. An extensive review of cost allocation methods, mostly based on cooperative game theory such as the Shapley value and the nucleolus, can be found in Tijs and Driessen (1986) and Young (1994). The Tennessee Valley Authority (TVA) case is a well-known cost allocation problem of a water resources development project (i.e. dams) among the project’s beneficiaries (e.g. hydroelectricity generation, flood control). Ransmeier (1942) provides a review of the allocation methods, not based on cooperative game theory, developed by the TVA, while Straffin and Heaney (1981) and Driessen (1988) applied cooperative game theory based cost allocation methods (e.g. τ-value, Nucleolus) to the TVA problem. We refer to Parrachino et al. (2005) for a recent review of allocation methods based on cooperative game theory in a water resources development project. The computing and analysis of some cost allocation methods on a case study similar to the one in this article is presented in Frisk et al. (2010) as well as a new method, based on a linear programming model, that aims for proportionally equal payoffs to each player.

There is no single and all-purpose method to achieve cost/savings allocation. Cooperative game theory provides a set of desirable *properties* for cost/savings allocations methods among a set of players. When choosing an existing method or developing a new one, we look for one that satisfies specific properties which are considered essential in our context. In the context of our collaborative organization, three of these properties must be satisfied by the allocation rule of each of the four business models. First, the property of *efficiency*, requires that the common cost/savings of a coalition must be entirely split among its players. Second, the property of *individual rationality*, requires that no player is worse off by collaborating in a coalition. Third, the *cross monotonic* property, requires that the payoff of a collaborating player does not decrease with the conclusion of new bilateral agreements between the LC and other NLCs. We also consider a fourth property recently introduced in the field of cooperation in transportation (see Özener and Ergun (2008); Perea et al. (2009); Audy et al. (2011a)), which is a reinforcement of the property of individual rationality: no collaborating player can receive a nil payoff. In other words, being a participant in a coalition must offer a positive benefit to the collaborating player. The allocation rule in business models 2-4 respects the four properties while the allocation rule in business model 1 respects only the last three properties. However, by applying a sorting rule on all solutions obtained from business model 1, it is possible to provide results that respect the cross monotonic property. Specifically, the sorting rule excludes all the potential sequences of coalition formation in which the payoff of at least one collaborating player decreases when a new collaborating player is recruited.

The allocation rules of the four business models are based on the same allocation scheme: an allocation according to the proportion of the stand-alone cost of each player in the coalition. This allocation scheme is easy to understand and to compute. Thus, each allocation rule is a close version of the others according to: i) a cost or a savings allocation approach; and ii) an altruistic or an opportunistic behaviour by the LC. In contrast to more advanced methods, the aim is to demonstrate through simple and easily customized allocation rules how the behaviour of the LC can affect benefit sharing among the collaborating players as well as the development and the size of the coalition.

Two business models follow a cost allocation rule while the two others follow a savings allocation rule. In both cost and savings approaches, the allocation rule is customized according to a plausible altruistic or opportunistic behaviour of the LC. The distinction between both behaviours is inherent to the sharing of the *marginal worth increase* when a player i accepts a bilateral agreement proposed by the LC. The allocation rule coming from an altruistic behaviour shares the marginal worth increase among all players of the new coalition ($S \cup \{i\}$), while the one coming from an opportunistic behaviour shares the marginal worth increase only between player i and the LC. Thus, the proposition of bilateral agreement by an 'opportunistic' LC includes only one payoff for the NLC (i.e. the immediate payoff) while the proposition by an 'altruistic' LC includes the immediate payoff as well as a description of the potential additional payoffs. Sprumont (1990) introduces the *population monotonic allocation scheme* to describe a situation in which the payoff to every player increases as the coalition to which he belongs grows larger (i.e. new players join). By sharing the marginal worth increase among all players of the new coalition, the two allocation rules customized to imitate an altruistic behaviour by the LC mimic such a scheme. However, these two allocation rules do not respect the core conditions: e.g., only one coalition can form in our business models rather than any coalition in the core. The indices, sets, parameters and decision variables used for the allocation rules are defined in Table 15.

Table 15 : Indices, sets, parameters and decision variables in the allocation rules.

Indices	
t	: a stage in the coalition formation, with $t=\{1,...,\lvert NL\rvert\}$
Sets	
L	: the set of all leading player(s)
NL	: the set of all non-leading players
Parameters	
$c(\{i\})$	: the stand-alone cost of player i
$c(S_t)$	: the cost of coalition S_t
$v(S_t)$	: the worth of coalition S_t with: $v(S_t)=\sum_{i\in S_t} c(\{i\})-c(S_t)$
i_t	: the player i, if any, that accepts a bilateral agreement at stage t
$m(S_t)$	: the marginal savings increase of coalition S_t, where $m(S_1)=\sum_{i\in L} c(\{i\})-c(\{S_1\})$ and $m(S_{t+1})=v(S_{t+1}\cup\{i_t\})-v(S_{t+1})$
S_t	: the coalition that forms after stage t, where $S_1=L$ and $S_{t+1}=S_t\cup\{i_t\}$
Decision variables	
$v_i^{S_t}$	: the payoff of player i in coalition S_t
$y_i^{S_t}$	: the cost/savings allocated to player i in coalition S_t

In business models 1 and 2, the payoff of any player i in coalition S_t is computed by Equation (2) while this payoff is computed by Equation (3) in business models 3 and 4:

$$v_i^{S_t}=\begin{cases} c(\{i\})-y_i^{S_t} & \forall i\in S_t \\ 0 & \forall i\notin S_t \end{cases} \qquad (2)$$

$$v_i^{S_t} = \begin{cases} \sum_{j \in \{1,\dots,t\}} y_i^{S_j} & \forall i \in S_t \\ 0 & \forall i \notin S_t \end{cases} \tag{3}$$

In the next subsections, we detail the allocation rules for each of the four business models.

6.4.1 Business model 1: cost allocation approach with altruistic behaviour

According to the rule of this business model, cost allocated to both LC and NLC are recomputed at each coalition S_t. Thus, cost of each coalition S_t is allocated among all its players by Equation (4):

$$y_i^{S_t} = c(S_t) \times \left(\frac{c(\{i\})}{\sum_{j \in S_t} c(\{j\})} \right) \quad \forall i \in S_t \tag{4}$$

6.4.2 Business model 2: cost allocation approach with opportunistic behaviour

According to the rule of this business model, cost allocated to the LC is recomputed at each coalition S_t while the cost allocated to the NLC is computed only once, that is, when the NLC accepts the bilateral agreement. Thus, cost of coalition S_1 is allocated with aforementioned Equation (4) while the cost of each coalition S_{t+1} is allocated in two steps. First, cost allocated to player i_t is computed as follows:

$$y_{i_t}^{S_{t+1}} = c(S_{t+1}) \times \left(\frac{c(\{i_t\})}{\sum_{j \in S_{t+1}} c(\{j\})} \right) \tag{5}$$

Second, because cost allocated to all NLCs already on coalition S_{t+1} stays the same, cost allocated to all LC must be reallocated by Equation (6) on the basis of the remaining (i.e. unallocated) cost of coalition S_{t+1}:

$$y_j^{S_{t+1}} = \left[c(S_{t+1}) - \sum_{w=\{1,\ldots,t\}} y_{i_w}^{S_{w+1}} \right] \times \left[\frac{c(\{j\})}{\sum_{k \in L} c(\{k\})} \right] \quad \forall j \in L \qquad (6)$$

6.4.3 Business model 3: savings allocation approach with altruistic behaviour

According to the rule of this business model, marginal savings increase of coalition S_t is allocated among all the players, both LC and NLC, as follows:

$$y_i^{S_t} = m(S_t) \times \left(\frac{c(\{i\})}{\sum_{j \in S_t} c(\{j\})} \right) \quad \forall i \in S_t \qquad (7)$$

6.4.4 Business model 4: savings allocation approach with opportunistic behaviour

According to the rule of this business model, marginal savings increase of coalition S_t, $m(S_t)$, is allocated to the LC at each coalition S_t while the allocation to the NLC is computed only once, that is, when the NLC accepts the bilateral agreement. Thus, $m(S_1)$ is allocated by Equation (8) while $m(S_{t+1})$ is allocated in two steps. First, $m(S_{t+1})$ allocated to player i_t is computed by Equation (9):

$$y_i^{S_1} = m(S_1) \times \left(\frac{c(\{i\})}{\sum_{j \in L} c(\{j\})} \right) \qquad (8)$$

$$y_{i_t}^{S_{t+1}} = m(S_{t+1}) \times \left(\frac{c(\{i_t\})}{\sum_{j \in S_{t+1}} c(\{j\})} \right) \qquad (9)$$

Second, because no $m(S_{t+1})$ is allocated to the NLC already on coalition S_{t+1}, the remaining part (i.e. unallocated to player i_t) of the $m(S_{t+1})$ is allocated among the LC as follows:

$$y_j^{S_{t+1}} = \left[m(S_{t+1}) - y_{i_t}^{S_{t+1}} \right] \times \left[\frac{c(\{j\})}{\sum_{k \in L} c(\{k\})} \right] \quad \forall j \in L \qquad (10)$$

A numerical example

Consider a simple example with three players, player 1 being the LC, in which the cost of coalition S is

$$c(\{1\}) = 4,\ c(\{2\}) = 8,\ c(\{3\}) = 5,\ c(\{1,2\}) = 10,\ c(\{1,3\}) = 8,\ c(\{2,3\}) = 10,\ c(\{1,2,3\}) = 13\,.$$

At each stage in the formation of the grand coalition by first proposing a bilateral agreement to player 2 and then to player 3, Table 16 (Table 17) shows the cost (savings) allocation and the payoff results of each player according to business models 1 and 2 (business models 3 and 4).

