Deployment by a Shipper of a Collaborative Approach with its Carriers

Mémoire

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Résumé

Un défi important dans l'industrie forestière consiste à réduire les coûts de transport globaux entre les fournisseurs et les clients. L'industrie forestière déplace de grandes quantités de bois des zones de récolte vers les terminaux et les usines. Lorsque de nombreuses organisations sont impliquées, une collaboration entre les fournisseurs et une utilisation efficiente des allocations permettent de trouver de meilleures solutions. Les allocations sont généralement basées sur des flux directs entre les nœuds d'approvisionnement et de demande. Cependant, de meilleures solutions peuvent être trouvées lorsque des itinéraires de retour en charge sont utilisés. Ceux-ci sont difficiles à trouver lorsque plusieurs parties prenantes sont impliquées, mais l'ajout d'informations provenant de la production de la récolte peut supporter une meilleure collaboration entre les fournisseurs ainsi que la détermination de plans plus efficients.

Le but de ce projet est d'élaborer un modèle capable de résoudre le problème de la livraison des multi-dépôts aux multi-clients, sur plusieurs périodes de temps, en minimisant les coûts de transport de différents types de bois. Proposer une nouvelle méthode pour le cas quand les clients seulement réceptionnent produits de fournisseurs fixés à l'avance. En outre, il analyse différentes méthodes de paiement des itinéraires de transport, afin de terminer un mécanisme qui incite les fournisseurs de transport à avoir recours au transport collaboratif. Nous décrivons les résultats obtenus avec une entreprise de pâtes et papiers au Québec, Canada.

Abstract

One important challenge in the forestry industry is to reduce the overall transportation cost between suppliers and clients. The forestry industry moves large quantities of wood from harvest areas to terminals and mills. When many organizations are involved, a collaboration between the suppliers as well as an efficient use of allocations, achieve better solutions. Allocations are typically based on direct flows between supply and demand nodes. However, better solutions can be found when return trip routes are used. These are difficult to find when there are several stakeholders involved, but adding information from harvest production can establish better collaboration between suppliers as well as more efficient plans.

The purpose of this project is to define a model that can resolve the delivery from multi-depots to multi-customers, in a multi-period of time, minimizing the cost of transport for different types of timber. To propose a novel method for scenarios where the clients only receive products from pre-determined suppliers. Also, it analyzes different methods of transport payment for backhaul routes, in order to establish a mechanism that encourages the transport suppliers to use collaborative transport. We describe results obtained with a pulp and paper company in Quebec, Canada.

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Introduction

General context

The forestry industry moves large quantities of wood annually, using for this purpose trucks, trains or a mix of both modes. The cost and time of transportation are important factors that need to be managed carefully. Some studies show that reducing empty truck trips by 11.6% can decrease transportation cost by 4%, which resulted in potential savings of more than $ 5,000,000 for a forest company in Canada [13].

The forest transportation represents approximately one-third of the total cost in logistic planning [9], and for that reason several practices have been developed to manage and reduce the transportation costs. Time is a relevant variable, with a period of one year necessary to facilitate the tactical planning of forest transportation. The position of the harvest centers which feed the clients is an important point, but also their size and the system of movement with load utilized: direct tour or backhaul. Direct tour is a transport system that moves loads from origin to destination returning to the origin without a load and backhaul is a transport system that moves the load from origin to destination and from destination to origin.

Backhauls in forest transportation are an important logistics practice to reduce costs, because they improve the efficiency of the forest transportation system by achieving the transportation of a quantity of products in less time and distance than direct tour systems. While direct tours have only 50% of the transportation distance with truck loads, in backhauls this percentage is higher. Investigations such as Rönnqvist (2010) have noted that the range of savings in backhauls is typically between 2-10% [4], with reduction of overall transportation distance and reduction of fuel consumption.

In addition, the collaboration between carriers can improve the results, with a reduction of transportation cost. Carlsson et al. (2009) emphasize the importance of inter-company collaboration, for example in transportation planning, to improve companies' results and reduce costs [1]. Karlsson et al. (2006) [6], developed a model where one of the aims was to understand which information and changes were necessary to create good coordination between contractors. Also, Palander and Vaatainen (2005) researched the benefit of inter-company collaboration, presented a model with backhauls, where backhauls denoted a reduction of transportation cost by 2% in relation to cases without backhauls [2].