Table 16 : Cost allocation and payoff results in business models 1 and 2.

	First stage ($t=1$) in the coalition formation with player 2 accepting a bilateral agreement ($i_1 = 2$)		**Second stage ($t=2$) in the coalition formation with player 3 accepting a bilateral agreement ($i_2 = 3$)**	
	Cost allocated to each player in coalition $S = \{1,2\}$	**Payoff of each player in coalition $S = \{1,2\}$**	**Cost allocated to each player in coalition $S = \{1,2,3\}$**	**Payoff of each player in coalition $S = \{1,2,3\}$**
Player	**Business model 1: the cost allocation approach with altruistic behaviour**			
1	3.33	0.67	3.06	0.94
2	6.67	1.33	6.12	1.88
3	0	0	3.82	1.18
Player	**Business model 2: the cost allocation approach with opportunistic behaviour**			
1	3.33	0.67	2.51	1.49
2	6.67	1.33	6.67	1.33
3	0	0	3.82	1.18

Table 17 : Savings allocation and payoff results in business models 3 and 4.

	First stage ($t=1$) in the coalition formation with player 2 accepting a bilateral agreement ($i_1 = 2$)		**Second stage ($t=2$) in the coalition formation with player 3 accepting a bilateral agreement ($i_2 = 3$)**	
	Savings allocated to each player in coalition $S = \{1,2\}$	**Payoff of each player in coalition $S = \{1,2\}$**	**Savings allocated to each player in coalition $S = \{1,2,3\}$**	**Payoff of each player in coalition $S = \{1,2,3\}$**
Player	**Business model 3: the savings allocation approach with altruistic behaviour**			
1	0.67	0.67	0.47	1.14
2	1.33	1.33	0.94	2.27
3	0	0	0.59	0.59
Player	**Business model 4: the savings allocation approach with opportunistic behaviour**			
1	0.67	0.67	1.41	2.08
2	1.33	1.33	0	1.33
3	0	0	0.59	0.59

6.5 Tree representation of the network formation game in extensive form

A finite game with perfect information in extensive form, such as the one in our article, can be represented by a tree where a node has a player's label and the outgoing edge(s) of this node corresponds to the available decision(s) for the player at this stage of the game. At each stage, the player can make only one decision (i.e. select only one of the available outgoing edge(s)). Using the small example in Section 6.4, Figure 18 shows a simple tree example with three players, player 1 being the LC.

The root node corresponds to the first player that must make a decision and, according to its decision, the subsequent node, if any, corresponds to the next player that would have to make a decision, and so on. In this article, our concept of business model imposes the LC at the root node and the available decisions are different between the LC and the NLC. The LC has three options: $\{E, O_2, O_3\}$, where E is to end the game and O_i is to offer a bilateral agreement to NLC i, $i = 2,3$, noting that an NLC cannot receive the agreement proposal twice. The NLC have only two options: $\{R, A\}$, where R is to refuse the agreement proposal and A to accept it. For instance, in Figure 18 at stage one, player 1 (the LC) can decide to end the game (edge E), offer a bilateral agreement to player 2 (edge O_2) or to player 3 (edge O_3) while players 2 and 3 (the NLC) are allowed to accept (edges labelled A) or refuse (edges labelled R) the offer. When the NLC accepts the offer, a link is formed between them and individual payoffs are obtained. On the other hand, when the NLC refuses the offer, no link is formed between them and no individual payoffs are obtained.

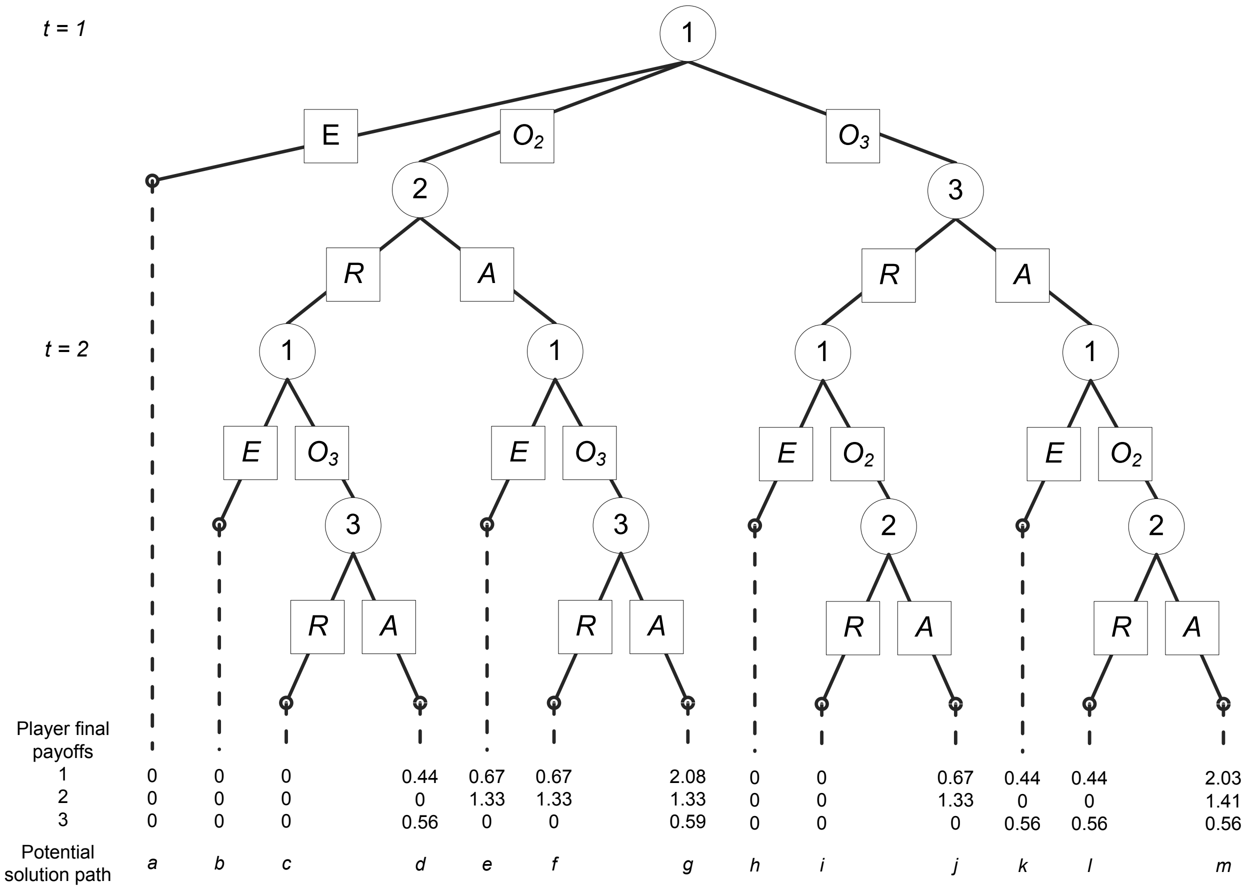

Figure 18 : Example of a three-player network formation game in extensive form with player 1 being the leading company.

A sequence of decisions by the players determines a path through the tree. The individual final payoffs (computed with the allocation rule of business model 4 in Figure 18) for the respective players are given at the end of each potential path, labelled from ‘a’ to ‘m’ in Figure 18. Each path provides an answer to both questions (b) and (c). For instance, path ‘e’ corresponds to, question (b): the formation of coalition {1, 2} and the singleton coalition {3}, and question (c): an individual final payoff of 0.67 for player 1, 1.33 for player 2 and zero for player 3. Moreover, a path gives us details about the issue of timing in the answers to both questions (b) and (c). For instance, path ‘g’ informs us that player 1 first makes the decision to make a proposition to player 2 and then to player 3, while in path ‘m’ it is the opposite case. And, as we can see by comparing the individual final payoffs of paths ‘g’ and ‘m’, the choice of the sequence to reach the same coalition (the grand coalition in paths ‘g’ and ‘m’) has an impact on the individual final payoff of player 1 as well as the two other players.

By providing a prediction about the decision of each self-interested player at each node, the solution concept of subgame perfect Nash equilibriun (SPNE) allows identifying which path, among all potential paths, will be taken and thus, answers questions (b) and (c). The method of backward induction is used to determine the solution path supporting the SPNE in the game (i.e. to determine the stable and credible coalitions). In essence, this method consists in starting the predictions at each decision node without successor and reaching back in the tree to the root node. For instance, solution path ‘g’ supports the SPNE in the game represented by Figure 18. The objective of the LC is to follow this optimal path that will form a stable and credible coalition in such a way that it will maximize the total individual final payoff of the LC.

6.6 Numerical results

The numerical results are based on a case study involving eight forest companies operating in Sweden. This case study is based on the same one described in Frisk et al. (2010) in which the potential benefits of two coordination opportunities (i.e. wood bartering volumes (Figure 17) and common back-haulage tours) are evaluated. These two industrial practices are not unique to Sweden (e.g. volume exchange exists in Chile and southwestern France, and common back-haulage tours are achieved in Finland and southern US). For an average Swedish mill, the one-way delivery distance for roundwood is 80 km and transportation operations account for 27% of its supply cost (Frisk, 2008). Moreover, transportation represents up to 0.45 billion €/year for the Swedish forest companies; approximately a third of this cost is fuel (Frisk, 2008). Given this large amount of money spent on transportation, a small cost reduction can lead to important savings. Furthermore, transportation is not a core activity for the wood processing mills and, consequently, this reduces the level of risk associated with the collaboration. These conditions (i.e. high potential return, low risk, not core activity) provide a good business context for the establishment of a collaborative organization in transportation.

6.6.1 Description of the case study

The data on the eight Swedish forest companies have been provided by the Forestry Research Institute of Sweden. The companies operate in southern Sweden and cover different geographical areas. Figure 19 shows the operation areas of the eight companies. The darker polygons indicate high volume supply areas of one or more supply points while bigger circles represent high volume demand points. Company 2 covers the entire region while the others only one or more parts. The data represent the transportation operations carried out during one month for a total of 898 supply points, 101 demand points and 12 wood assortments.

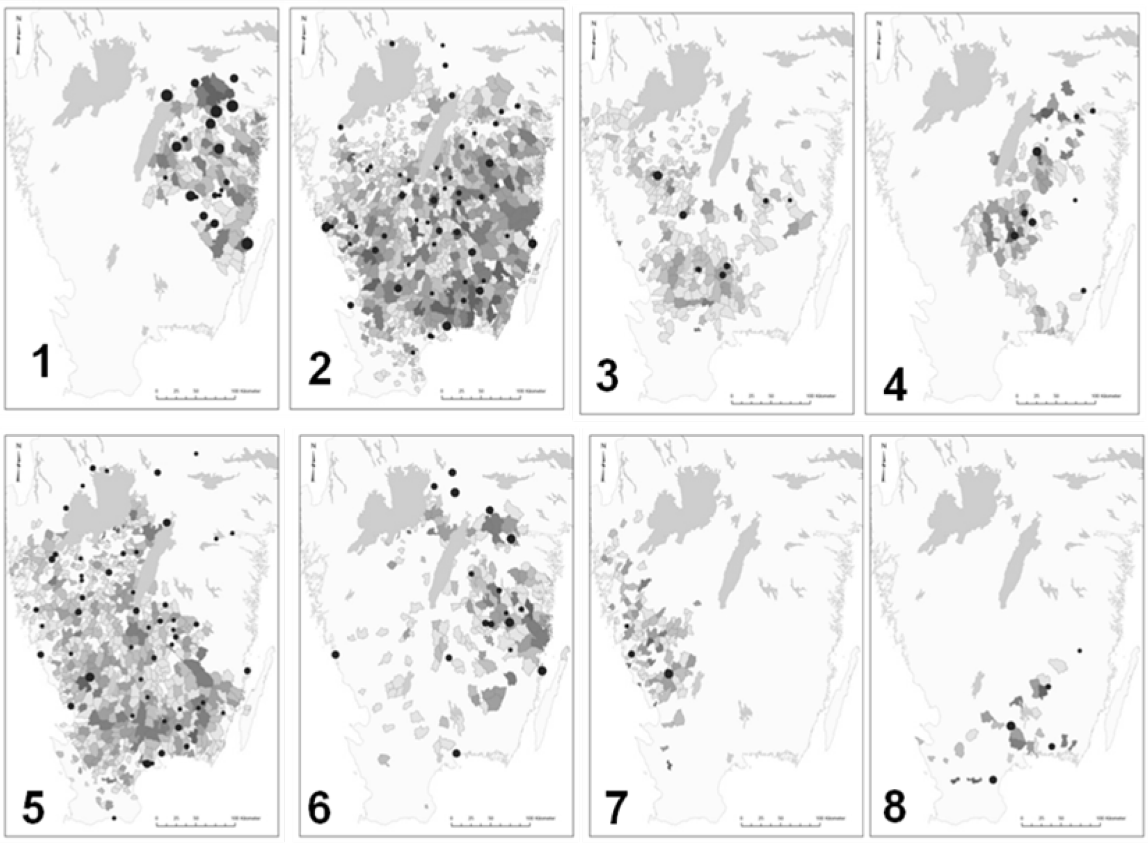

Figure 19 : The operation areas for the eight companies.

The volumes moved by the companies are uneven. Table 18 gives the proportion of total volume and stand-alone cost per company. We see that both proportions are strongly linked.

Table 18 : Proportion of the total volume and stand-alone cost per company.

Company	**Volume**	**Stand-alone cost**
1	8.8%	8.6%
2	34.2%	34.8%
3	10.1%	11.1%
4	5.0%	4.8%
5	26.3%	24.0%
6	10.7%	11.4%
7	4.2%	4.5%
8	0.7%	0.8%

To apply the proposed network model according to the four business models, with any leadership scenario among the eight forest companies, prior work on the data in the case study is required. First, we need to compute, with Equation (1), a worth for each coalition $S \subseteq N$. To use Equation (1), planning of the forest transportation model for all coalitions involving 2-8 of the companies has been performed with the FlowOpt system in order to provide the cost of 247 (= $2^8 - 8 - 1$) possible coalitions. Also, to obtain the stand-alone cost of each player (e.g. the eight singleton coalitions), the planning of the forest transportation model with only the supply and demand points of the company has also been done with the FlowOpt system. Second, according to the aforementioned allocation rule in each of the four business models, we need to compute, for each leadership scenario, the individual payoffs of all potential bilateral agreement propositions.

6.6.2 Description of the leadership scenario

Each business model has been evaluated according to four leadership scenarios in which one, two or four companies among the eight are the LC. The choice of these four leadership scenarios is based on the hypothesis below and other leadership scenarios could be evaluated.

6.6.2.1 Leadership scenario 1: the largest player

The companies with a large volume evenly distributed over different geographical areas can usually generate the greatest savings by collaborating with any other company. Thus, it appears realistic to suppose that one or more LCs with a large volume and a fairly good geographical coverage (in both harvest areas and mills) could reach a critical size allowing it to initiate the collaboration with initial propositions including enough payoffs to convince a few first players to accept to collaborate. Then, with a greater size, substantial payoff can be generated with any player outside the present coalition and thus facilitate the snowball effect on the growth of the collaborative organization. With more than a third of the total volume transported and harvest areas and mills covering the entire region, company 2 alone surpasses our notion of critical size and it is the LC in this first scenario.

6.6.2.2 Leadership scenario 2: the second largest player with a player completing its coverage

In this second scenario, companies 1 and 5 are jointly the LC, and this sharing of leadership by the two companies is mutually advantageous. Together, they obtain a proportion of the total volume and a geographical coverage almost equal to company 2 and thus, they attain together a business position to initiate the collaboration that is as advantageous as that of company 2. Also, for the second largest company 5, a shared leadership with company 1 specifically is highly strategic from the point of view of the geographical coverage. Both companies do not operate within the same geographical areas and the combination of their respective geographical coverage fits like two pieces of a puzzle. Their collaboration only generates a modest savings of 0.8% ($110,146), which is not surprising considering what was just said.

6.6.2.3 Leadership scenario 3: the two mid-size players

In this third scenario, companies 3 and 6 are jointly the LC and these two companies are the two mid-size players among the eight players. Together, they increase their proportion of the total volume and obtain a partial, but well distributed coverage of the entire region. Their similarities (i.e. volume and dispersed cover) favour a joint leadership while they generate together a savings of 1.3% ($121,897).

6.6.2.4 Leadership scenario 4: the four smaller players

In this last scenario, companies 1, 4, 7 and 8 are jointly the LC and, among the eight companies, they are the four smaller players in proportion of the total volume per company. Together, they become the third largest proportion of the total volume and obtain coverage in many geographical areas. Their similarities (i.e. small volume, narrow and isolated coverage) favour a joint leadership while they generate together a savings of 1.7% ($134,188).

6.7 Results analysis

Table 19 shows the results with leadership scenario 1 computed according to the four different business models. Table 20-Table 22 show the same results for, respectively, leadership scenarios 2, 3 and 4. In the columns 'Optimal path' and 'Worst path' we provide, respectively, the most and least lucrative paths for the LC. The worst path leads to the exact same final coalition as the optimal path, but with the sequence providing the lowest final payoff to the LC. The difference between both optimal and worst paths is provided, in percentage and cost value, in the column 'Difference'.

In business model 1, all paths which lead to the final coalition maximizing the total individual final payoffs of the LC are optimal paths. Consequently, we indicate the number of optimal paths that are available for the LC to form this final coalition. In leadership scenario 4 (i.e. the four smaller players), we should note an exception to the previous statement. In order to respect the cross monotonic property in the allocation, we apply the aforementioned sorting rule (see Section 6.4) for two paths (i.e. 3, 5, 2, 6 and 3, 5, 6, 2) among the 24 potential paths to reach the grand coalition. Indeed, in both of them, the payoffs of player 3 are reduced by 0.19% ($9,079) when player 5 joins the coalition. In the three other leadership scenarios, all the available optimal paths respect the cross monotonic property.

Column 'LC total final payoff' shows, in percentage (compared to the total stand-alone cost of the LC) and in cost value, the total final payoff of the LC. The last column shows the percentage of the worth of the final coalition taken by the LC or, in other words, the percentage part the final payoff of the LC represented on the sum of the final payoff obtained by all the collaborating companies. The case study highlights several results. In the following subsections, we analyze a number of them.

Table 19: Main results of leadership scenario 1 - the largest player.