In previous forest transportation studies, authors developed an integer linear programing model of minimum cost for transporting different products daily to several clients using column generation; Rey, Munoz, Weintraub (2009) [16]; algorithm for reducing the time of empty transport at forestry industry, Gingras (2007) [13]; cost allocation methods in collaborative transportation based in cooperative game theory Guajardo and Rönnqvist (2015) [5] and Frisk, Göthe-Lundgren, Jörnsten, Rönnqvist (2010) [3]. Also, Frisk et al. (2016) [7], showed a model of transport that involve other aspects, such as production, inventory and idle time.

This master's thesis will review the forest transportation of a Canadian pulp and paper company located in North America (hereinafter shipper). As part of its mission and values, in recent years it has been improving its production. Located in Quebec province, the mill has been improved with an investment of 2.5 billion dollars, achieving the best standard of safety and one of the best productions of fiber line pulp in North America.

The level of production of the shipper's mill requires a big quantity of wood, which makes this mill the biggest consumer of wood harvested on private forest land in Québec province. Hence, the transportation of logs is one of the key variables that needs to be carefully managed by the shipper. Reducing the number of direct flows and transforming those routes into backhauls can improve the performance of transportation [12]. Forest transportation is an activity that represents a significant cost for a forestry company [9] and the shipper is no exception to the rule.

The shipper's plans included a roadmap of 2015 with a strong focus on the competitiveness and sustainability of the business, meaning a goal that rests on eight priorities: safety, health, environment, quality, costs, productivity, trusted relationship and continuous improvement [10].

Improving the efficiency of actions, as well as of the actors, will allow the shipper to position itself as a world-leading reference in the sustainable management of the forestry industry. The importance of engaging every part of the business as much as possible will bring success to the company.

The model presented in this master's thesis shows an alternative for minimizing the cost of transport of different types of product, from multi-depots to clients, in a multi-period delivery time. This model can program two time periods (or more) of product deliveries. To resolve this problem, the model is supported in some assumptions:

- The transport of the woods from the depot to the client is done in full truck loads [13].
- The trucks that end the tour in the same depot were the same one that started the trip.
- The model uses direct tours and backhauls for cover all the client's necessities, because the trucks are full loading from depot to clients.
- There is no limit on the size of the truck fleet.
- The backhauls allow the transport of two different products (also one).

Also, this master's thesis will review different forms of cost structures, the impact of the cost structures in the forestry transport and the system of transport with direct tour and backhauls. A novel method is developed when the clients receive products only from pre-determined suppliers designated by the shipper.

For this work, when a truck transports the product, the truck uses its full loading capacity. The capacity is measured in DMT (dry metric tons). The route time is based on the distance by type of road and average speed by type of road, but without consideration of the slopes of roads. Also, we are not considering speed reductions in protected zones or toll booths. Forest transportation research typically only considers log hauling trucks to cover the distances, without including other modes of transport such as train due to the short distances between clients and suppliers. This investigation covers a period of one year, working at the tactical planning level, being a useful tool for the operational planning.

The structure of this master's thesis is the following: Chapter 1 shows the problem description and backhaul forest model. Chapter 2 shows the backhaul model with time periods and proposes an innovative approach to resolve scenarios where the clients receive products from pre-determined suppliers. Chapter 3 describe the case study, reviewing the model and the objective function of every cost structure. Chapter 4 analyzes the results of the cost structures, and finally chapter 5 reviews the discussion of the research.

Objectives and contribution of the research

The first objective of the research is to measure the impact on a transportation plan that produces the cost of transport for both shipper and carriers, analyzing different forms of transport payment for backhaul routes that motivate the shipper and carriers to use backhaul.

The second objective and contribution is to develop a backhaul planning model with a restriction, where the clients receive products only from pre-determined suppliers, ensuring that the allocation of transportation satisfies the expectations of the shipper and carriers. That means reduction of transport costs and reduction of time-distance when the truck is without a load (empty).

1 Problem description

1.1 Transportation problem

The shipper starts with strategic planning over a long term (10 years). This time is necessary for the sustainable management of the resource, to achieve a viable production and reach a good size of trees for felling and delivery to the clients. After, the period of 10 years is divided in 2 periods of 5 years, for following up the growth of the species and the general state of the forest. With the information generated in strategic and tactical planning, the shipper proceeds with the annual harvest forest plan and finally the weekly planning with the carriers that transport the logs.