Business model	Optimal path	Worst path	Difference		LC total final payoff		LC proportion of the total worth of the final coalition
1	All the 720 paths that lead to the final coalition {2,3,4,5,6,7,8}				9.5%	$1,400,519	38.0%
2	1, 5, 8, 4, 6, 7, 3	3, 7, 6, 4, 8, 5, 1	5.2%	$761,378	16.2%	$2,383,788	60.5%
3	3, 7, 8, 4, 6, 5, 1	5, 1, 6, 8, 4, 7, 3	2.9%	$426,256	15.0%	$2,201,067	55.8%
4	4, 1, 6, 3, 8, 7, 5	3, 5, 6, 7, 4, 1, 8	1.1%	$161,356	22.4%	$3,282,559	83.3%

Table 20: Main results of leadership scenario 2 - the second largest player with a player completing its coverage.

Business model	Optimal path	Worst path	Difference		LC total final payoff		LC proportion of the total worth of the final coalition
1	All the 720 paths that lead to the final grand coalition				9.3%	$1,286,565	32.6%
2	2, 8, 4, 6, 7, 3	7, 3, 2, 4, 6, 8	3.1%	$432,052	16.2%	$2,239,878	56.8%
3	7, 3, 4, 8, 2, 6	2, 6, 8, 4, 7, 3	1.6%	$218,603	13.5%	$1,868,065	47.4%
4	2, 8, 4, 7, 6, 3	3, 2, 6, 7, 8, 4	1.6%	$214,011	22.1%	$3,049,227	77.4%

Table 21: Main results of leadership scenario 3 - the two mid-size players.

Business model	Optimal path	Worst path	Difference		LC total final payoff		LC proportion of the total worth of the final coalition
1	All the 120 paths that lead to the final coalition {2,3,4,5,6,7,8}				9.5%	$908,812	24.7%
2	1, 5, 8, 4, 2, 7	7, 4, 2, 8, 5, 1	8.6%	$818,603	19.8%	$1,889,297	47.9%
3	7, 4, 2, 8, 5, 1	5, 1, 2, 8, 4, 7	4.0%	$377,708	16.9%	$1,606,806	40.8%
4	1, 5, 8, 4, 7, 2	2, 1, 4, 5, 7, 8	3.0%	$288,121	29.5%	$2,807,986	71.2%

Table 22: Main results of leadership scenario 4 - the four smaller players.

Business model	**Optimal path**	**Worst path**	**Difference**		**LC total final payoff**		**LC proportion of the total worth of the final coalition**
1	All the 24 paths that lead to the final grand coalition except paths 3, 5, 2, 6 and 3, 5, 6, 2				9.3%	$736,118	18.7%
2	5, 2, 6, 3	3, 6, 2, 5	10.6%	$838,410	24.9%	$1,963,205	49.8%
3	3, 6, 2, 5	5, 2, 6, 3	3.4%	$267,622	16.5%	$1,305,700	33.1%
4	2, 6, 5, 3	3, 6, 2, 5	3.9%	$309,085	36.3%	$2,863,558	72.6%

6.7.1 Business model 1 and player 1

If player 1 is one of the LCs in business model 1 (i.e. leadership scenarios 2 and 4), the grand coalition will form with a 9.3% final individual payoff for each of the eight players. On the other hand, if player 1 is not one of the LCs (i.e. leadership scenarios 1 and 3), the final coalition {2, 3, 4, 5, 6, 7, 8} will form and player 1 will end up in a singleton coalition {1}. Alone in its singleton coalition, player 1 is therefore the loser of this result with a nil payoff while the seven other players receive a 9.5% final individual payoff. The reason for this exclusion is simple: even though the addition of player 1 to coalition {2, 3, 4, 5, 6, 7, 8} results in a marginal worth increase of 0.61%, under the altruistic cost allocation rule in business model 1, its inclusion in the coalition reduced by 0.2% the payoffs of the seven other players. In other words, in business model 1, at the expense of the other players, player 1 receives more benefits than its volume can generate in the grand coalition. Overall, the exclusion of player 1 in leadership scenarios 1 and 3 leads to final coalitions that do not capture the entire economic potential in collaboration. The loss of overall supply chain profitability because of self-interested players has been greatly studied in the literature on vertical cooperation in supply chain management (see, e.g. Simatupang and Sridharan (2002)).

If, for any reason, excluded player 1 has an influence on the LC (e.g. player 1 assumes a portion of the supply of one or several of the mills of leading player 2 in the leadership scenario 1), player 1 can use its influence to force leading player 2 to make a bilateral agreement proposition. Such a notion of influence of a potential user, of an on-going implementation inter-organizational system, against another potential user has been studied in the information systems field, see, e.g. Boonstra and de Vries (2008). To maintain its final individual payoff, leading player 2 must propose a final individual payoff to player 1, which is, at most, equal to the marginal worth increase of 0.61%. By accepting an individual payoff equal to its marginal worth increase, player 1 obtains 76.2% (a loss of $80,820) of the individual payoff that he would have obtained if he had been one of the LCs or if we had addressed the formation of the coalition according to a maximization objective of the coalition’s worth rather than the total final individual payoff of the LC (i.e. a subset of the players).

6.7.2 Altruistic versus opportunistic behaviour

In the four computed leadership scenarios, by adopting an opportunistic behaviour rather than an altruistic one in the same cost/saving allocation approaches, the leading companies have obtained an additional individual payoff of 6.7-19.8%. The greater difference belongs to the last leadership scenario in which the four smaller players have increased their total individual payoff by 15.6% (a gain of $1,227,087) and 19.8% (a gain of $1,557,858) in, respectively, the cost and saving allocation approaches. Obviously, this additional benefit for the LC with an opportunistic behaviour was made at the expense of the benefit share for the NLC but, as with the adoption of altruistic behaviour, all four proprieties in the allocation were respected with the opportunistic behaviour.

In 2008, three of the eight companies involved in the case study formed a coalition where monthly coordinated planning duties were performed by the Forestry Research Institute of Sweden. Based on this development, we note that an altruistic behaviour seems more suitable to a collaborative organization driven by one or a set of shipping companies (as in our leadership scenarios) while an opportunistic behaviour seems closer to a collaborative organization driven by one or several carriers or third party logistics. More details on the latter collaboration organizations are provided in Table 23.

6.7.3 Optimal and worst sequence

In business models 2 to 4 in the four computed leadership scenarios, by taking to their advantage the decision on the sequence in which to propose a bilateral agreement to the

NLC, the LC have obtained a 1.1-10.6% additional total payoff. For example, in business model 2 with the leadership scenario 1 (numeric results are presented in Table 19), leading player 2 obtains an additional individual payoff of 5.2% (a gain of $761,378) by following the (optimal) sequence 1, 5, 8, 4, 6, 7, 3 rather than the (worst) sequence 3, 7, 6, 4, 8, 5, 1. Figure 20 shows both optimal (left) and worst (right) paths for this specific case.

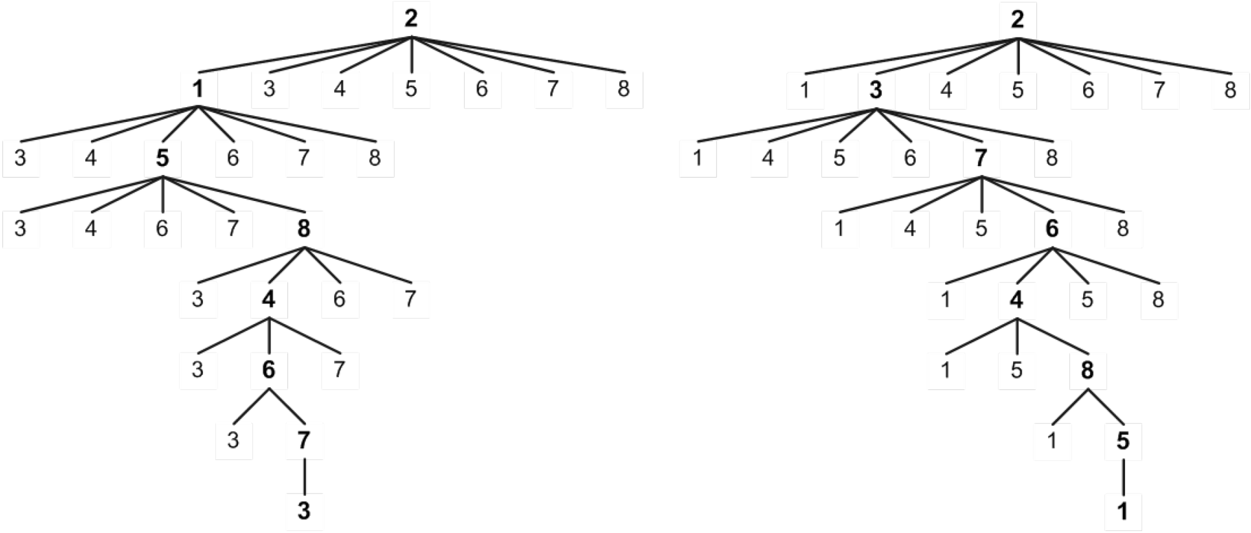

Figure 20 : Optimal (left) and worst paths (right) for leading player 2 in business model 2.

Among the four leadership scenarios, it is interesting to note that in business models 2 and 3, the sequence of the worst path is (or almost) the reverse of the optimal path (e.g. Figure 20). The reason for this is different for the two business models.

In business model 2, there are players with important volumes and dense coverage of their respective geographical areas (i.e. players 1, 2 and 5, which for the sake of clarity we denoted as the α players) in the beginning of the optimal sequence of the four computed scenarios. The transportation planning of the volume belonging to the α players with the volume belonging to the LC will generate new coordination opportunities with any LC or α player. In this business model, the proposition to the NLC includes only one individual payoff (i.e. the immediate payoff). Thus, it is advantageous for the LC to fix the individual payoff of the α players as early as possible in the sequence in order to avoid sharing with them later the savings coming from the synergies generated with their volume.

In business model 3, the players with small volume and lean, partial and dispersed geographical coverage (e.g. players 4, 7 and 8, which for the sake of clarity we denoted as the β players) are at the beginning of the optimal sequence of the four computed scenarios while the α players are predominantly at the end of the optimal sequence. In this business model, the marginal worth increase of any new coalition S_{t+1} is shared with all players already in the coalition and the player i_t, using the proportion of the stand-alone cost of each player. Thus, it is more advantageous for the LC to start with the β players and player 3 than the α players. Together with the volume of the LC, the volume of the β players and player 3 (see discussion in next paragraph) will generate a smaller marginal worth increase than the volume of the α players. However, the LC will obtain a greater part of this small marginal worth by not starting the sequence with the α players that, with their relative high stand-alone cost, received a larger part of the further marginal worth increases.

Players 3 and 6 are similar players both in their proportions of volume and stand-alone cost (compared to the grand coalition, see Table 18) and the characteristics of their geographical coverage. However, in business model 3, player 3 is at the beginning of the sequence while player 6 is at the end of the sequence or just before the α players. The difference in the location of the main operation areas of players 3 (i.e. in the southwest) and 6 (i.e. in the northeast) mostly explains the results. With its location, player 3 provides the LC with more synergies than player 6. All told, these additional synergies allow the LC more benefits than the larger part of the further marginal worth increases player 3 will receive with its higher (compared to the β players) proportion of stand-alone cost.

6.7.4 The value of being a leading player

By being a leading player instead of a non-leading player, a company improves (or at least does not reduce) its final individual payoff. In business model 1, there is an exception according to the impacts of player 1 on the results (see previous discussion in Section 6.7.1): if player 1 is a leading player, regardless of whether or not any other player shares leadership with player 1, this player will reduce its final individual payoff. In other words, in business model 1, any of the players 2-8 will reduce its final individual payoff if player 1 is a leading player, regardless of also being a leading player.

For each of the four business models, Figure 21 illustrates the final payoff of player 2 according to the four leadership scenarios. We see that player 2 obtains higher payoffs by being an LC (i.e. leadership scenario 1) rather than being an NLC (i.e. leadership scenarios 2, 3 and 4). Especially, by assuming sole leadership in scenario 1, player 2 improves by 1.5% ($20,488), 59.9% ($1,427,215), 45.3% ($996,870) and 80.4% ($2,638,443) for, respectively, the business models 1, 2, 3 and 4, if we compare this to its average final payoff in scenarios 2-4. These values represent the opportunity cost of not being, alone or with another specific player, an LC in each business model.

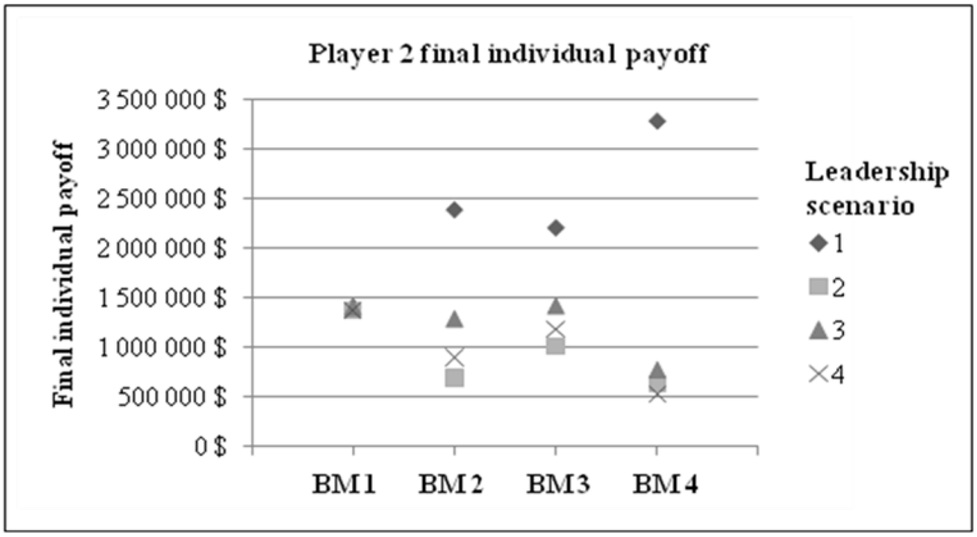

Figure 21 : The opportunity cost for player 2 of not being the sole LC in each business model.

Being the sole leading company provides the highest final payoff for each player. However, taking the leadership involves investments (e.g., human resources, time and money) that can drive a company to share this leadership, and required investments, with one or more players. Moreover, for some players, sharing the leadership is, in practice, necessary to reach the aforementioned ‘critical size’. In such a situation, selection by a company of its leading partner(s) has an impact on final payoff. For instance, by sharing the leadership with players 4, 7 and 8 (i.e. leadership scenario 4) instead of player 5 (i.e. leadership scenario 2), player 1 obtains a higher final payoff in business models 2-4.

6.8 Discussion

As reported in our case study as well as in other aforementioned case studies with horizontal cooperation in transport planning, there are important savings with collaborative planning. In this article, we study the allocation of these savings as well as formation of the collaborating groups based on one perspective of a collaboration organization. However, there are other perspectives of collaboration organization that could be evaluated (see Wang et al. (2007)). Among stakeholders that could be involved in different OR problems occurring in transportation planning in forestry, we can identify five potential categories of organizations that can perform collaborative planning. They are presented in Table 23, and some examples are provided.

Table 23: The five categories of organizations that can perform collaborative planning.

Category	Description
1	A shipping company performs the planning. An example is the Swedish forest companies Holmen Skog (HS) and Norra Skogsägarna (NS) (Eriksson and Rönnqvist, 2003). By using the decision support system ÅkarWeb, HS advises about the backhauling opportunities among both its under-contract carriers and some from NS in order to allow coordination among the carriers in truck routing.
2	More than one shipping company performs the planning. An example is the buyers' network of the Canadian wood logs supplier Groupe Transforêt (Audy et al., 2007). By using the decision support system VTM, truck routing is performed on the entire volume to deliver in the network in order to schedule shared routes among two or more buyers.
3	A carrier or a third party logistics (3PL) performs the planning. An example is the Swedish forest products carrier Skogsåkarna (http://www.skogsakarna.se/) that furnishes the transport activities of several forest companies. Another example is the Swedish company Sydved (http://www.sydved.se/) that organizes the purchase and transport of logs for its owners, the forest companies Stora Enso and Munksjö.
4	More than one carrier or 3PL performs the planning. An example is the Swedish logging and transportation company VSV (http://www.vsv.se/english.html) grouping together many collaborating independent carriers.
5	Shipper(s), Carrier(s) and 3PL(s) perform the planning.

There are also several practical aspects to consider for successful collaborating groups. For instance, ensuring the respect of the chain of custody or supply restriction associated to the absence of forest management certification. Below we discuss some of them and we refer to Frisk et al. (2006) for a discussion on other relevant aspects (e.g., valuation of wood, legality, tactical versus operational planning and shared information and quality).

6.8.1 Sequential bilateral agreement

We study sequential bilateral agreements for the formation of the coalition since, in practice the evaluation of the potential benefit is often realized between two companies at a time. Each company uses its internal method to anticipate the potential benefit of the collaboration. It appears realistic to suppose that the proposition of collaboration by the LC must also be evaluated on a two-company basis while considering the previously collaborating companies as only one company dealing with another potentially collaborating company. Then, the larger group of collaborating companies can continue the bilateral evaluation and so on until the final coalition is formed.

6.8.2 Conflict of interest

The collected information for collaborative planning may include sensitive business information. The collaborative plan (i.e. the coordination opportunities and the monetary benefit share) to put into practice by each company is generated by means of the solution of two models: the forest transportation model (the coordination opportunities) and, according to a specific business model, the network model (the monetary benefit share). To avoid possible conflict of interest when providing the collaborative plan to each collaborating company, the LC must follow the obtained solutions. In a discussion on inter-organizational systems, Kumar and van Dissel (1996) identify possible risks of conflict and strategies for minimizing the likelihood of such conflicts. More recently, Clifton et al. (2008) use cryptographic techniques to perform the transportation planning among potential competitors' carriers without the requirement of a central broker and with minimal information sharing. However, possible conflicts of interest or the appearance of such still remain, essentially because the collaborative organization of the LC is not an independent one. In this article, we consider that the NLC accept this risk since the collaborative organization of the LC must be considered as a kind of specialized logistics service provider.

6.8.3 Coalition establishment and management costs

No cost was calculated for the establishment and then the management of the coalition while, in practice, both will reduce the final payoff.

Establishment cost has been studied by some authors in the literature on network formation. Slikker and van den Nouweland (2000) introduce a connecting cost when players form links and study how different values of that fixed cost influence the formation of the network. Galeotti et al. (2006) also use a connecting cost but this cost varies across the players and in addition, for the same player, the cost is sensitive to the identity of the potential partner-player. In practice, this variable connecting cost makes sense since some players in the case study share more affinities (e.g. for the connection of their own IT system). However, the drawback of such a bilateral approach excludes the complete coalition structure which, according to Macho-Stadler et al. (2006), should be considered since the authors note that the establishment cost of a coalition seems much higher when more companies are involved.

In contrast to establishment cost, management cost refers to a repeating cost of running the collaboration over time. Some authors (e.g. Audy et al., 2011a) use a fixed unit cost which is e.g. linked to the volume to deliver, while others (e.g. Cruijssen et al., 2005) levy a part of the savings.