The tactical planning of transport between shipper, carriers and clients is very important for the procurement of every processing mill. According with that policy, the shipper and carriers work with an annual schedule of production that could be adjusted once per month due to changes of demand. When the tactical planning is agreed, the next step is to fix transport of logs per week. This procedure is part of the operational planning and generate a support for next transport of logs.

In this case, the tactical planning tool used in the annual forest transportation problem is the backhaul model with periods. This linear programming model will allow to find the solutions of transport per week during a period of one year using backhauls.

1.2 Direct tours and backhauls forest model

The most common form of transport between supply nodes (origin) to demand nodes (destination) is through direct tours (Figure 1). This transport system moves loads from origin to destination returning to the origin without a load. This system achieves only a 50% of efficiency.

The transportation problem can be written as follow [11]:

$$\min Z = \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij} \cdot X_{ij}$$

Subject to:

$$\sum_{j=1}^{n} X_{ij} \leq S_i \; , i = 1, \dots, m$$

$$\sum_{i=1}^{m} X_{ij} \geq D_j \; , j = 1, \dots, n$$

$$X_{ij} \geq 0, i = 1, \dots, m; j = 1, \dots, n$$

Here the variables are defined as:

$$X_{ij} = flow\ (logs)\ from\ facility\ i\ to\ customer\ j, \qquad i = 1, \dots, m;$$
$$j = 1, \dots, n$$

And the parameters are:

$$C_{ij} = unit\ transportation\ cost\ from\ facility\ i\ to\ customer\ j, i = 1, \dots, m;$$
$$j = 1, \dots, n$$
$$S_i = supply\ at\ facility\ i, \qquad i = 1, \dots, m$$
$$D_j = demand\ at\ customer\ j, j = 1, \dots, n$$

This basic model has been very important for the development of the transportation problem. There are a lot of problems related with food, construction, trash transportation (only for mention some of them) that have been improved through this model.

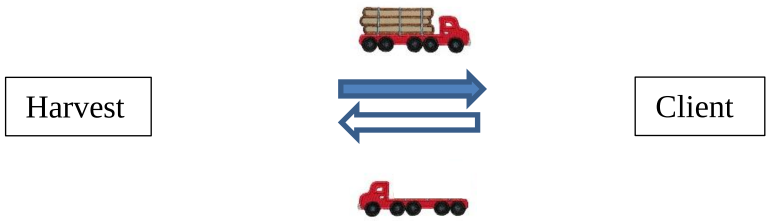


Figure 1: An ilustration of direct tour.

The backhauls transport forest model is based in the previous research of Carlsson and Rönnqvist (2007) [12], as an alternative of solution for forest transportation. The model can solve big size of problems (big number of supply points and clients) in less time based in the procedure of column generation. This method, well-known as Column Generation, is used to solve *LP models*.

Figure 2 shows the backhaul transport system. While direct tours transport system uses a full truck loading only in one way, for transport the logs from harvests to clients, in backhauls one truck can cover all the demand of clients. The filled arrows with a truck show the routes where the truck is load with the product. In backhaul transport system is called linehaul the first way with truck load.

The following is the backhauls transport forest model:

$$Minimize \sum_{r \in D} CD_r * X_r + \sum_{k \in B} CB_k * B_k$$

$$Subject\ to \sum_{r \in D} DH_{jr} * X_r + \sum_{k \in B} BH_{jk} * B_k \leq S_j, \forall\, j \in J$$

$$\sum_{r \in D} DS_{ir} * X_r + \sum_{k \in B} BS_{ik} * B_k \geq D_i, \forall\, i \in I$$

$$X_r \geq 0, \qquad \forall\, r \in D$$

$$B_k \geq 0, \qquad \forall\, k \in B$$

Where D is a set of direct tours, B is a set of backhauls, J is a set of harvest and I is a set of clients.