6.8.4 Cost-reduction perspective and negotiation

In this article, the decision to collaborate or not strictly focuses on a cost-reduction perspective while, as detailed in the literature review of Cruijssen et al. (2007a), there exist several other potential benefits (e.g. faster delivery time) than cost-reduction to perform horizontal cooperation in transportation and logistics. Although cost-reduction is usually by far the most important of the potential benefits, a question still remains: what payoff is required to incite a player to collaborate? At its least a payoff is just slightly greater than zero but, in practice, this issue is much more complex and it is based on a negotiation between the companies. Nagarajan and Sošic (2008) provide an exhaustive review of cooperative bargaining models in supply chain management that could support such payoffs determination in a negotiation context. In such bargaining models, the negotiation power of each player is highly relevant.. For instance, when two players negotiate, we should expect that the player with the higher negotiation power will receive a larger payoff than its weaker counterpart.

Moreover, before engaging in costly and time-consuming establishment work, a more strategically oriented reflection must be considered by the potential collaborating players. For instance, based on a total of 58 key performance indicators found through in-depth interviews and a literature study, Naesens et al. (2007) propose a framework to address, at a low cost and in a short period of time, such issues for reflection. Sometimes, even with large potential benefits, two companies can be confronted with insurmountable practices (e.g. differences in culture) that inhibit their collaboration. Several impediments and threats to horizontal cooperation are also detailed in the literature review of Cruijssen et al. (2007a).

6.9 Conclusion

It has been shown that coordination of the wood flows among companies within the same region can lead to a significant transportation cost reduction. There exist decision support systems that can establish transportation plans including such coordination opportunities and thus quantify the value of the savings by any group of collaborators in the region. However, these systems raise questions on how to share the obtained savings among the collaborating companies and how the collaborating group(s) will form. We study both questions within a network formation game in extensive form to take into account several restrictions raised by our notion of business model. This business model approach allows the integration of practical considerations in defining the allocation rule (e.g. altruistic or opportunistic behaviour by some players) as well as the coalition formation process (e.g. leading position by some players). To find the stable and credible collaborating group and the payoffs in the studied game, we propose a network model. This model has been applied in a case study with eight companies involved in forest transportation in Sweden. A total of four distinct business models have been considered in this article and each has been evaluated with the network model according to four distinct leadership scenarios. The tests highlight several results.

In the four computed leadership scenarios in which one, two or four companies among the eight are the LC, by adopting an opportunistic behaviour rather than an altruistic one, the leading companies obtained an additional individual payoff of 6.7-19.8%. Furthermore, among the four computed scenarios, the savings allocation approach (i.e. business models 3 and 4) was more advantageous for the leading companies than the cost allocation approach (i.e. business mode1s 1 and 2) by allowing a larger part of the worth of the final coalition to the leading players than the non-leading ones.

It was shown that in a group of companies, specific business models could lead to the formation of final coalitions that do not capture the entire economic potential of the group.

By deciding which optimal sequence in which to propose bilateral agreement to the same set of non leading companies, the leading companies obtained a total 1.1-10.6% additional payoff.

The opportunity cost of not being a leading company (alone or with other specific companies) has also been evaluated for one of the leadership scenarios: for company 2 this could result in a loss of 80.4% of its best final payoff as a leader.

As future research, different business models in which the LC can develop their coalition in various ways could be examined, e.g. recruiting more than one player at a time, recruiting the players in a context of competition by allowing the formation of a coalition without the LC, recruiting a player by including in the collaboration only the proportion of its volume that provides savings, recruiting a player with the savings detailed by volume delivered for a specific pair of supply-demand points (see transportation games in Sánchez-Soriano et al. (2001)). Another issue to be addressed relates to evolution of the formed coalition(s) as time goes by and thus more planning periods are considered. Formation of coalitions without complete or accurate information should also be addressed. Finally, the additional payoffs for a company to join more than one coalition (i.e. overlapping coalitions) by splitting its demand/supply should be investigated.

6.10 Acknowledgements

The authors thank Philippe Marier of FORAC Research Consortium for his technical assistance in computer programming. The authors also acknowledge the financial support of the Natural Sciences and Engineering Research Council of Canada and the private and

public partners of the FORAC Research Consortium. Finally, the authors thank the Forestry Research Institute of Sweden for the data used in the case study.

6.11 References

Andersson, G., Flisberg, P., Lidén, B., Rönnqvist, M., 2008. RuttOpt: a decision support system for routing of logging trucks. Canadian Journal of Forest Research, 38(7): 1784-1796.

Arun Kanda, A., Deshmukh, S.G, 2008. Supply chain coordination: perspectives, empirical studies and research directions. International Journal of Production Economics, 115(2) : 316-335.

Audy, J.-F., D'Amours, S., Rousseau, L.-M., Favreau, J., Marier, P., 2007. Virtual transportation manager: a web-based system for transportation optimization in a network of business units. In: Gingras, J.-F., (Ed.), 3rd Forest Engineering Conference, 1-4 October 2007, Mont-Tremblant, Canada.

Audy, J.-F., D'Amours, S., Rousseau, L.-M. 2011a. Cost allocation in the establishment of a collaborative transportation agreement - an application in the furniture industry. Journal of the Operational Research Society, 62(6): 960-970.

Audy, J.-F., Lehoux, N., D'Amours, S., Rönnqvist, M., 2011b. A framework for an efficient implementation of logistics collaborations. International Transactions in Operational Research, 18: no. doi: 10.1111/j.1475-3995.2010.00799.x

Aumann, R., Myerson, R., 1988. Endogenous formation of links between players and of coalitions: an application of the Shapley value. In: Roth, A. E., (Ed.). The Shapley Value: Essays in Honor of Lloyd Shapley, Cambridge: Cambridge University Press, 175-191.

Barratt, M., 2004. Understanding the meaning of collaboration in the supply chain. Supply Chain Management: An International Journal, 9(1): 30-42.

Bloch, F., Dutta, B., 2008. Formation of networks and coalitions. Available from: http://www.vcharite.univ-mrs.fr/PP/bloch/papers/networksurvey.pdf [accessed 24 March 2009].

Boonstra, A., de Vries, J., 2008. Managing stakeholders around inter-organizational systems: A diagnostic approach. Journal of Strategic Information Systems, 17(3): 190-201.

Cachon, G.P., Netessine, S., 2006. Game theory in supply chain analysis. In: Johnson, M. P., Norman, B., Secomandi, N., (Eds.). Tutorials in Operations Research: Models, Methods and Applications for Innovative Decision Making. Hanover: Institute for Operations Research and the Management Sciences, 200-233.

Carlsson, D., Rönnqvist, M., 2007. Backhauling in forest transportation: models, methods, and practical usage. Canadian Journal of Forest Research, 37(12): 2612-2623.

Clifton, C., Iyer, A., Cho, R., Jiang, W., Kantarcioglu, M., Vaidya, J., 2008. An approach to securely identifying beneficial collaboration in decentralized logistics systems. Manufacturing & Service Operations Management, 10(1): 108-125.

Cruijssen, F., Borm, P., Fleuren, H., Hamers, H., 2005. Insinking: a methodology to exploit synergy in transport, Center Discussion Paper 2005-121, Tilburg University, Netherlands.

Cruijssen, F., Dullaert, W., Fleuren, H., 2007a. Horizontal cooperation in transport and logistics: a literature review. Transportation Journal, 46(3): 22-39

Cruijssen, F., Borm, P., Dullaert, W., Hamers, H., 2007b. Joint hub network development. Center Discussion Paper 2007-76, Tilburg University, Netherlands.

D'Amours, S., Rönnqvist, M., Weintraub, A., 2008. Using operational research for supply chain planning in the forest products industry. Information Systems and Operational Research, 46(4): 265-281.

Demange, G., Wooders, M., 2005. Group formation in economics: networks, clubs and coalitions. In: Demange, G., Wooders, M., (Eds.). Cambridge University Press, Cambridge.

Driessen, T. S. H., 1988. Cooperative Games, Solutions and Applications. Theory and Decision Library C, Vol. 3, Dordrecht: Kluwer Academic Publishers.

Epstein, R., Karlsson, J., Rönnqvist, M., Weintraub, A., 2007. Forest transportation. In: Weintraub, A., Romero, C., Bjorndal, T., Epstein, R., (Eds.). Handbook on Operations Research in Natural Resources, International Series in Operations Research and Management Science, Vol. 99, Chapter 20. New York: Kluwer Academic Publishers, 391-403.

Ergun, O., Kuyzu, G., Savelsbergh, M., 2007a. Reducing truckload transportation costs through collaboration. Transportation Science, 41(2): 206-221.

Ergun, O., Kuyzu, G., Savelsbergh, M., 2007b. Shipper collaboration. Computers and Operations Research, 34(6): 1551–1560.

Eriksson, J., Rönnqvist, M., 2003. Transportation and route planning: Åkarweb - a web-based planning system. In: Iwarsson Wide, M., Hallberg, I., (Eds.). 2nd Forest Engineering Conference, 12-15 May 2003, Växjö, Sweden. Uppsala: SkogForsk. 48-57.

European Union, 2001. Guidelines on the applicability of Article 81 of the EC Treaty to horizontal cooperation agreements. Official Journal of the European Communities, 2001/C 3/02. Available from: http://europa.eu/scadplus/leg/en/lvb/l26062.htm [accessed 24 March 2009].

Forsberg, M., Frisk, M., Rönnqvist, M., 2005. FlowOpt: a decision support tool for strategic and tactical transportation planning in forestry. International Journal of Forest Engineering, 16(2): 101-114.

Frisk, M., Göthe-Lundgren, M., Jörnsten, K., Rönnqvist, M., 2006. Cost allocation in collaborative forest transportation. Discussion Paper 2006-15, Norwegian School of Economics and Business Administration, Department of Finance and Management Science, Norway.

Frisk, M., 2008. Forestry Research Institute of Sweden, personal communication, November.

Frisk, M., Jörnsten, K., Göthe-Lundgren, M., Rönnqvist, M., 2010. Cost allocation in collaborative forest transportation. European Journal of Operational Research, 205(2): 448-458.

Galeotti, A., Goyal, S., Kamphorst, J., 2006. Network formation with heterogeneous players. Games and Economic Behavior, 54(2): 353-372.

Gingras, C., Cordeau, J.-F., Laporte, G., 2007. Un algorithme de minimisation du transport à vide appliqué à l'industrie forestière [An algorithm for minimizing unloaded transportation applied to the forest industry]. Information Systems and Operational Research, 45(1): 41-47.

Hageback, C., Segerstedt, A., 2004. The need for co-distribution in rural areas - a study of Pajala in Sweden. International Journal of Production Economics, 89(2): 153-163.

Jackson, M.O., 2008. Representing and Measuring Networks. Social and Economic Networks. Princeton: Princeton University Press. 20-53.

Kilger, C., Reuter, B., Stadtler, H., 2008. Collaborative planning. In : Stadtler, H., Kilger, C., (Eds.). Supply Chain Management and Advanced Planning: Concepts, Models, Software, and Case Studies, Springer-Verlag, Berlin Heidelberg, 263-284.

Krajewska, M.A., Kopfer, H., Laporte, G., Ropke, S., Zaccour, G., 2007. Horizontal cooperation among freight carriers: request allocation and profit sharing. Journal of the Operational Research Society. 59(11): 1483-1491.

Kumar, K., van Dissel, H.G., 1996. Sustainable collaboration: managing conflict and cooperation in interorganizational systems. Management Information Systems Quarterly, 20(3): 279-300.

Leng, M., Parlar, M., 2005. Game theoretic applications in supply chain management: A review. Information Systems and Operational Research, 43(3): 187-220.

le Blanc, H.M., Cruijssen, F., Fleuren, H. A., de Koster, M.B.M., 2007. Factory gate pricing: an analysis of the Dutch retail distribution. European Journal of Operational Research, 174(3): 1950-1967.

Macho-Stadler, I., Pérez-Castrillo, D., Porteiro, N., 2006. Sequential formation of coalitions through bilateral agreements in a Cournot setting. International Journal of Game Theory, 34(2): 207-228.

Mason, R., Lalwani, L., Boughton, R., 2007. Combining vertical and horizontal collaboration for transport optimisation. Supply Chain Management: An International Journal, 12 (3): 187-199.

Myerson, R.B., 1977. Graphs and cooperation in games. Mathematics of Operations Research, 2(3): 225–229.

Naesens, K., Gelders, L., Pintelon, L., 2007. A swift response tool for measuring the strategic fit for resource pooling: a case study. Management Decision, 45(3): 434-449.

Nagarajan, M., Sošic, G., 2008. Game-theoretic analysis of cooperation among supply chain agents: review and extensions. European Journal of Operational Research, 187(3): 719-745.

Nash, J.F., 1951. Non-cooperative games. The Annals of Mathematics, 54(2): 286–295.

Özener, O.Ö., Ergun, Ö., 2008. Allocating costs in a collaborative transportation procurement network. Transportation Science, 42(2): 146-165.

Palander, T., Väätäinen, J., 2005. Impacts of interenterprise collaboration and backhauling on wood procurement in Finland. Scandinavian Journal of Forest Research, 20(2): 177-183.

Parrachino, I., Dinar, A., Patrone, F., 2005. Cooperative game theory and its application to natural, environmental, and water resource issues: 3. Application to water resources. The World Bank Group, Policy Research Working Paper 4074.

Perea, F., Puerto, J., Fernández, F.R., 2009. Modeling cooperation on a class of distribution problems. European Journal of Operational Research, 198(3): 726-733.

Ransmeier, J.S., 1942. The Tennessee Valley Authority: A Case Study in the Economics of Multiple Purpose Stream Planning. Vanderbilt University Press, Nashville, United States.

Rönnqvist, M., 2003. Optimization in forestry. Mathematical Programming, 97(1-2): 267-284.

Sánchez-Soriano, J., López, M.A., García-Jurado, I., 2001. On the core of transportation games. Mathematical Social Sciences, 41(2): 215-225.

Shapley, L.S.,1953. A value for n-person game. In: Kuhn, H.W., Tucker, A.W., (Eds.). Contributions to the Theory of Games, Vol. 2. Princeton: Princeton University Press, 307-317.

Simatupang, T.M., Sridharan, R., 2002. The collaborative supply chain. International Journal of Logistics Management, 13(1): 15-30.

Slikker, M., van den Nouweland, A., 2000. Network formation models with costs for establishing links. Review of Economic Design, 5(3): 333-362.

Sprumont, Y., 1990. Population monotonic allocation schemes for cooperative games with transferable utility. Games and Economic Behavior, 2(4): 378-394.

Straffin, P.D., Heaney, J.P., 1981. Game theory and the Tennessee Valley Authority. International Journal of Game Theory, 10(1): 35-43.

Tijs, S. H. and T. S. H. Driessen, 1986. Game theory and cost allocation problems. Management Science, 32(8): 1015-1058.

Young, H.P., 1994. Cost allocation. In: Aumann, R.J., Hart, S., (Eds.). Handbook of Game Theory with Economic Applications. Amsterdam: North-Holland, 1193-1235.

van den Brink, R., van der Laan, G. , Casil'ev, V., 2007. Component efficient solutions in line-graph games with applications. Economic Theory, 33(2): 349-364.

van den Nouweland, A., 2005. Models of network formation in cooperative games. In: Demange, G., Wooders, M., (Eds.). Group Formation in Economics: Networks, Clubs and Coalitions. Cambridge: Cambridge University Press, 58-88.

Vidal-Puga, J.J., 2008. Forming coalitions and the Shapley NTU value. European Journal of Operational Research, 190(3): 659-671.

Wang, Y., Potter, A., Naim, M., 2007. Electronic marketplaces for tailored logistics. Industrial Management & Data Systems, 107(8): 1170-1187.

Weintraub, A., Epstein, R., Morales, R., Seron, J., Traverso, P., 1996. A truck scheduling system improves efficiency in the forest industries. Interfaces, 26(4):1-12.

Zäpfel, G., Wasner, M., 2002. Planning and optimization of hub-and-spoke transportation networks of cooperative third-party logistics providers. International Journal of Production Economics, 78(2) : 207–220.

7 Conclusion

This section presents the main contributions of each of the five articles included, proposes a number of research directions in light of the thesis and final remarks complete the discussion.

7.1 Contributions

7.1.1 First article

The main contribution of the first article is threefold. First, we propose a general description of a Vehicle Routing Problem (VRP) in timber transportation.

This description is supported by the second contribution: we present an exhaustive 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, we present a literature review of decision support systems for VRP in timber transportation with a discussion of a number of issues related to their adoption in the industry.

7.1.2 Second article

The main contribution of the second article is twofold. First, we propose a framework for building and managing collaboration in transportation, and more generally in logistics. This framework includes the proposition of five generic coordination mechanisms for information sharing, planning and execution of the logistics (transportation) activities, and the benefit sharing. Three case studies on logistics collaboration are detailed and related to the coordination mechanisms.

The proposed framework is supported by the second contribution: through the themes addressed in the framework, we present a literature review on collaborative logistics (transportation).

7.1.3 Third article

The main contribution of the third article is twofold. First, we describe a DSS for forest truck routing that is explicitly designed to address an inter-firm collaboration context. The

DSS provides a logistics service to distinct decision makers (belonging or not to the same company) for collaborative transportation organization of different product types and this, respecting data confidentiality and standardization issues. How transportation collaboration is organized using the DSS is described in a step-by-step fashion.

Second, through the presentation of an industrial case study where the DSS usage is illustrated and numerical results reported, we detail the VRP addressed and the planning method proposed.

7.1.4 Fourth article

The main contribution of the fourth article is twofold. First, we propose a cost allocation method specifically designed to support the establishment of a collaborative agreement in a transportation coalition in the furniture industry. The method is based on a linear programming (LP) model embedded in the cost allocation method called *Equal Profit Method* and includes two main adaptations: (i) the reach of a minimum bottom-line cost-savings percentage for all partners; and (ii) the introduction of three different non-transferable costs that cannot be allocated freely in the LP model. Moreover, for one of the non-transferable costs, we use the solution concept of a cost allocation method called *Alternative Cost Avoided Method* in order to discover how to distribute among the partners the additional cost incurred to satisfy the heterogeneous requirements of some partners. This new method allows a share according to the impact of the requirements of each partner on the cost of the collaborative plan. Thus, the partner who most increases the cost of the collaborative plan obtains the greatest part of the additional cost incurred to satisfy the requirements of all partners.

Second, we describe a complex transportation planning problem in the furniture industry that allows collaboration in outbound transportation according to the results computed.

7.1.5 Fifth article

The main contribution of the fifth article is twofold. First, by including practical business considerations in our study of two key questions in collaboration (i.e., sharing cost-savings and coalition formation), we analyze them according to the self-interested objective of a subset of the companies - rather than all companies as in most of the literature on horizontal collaboration in transportation - and we demonstrate the impacts on the results of both questions.