Variables:

$$B_k = Flow\ transported\ in\ backhaul\ k$$

$$X_r = Flow\ transported\ in\ direct\ tour\ r$$

Parameters:

$$CD_r = Cost\ in\ direct\ tour\ r$$

$$CB_k = Cost\ in\ backhaul\ k$$

$$D_i = Demand\ client\ i$$

$$S_j = Supply\ harvest\ j$$

$$DH_{jr} = 1\ if\ direct\ tour\ r\ takes\ product\ in\ harvest\ j, 0\ otherwise$$

$$BH_{jk} = 1\ if\ backhaul\ k\ takes\ product\ in\ harvest\ j, 0\ otherwise$$

$$DS_{ir} = 1\ if\ direct\ tour\ r\ delivery\ product\ in\ client\ i, 0\ otherwise$$

$$BS_{ik} = 1\ if\ backhaul\ k\ delivery\ product\ in\ client\ i, 0\ otherwise$$

The objective function minimizes cost of transport in direct tours and backhauls. The first constraint ensures the quantity of products picked up from every harvest area is equal or less that the quantity generated. The second constraint ensures that the total quantity demanded for the clients of each product, is less or equal to the quantity that is transported from the harvest zones of the suppliers.

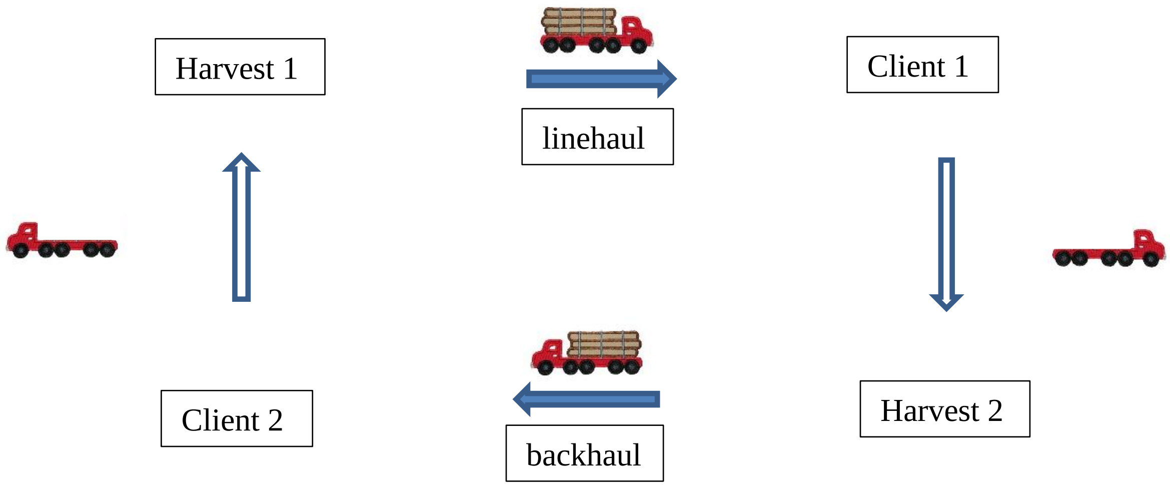


Figure 2: An illustration of a backhaul route.

1.3 Clients, suppliers and carriers

The clients (destination points) are mainly sawmills and pulp and paper companies that are located in the region of harvest zones. As part of the process of production, they need raw material that finally will be converted in: pulp, paper, kitchen furniture, etc.

The clients request different types of wood. That request depends on the product specifications of the clients.

The suppliers (origin points) are harvest zones where are harvested the logs. For transporting the logs, only one volume capacity of truck is considered on this research. The transport of the logs from origin to destination is done in consolidated loads. That means, using all the volume of the truck for transporting the products. The capacity can be measure in different units. The total number of trucks that are using in the transport is not relevant for this research.

Finally, the transaction of transport is measured in periods of one week. Every week has transactions that represent movements of trucks with products, between origin and destinations. Some weeks have more movements that others as well as other doesn't have transactions. Weather conditions and some holidays are part of the reason for the absent of movement in some weeks.

1.4 Routes and routes cost

The routes are arcs that join nodes i with nodes j into the network. The nodes with index i are all the harvest zones, and the nodes j are all the clients.

There are primary roads and secondary roads. The primary roads are the highways and pavement routes. Classified as secondary routes, are all the forest roads, gravel or unpaved roads, as shows Figure 3.

The costs associated to the model have relation with the displacement between nodes and the time spent in every route. The cost is the same for one way to the other (symmetric). The cost of transport is in relation to diesel consumptions, time used and distance traveled.

Figure 3: Log hauling truck travels on secondary road [18].

1.5 Example

Two sawmills need to be fed with three different products on a weekly basis. In this scenario, there are three harvest locations that can provide the three types of wood which the clients need during 2 periods.

The products demanded by sawmills are:

- Product 1
- Product 2
- Product 3

The clients and suppliers are located at distances that are specified at the Figure 4. The costs of the transport are measure in time and distance. The system of transport is in direct tours and backhauls following the payment model used for the shipper. That means, for one direct tour is paid all the diesel consumption and time spent in transport and load-unload process; for linehauls is paid as direct tours and for backhauls is paid only the time spend in load routes. The cost of direct tours and backhauls are in Table 1.

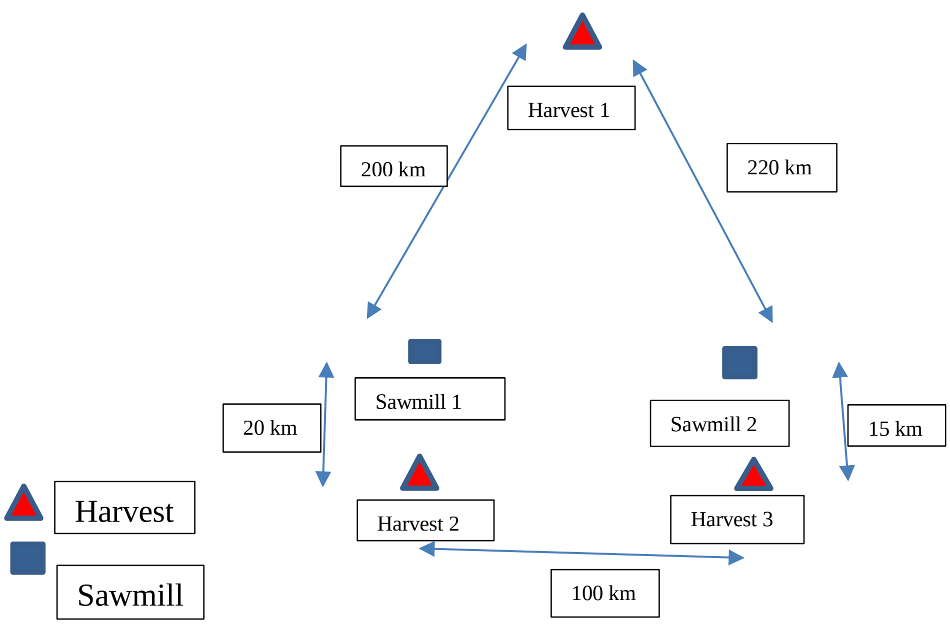


Figure 4: General map with the positions of the facilities.

Table 1: Cost (dollars) of direct tours and backhauls between origin and destination.

	Direct tour cost			**Backhaul cost**	
Harvest	Sawmill 1	Sawmill 2	Harvest	Sawmill 1	Sawmill 2
1	290	310	1	260	250
2	30	160	2	25	130
3	150	25	3	120	20

All the requirements of the two sawmills in all the periods must be fulfilled by the 3 harvest zones. The harvest zones have the same production as the demand per product of the clients per period. The detail of demand and production per period are in Table 2. All the quantities are in number of full trucks load. That means, for example, sawmill 1 needs for week1, 100 full trucks load of product 1.

Table 2: Demand and production per period and product.

Week 1						
Demand	**Sawmill 1**	**Sawmill 2**	**Production**	**Harvest 1**	**Harvest 2**	**Harvest 3**
Product 1	100	0	Product 1	100	0	0
Product 2	200	150	Product 2	200	100	50
Product 3	0	300	Product 3	300	0	0
Week 2						
Demand	Sawmill 1	Sawmill 2	Production	Harvest 1	Harvest 2	Harvest 3
Product 1	200	0	Product 1	0	100	100
Product 2	300	0	Product 2	0	0	300
Product 3	200	400	Product 3	0	200	400

The objective of the model is to minimize the cost of transport using a backhaul model. For this model, have been considered the following restrictions:

- All the requirements ordered by the clients must be fulfilled for the suppliers in all the periods.
- All the routes start and finish in the same depot.

- The loads are completed between suppliers and clients. The transhipment are not allowed.