Second, we propose a network model as a method to determine the stable coalition(s) required by our analysis in the first contribution. The literature on horizontal collaboration in transportation almost never pays attention to the formation of stable coalition(s). Rather, most of the literature presumes that the coalition with the highest benefit (i.e. the grand coalition) always forms, while in practice the companies, in making their cost-savings sharing and coalition formation decisions, can face limitations, such as the ones included in our study.

7.2 Future research

In the academic and professional literature on freight transportation, collaboration among companies has been investiguated as a way to gain efficiency in the transportation activities and, in turn, provide benefits – including cost-savings – to the collaborators. Despite the significant results reported and growing case studies, sustainable and prosperous collaboration in transportation (and, more generally in logistics) appears to be a real challenge and a limited practice compared to the expected potential of application. Collaboration involves complex issues – at least as complex as the ones faced by each collaborator - and many of them are still open questions or ones to be addressed. These issues often call for interdisciplinary solutions and solutions tailored (i.e. no single and all-purpose solution) to the context of a given collaboration. Moreover, to be worthwhile in inter-firm collaboration, a number of models, concepts and methods used in a non-collaborative context could be adapted to the realities and requirements of a collaborative environment. In light of the research presented in this thesis, a number of future research orientations are discussed below. More research opportunities are found in each article.

Recently, planning methods for VRP in forest transportation with foldable containers or for forest fuel with potential in-field chipping operations have been proposed in the literature. In the forest industry other variants of VRP also exist that are seldom or not at all addressed in the literature: e.g.,VRP involving bi/multi-modal system or merchandising yard.

Truck waiting time (i.e., queuing), mainly at the destination sites, is a major concern in forest transportation. Reserved short-time slots for pickup/delivery or enhanced coordination between the truck routing and the scheduling of on-site resources (e.g. loaders, truck weighing station) are potential solutions for queuing time reduction. However, any solution will also require the study of how efficient the wood yard layout is and the reception strategy to minimize internal wood flow and keep a continuous supply to the production line(s).

To better tackle stochastic events intrinsic to forest transportation (e.g. mill reception closure, equipment breakage), insights from the prolific literature on dynamic VRPs must be investigated as well as, as recently proposed by Marques et al. (2013), by combining optimization and simulation methods. Ultimately, real-time decision-making systems must be deployed/developed and integrated with operational ones in order to adjust previous planned decisions to the current situation.

Another research direction concerns development of business models that enable sustainable and prosperous collaboration in transportation. These business models will need to address a number of issues such as the legality of the collaboration. Indeed, many countries are concerned about potential collusive activities and therefore legislate to avoid them (e.g. antitrust law). Another issue is current payments method in the industry that mostly does not foster collaboration and therefore, must be revised to provide all transportation actors with a fair and sustainable financial incentive to collaborate.

The sharing of benefits may have to deal with benefits that are difficult to evaluate. For example, in the fourth article, collaboration allows some companies to access new markets and/or to deliver more rapidly to some markets. What is the value of the increased market coverage or the faster deliveries? Cost (profit) reduction (increase) is usually the most important incentive for collaboration but a question remains: what level of cost (profit) improvement is required to incite a company enough to collaborate? At least the cost (profit) improvement must be greater than zero but, in practice, this question is much more complex and usually involves uneven negotiation power between the collaborators.

The cost associated with the implementation of a given collaboration appears complex to define and to anticipate, even though it represents a risk for collaborators. Management cost of the collaboration should also be evaluated as it reduces the savings. Furthermore, similar to the business environment of each collaborator, a given collaboration is subject to change.

How should this dynamic be considered upfront? How often should the terms of the collaboration be reviewed?

Development of a coalition could be examined in several other ways than in the fifth article: for instance, by recruiting more than one company at a time, recruiting the companies in a context of competition by other coalitions in-development or by allowing a company to join more than one coalition by splitting its needs in transport.

7.3 Concluding remarks

Many business entities are involved in the extended value creation network of the Canadian forest products industry and many more are expected to do so, given the fact of industry transformation toward the global bio-economy. Fostering the implementation of sustainable and prosperous collaborations in the industry represents a challenge to the level of the expected benefits of these collaborations. It is my hope that the research presented in this thesis will stimulate further R&D on collaboration in transportation and, more generally in collaborative logistics, and that this will attract practitioners’ attention in the coming years.

References

Andersson, G., Forestry Research Institute of Sweden, personal communication, March 2012.

Brown, M.W., University of the Sunshine Coast and CRC for Forestry, personal communication, March 2012.

CCFM (Canadian Council of Forest Ministers), 2012. National Forestry Database. http://nfdp.ccfm.org/data/graphs/graph_21_a_e.php [On-line]: 12-04-19.

Clifton, C., Iyer, A., Cho, R., Jiang, W., Kantarcioglu, M., Vaidya, J., 2008. An approach to securely identifying beneficial collaboration in decentralized logistics systems. Manufacturing & Service Operations Management, 10 (1), 108-125.

Cruijssen, F., Dullaert, W., Fleuren, H., 2007. Horizontal cooperation in transport and logistics: a literature review. Transportation Journal 46(3) : 22–39.

Dai, B., Chen, H., 2012. Profit allocation mechanisms for carrier collaboration in pickup and delivery service. Computers & Industrial Engineering, 62 (2): 633-643.

El Hachemi, N., Gendreau, M, Rousseau, L.-M., 2009. A heuristic to solve the weekly log-truck scheduling problem. In: International Conference on Industrial Engineering and Systems Management, May 13-15, Montreal, Canada.

El Hachemi, N., Gendreau, M, Rousseau, L.-M., 2011. A hybrid constraint programming approach to the log-truck scheduling problem. Annals of Operational Research, 184(1): 163-178.

El Hachemi, N., Gendreau, M, Rousseau, L.-M., 2013. A heuristic to solve the weekly log-truck scheduling problem. Computers and Operations Research, 40(3): 666-673.

Ergun, O., Kuyzu, G., Savelsbergh, M., 2007. Reducing truckload transportation costs through collaboration. Transportation Science, 41 (2), 206-221.

Forsberg, M., Frisk, M., Rönnqvist, M., 2005. FlowOpt: a decision support tool for strategic and tactical transportation planning in forestry. International Journal of Forest Engineering, 16(2): 101-114.

Frisk, M., Jörnsten, K., Göthe-Lundgren, M., Rönnqvist, M., 2010. Cost allocation in collaborative forest transportation. European Journal of Operational Research, 205(2), 448-458.

Gingras, C., Cordeau, J.-F., Laporte, G., 2007. Un algorithme de minimisation du transport à vide appliqué à l'industrie forestière [An algorithm for minimizing unloaded transportation applied to the forest industry]. Information Systems and Operational Research, 45(1): 41-47.

Greene, D., University of Georgia, personal communication, March 2012.

Krajewska, M.A., Kopfer, H., Laporte, G., Ropke, S., Zaccour, G., 2007. Horizontal cooperation among freight carriers: request allocation and profit sharing. Journal of the Operational Research Society, 59(11): 1483-1491.

le Blanc, H.M., Cruijssen, F., Fleuren, H. A., de Koster, M.B.M., 2007. Factory gate pricing: an analysis of the Dutch retail distribution. European Journal of Operational Research, 174(3): 1950-1967.

Lehoux, N., Audy, J.-F., D'Amours, S., Rönnqvist, M., 2009. Issues and experiences in logistics collaboration. In: Camarinha-Matos, L., Paraskakis, I., Afsarmanesh, H., (Eds.). IFIP International Federation for Information Processing, Volume 307, Leveraging knowledge for innovation in Collaborative Networks. PRO-VE 2009- 10th IFIP Working Conference on Virtual Enterprises, October 7-9, Thessaloniki, Greece. Boston: Springer, 69-77.

Lepage, D., FPInnovations, personal communication, August 2012.

Marier, P., Gaudreault, J., D'Amours, S., 2009. Network collaboration and optimization: chip supply in an integrated pulp and paper company. 14th Annual International Conference on Industrial Engineering Theory, Applications & Practice, October 18-21, Anaheim, United-States.

Marques, A., Pinho de Sousa, J., Rönnqvist, M., Jafe, R. 2013. Combining optimization and simulation tools for short-term planning and analysis in forest operations. Fortcoming in Scandinavian Journal of Forest Research.

Michaelsen, J., FPInnovations, personal communication, March amd April 2012.

Murphy, G., 2003. Reducing trucks on the road through optimal route scheduling and shared log transport services. Southern Journal of Applied Forestry, 27(3): 198-205.

Özener, O.Ö., Ergun, Ö., 2008. Allocating costs in a collaborative transportation procurement network. Transportation Science, 42 (2), 146-165.

Palander, T., Väätäinen, J., 2005. Impacts of interenterprise collaboration and backhauling on wood procurement in Finland. Scandinavian Journal of Forest Research, 20(2): 177-183.

Palmgren, M., Rönnqvist, M., Varbrand, P., 2004. A near-exact method to solve the log-truck scheduling problem. International Transactions in Operations Research. 11(4): 447-464.

Rix, G., Rousseau, L.M., Pesant, G., 2012. Solving a multi-period log-truck scheduling problem with column generation. 34th Council of Forest Engineering Conference, June 12-15, Quebec City, Canada.

Visser, R., University of Canterbury, personal communication, March 2012.

Weintraub, A., Universidad de Chile, personal communication, March 2012.