The detail of the results is in Table 3. The table shows that are 6 types of direct tours and 4 types of backhauls for fulfilling the demand of clients.

Table 3: Demand and production per period and product.

Direct tour	**Product**	**Sawmill**	**Harvest**	**Week**	**Quantity**
1	1	1	1	1	100
2	2	1	1	1	50
3	3	2	1	1	300
4	1	1	3	2	100
5	2	1	3	2	300
6	3	2	3	2	100
Backhaul tour	Product	Sawmill	Harvest	Week	Quantity
	2	1	2	1	100
1	2	2	1	1	100
	2	1	1	1	50
2	2	2	3	1	50
	1	1	2	2	100
3	3	2	3	2	100
	3	1	2	2	200
4	3	2	3	2	200

Table 4 shows the details of how calculate the objective function the minimum cost of transport. For example, for transporting 1 full truck load from harvest 1 to sawmill 1, the direct cost is $290. If the total of full trucks in direct tours is 100, the total is $29,000.

In the case of backhauls for transporting 1 full truck from harvest 2 to sawmill 1 in line haul cost is $30 (the same of direct tours) and the cost of return in backhaul from harvest 1 to sawmill 2 is $250. As the total trucks in movement is 100, the total cost of backhaul is: $30 x 100 + $250 x 100 = $28,000. The total cost for the objective function is $ 256,250.

Table 4: Details of transport cost.

Harvest	**Sawmill**	**Product**	**Quantity**	**Cost Direct Tour ($)**	**Total ($)**
1	1	1	100	290	29 000
1	1	2	50	290	14 500
1	2	3	300	310	93 000
3	1	1	100	150	15 000
3	1	2	300	150	45 000
3	2	3	100	25	2 500
Total Cost Direct Tours ($) (1)					199 000
Harvest	Sawmill	Product	Quantity	Cost Linehaul-Backhaul Tour	Total
2	1	2	100	30	3 000
1	2	2	100	250	25 000
3	2	2	50	25	1 250
1	1	2	50	260	13 000
2	1	1	100	30	3 000
3	2	2	100	20	2 000
2	1	3	200	30	6 000
3	2	3	200	20	4 000
Total Cost Linehauls-Backhauls ($)(2)					45 250
Total Cost of Transport ($) (1+2)					244 250

2 Model and method

The backhaul model with periods allows planning the forest transport in tactical planning. With a vision over a year, the model permits a revision of tactical planning based in flow of products through backhauls [8].

The objective function of the model is minimizing the costs of forest transport. The first restriction ensures the quantity of products picked up from every harvest area is equal or less that the quantity generated by the period t of production. The second restriction ensures that the total quantity demanded for the clients of each product at each period, is the same quantity that is transported from the harvest zones of the suppliers.

Parameters

$$D^{h}_{iptv} = 1\ if\ direct\ tour\ v\ takes\ product\ p\ at\ supply\ i\ in\ time\ t, 0\ otherwise$$

$$B^{h}_{iptk} = 1\ if\ backhaul\ k\ takes\ product\ p\ at\ supply\ i\ in\ time\ t, 0\ otherwise$$

$$D^{s}_{rptv} = 1\ if\ direct\ tour\ v\ delivery\ product\ p\ to\ client\ r\ in\ time\ t, 0\ otherwise$$

$$B^{s}_{rptk} = 1\ if\ backhaul\ k\ delivery\ product\ p\ to\ client\ r\ in\ time\ t, 0\ otherwise$$

$$C^{d}_{v} = Cost\ for\ direct\ tour\ v$$

$$C^{b}_{k} = Cost\ for\ backhaul\ k$$

$$D_{prt} = Demand\ of\ product\ p\ from\ client\ r\ in\ time\ t$$

$$Q_{pit} = Production\ quantity\ of\ product\ p\ in\ supply\ i\ in\ time\ t$$

$$S = Supply$$

$$D = Demand$$

$$P = Products\ types$$

$$T = Time\ period$$

Variables

$$R_{vt} = quantity\ of\ product\ delivery\ in\ direct\ tour\ v\ at\ time\ t$$
$$B_{kt} = quantity\ of\ product\ delivery\ in\ backhaul\ k\ at\ time\ t$$

Multi-period Forest Transportation Model

$$Minimize\ \sum_{t \in T} \sum_{v \in V} C_v^d * R_{vt} + \sum_{t \in T} \sum_{k \in K} C_k^b * B_{kt}$$

$$Subject\ to \sum_{v \in V} D_{i,p,t,v}^h * R_{vt} + \sum_{k \in K} B_{i,p,t,k}^h * B_{kt} \leq Q_{pit}, \quad \forall p \in P, \quad \forall i \in S, \quad \forall t \in T \ (1)$$

$$\sum_{v \in V} D_{r,p,t,v}^s * R_{vt} + \sum_{k \in K} B_{r,p,t,k}^s * B_{kt} \geq D_{prt}\ , \quad \forall\ p \in P, \quad \forall\ r \in D, \quad \forall\ t \in T (2)$$

$$R_{vt} \geq 0, \quad \forall\ v \in V\ (3)$$
$$B_{kt} \geq 0, \quad \forall\ k \in K\ (4)$$

It is important to mention that in this model there is no flow connection between each time periods. It means is not used the inventory of one week to other.

Method to solve

The method used for solving the transportation problem, in practice the same model of one period, starts with the presentation of all possible direct flows between origin and destination. These are routes pre-designated by the shipper which connect harvest zones with mills and product demanded. After, with all the direct tour shown, the model begins generating all possible backhauls. But this form of backhauls generation could take a long time, especially if there is a big quantity of harvest zones and mills as in this problem.

The method used for trying to find a solution to the problem with backhauls in a shorter computing time, consists in generating once all the possible alternatives. The method allows generating a pool of potential backhauls, avoiding generation of all backhauls and hence reducing the time to solve the problem. After the potential backhauls are generated, the objective function minimizes the cost of transportation and generates the optimal solution.

Method used when client receives products only from pre-determined suppliers

Until now, the method is considering all the combination routes that were possible for backhauls and direct tours, that means all suppliers that can meet clients' requirements were used. But what happens when you must use specific suppliers designated by the shipper to fulfill the requirements of clients, even though there are best alternatives of supply to client allocation. In that case, the backhaul model with periods must choose the best alternatives with the restriction for using only one or some suppliers for certain clients. That restriction could be adapted to the model, but for that it is necessary to create new restrictions. In this research, to avoid implementing new restrictions, a novel approach is proposed, specifically new and fictitious products are created in order to respect the possible solution (i.e. shipper decision on supply to client allocation) where only suppliers and clients designated by the shipper can work together. Therefore, and going back to the novel approach proposed, if for example the shipper wants that the client 1 receives the same product A only from supplier 1 and 2 and leave the third supplier aside, with the implementation of a new fictitious product C, product A will be supplied only by supplier 1 and 2. The third supplier goes on with the production of product A, but all the product will be sold to client 2.

Figure 5 shows the original scenario of demand and production. The original scenario is the optimal solution of products flow between suppliers and clients without shipper decision on supply client allocation. The different colors of the lines to show the products flows between suppliers and clients: orange color represent the products flow from supplier

1 to client 1; blue color represent the products flow from supplier 2 to client 1 and client 2; green color represent the products flow from supplier 3 to client 1 and client 2.

Figure 6 shows the implementation form of fictitious product C. With the implementation of fictious product C, all the production of supplier 3 is going to client 2 and supplier 1 and supplier 2 sent all the production to client 1.

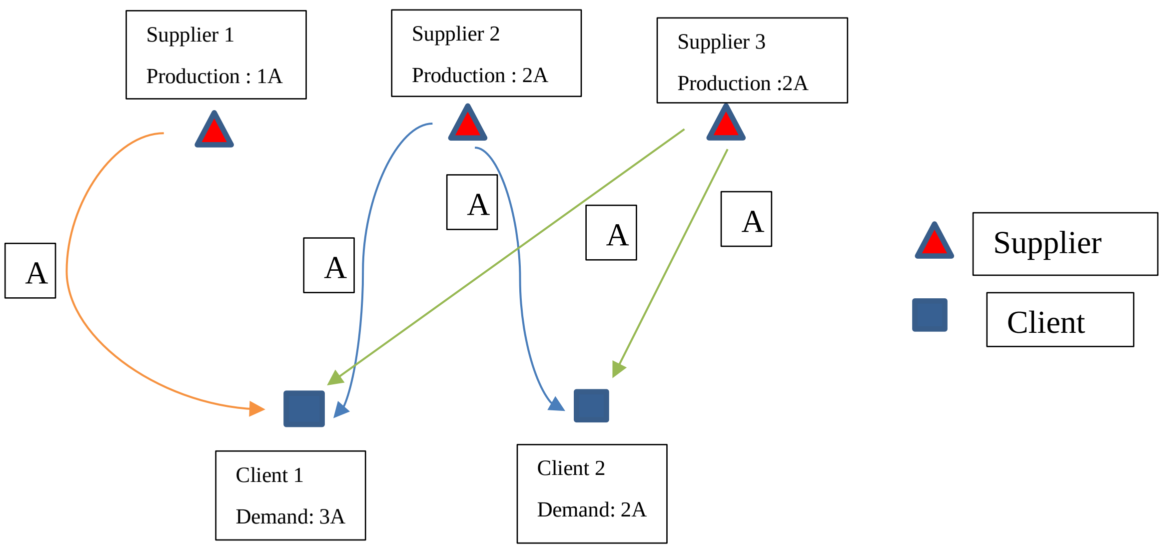
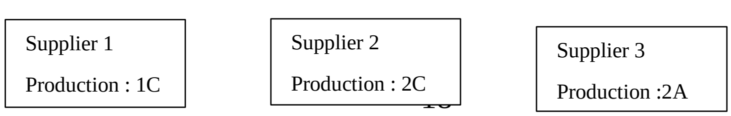


Figure 5: Original scenario of demand and production.



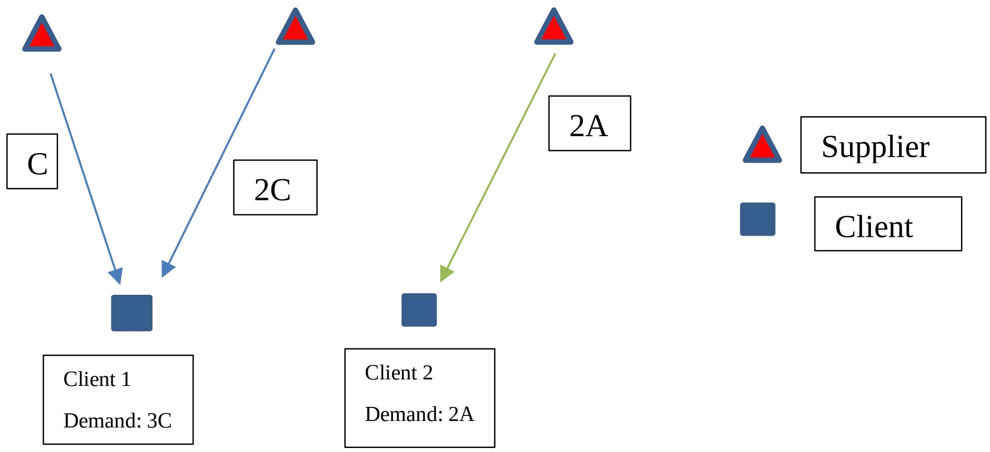


Figure 6: Modified scenario with the fictitious product C.

As fictitious product C is in fact product A, both clients receive the same quantity of Product A that they demand, but after the implementation client 1 only received from supplier 1 and 2.

Using the same example of section 2.5, where all requirements of two sawmills in all periods were fulfilled by 3 harvest zones, now the following restrictions, based on the shipper allocation decision will be used:

- Sawmill 1 receives product 3 only from harvest 3
- Sawmill 2 receives product 2 only from harvest 1 and harvest 2

Therefore, the requirements of sawmill 2 in relation to product 2 and the requirements of sawmill 1 in relation to product 3 will be open in two new fictitious products: product 4 and product 5. Product 4 will be the total product 2 sent by harvest 1 and harvest 2 to sawmill 2. Product 5 will be the total product 3 sent by harvest 3 to sawmill 1. The new fictitious products are created, because is necessary ensure that the shipper allocation decision is fulfilled, avoiding allocations with lower transport cost, but not designated by the shipper. The new production and demand are shown in Table 5:

Table 5: Demand and production per period and product.

Week 1						
Demand	**Sawmill 1**	**Sawmill 2**	**Production**	**Harvest 1**	**Harvest 2**	**Harvest 3**
Product 1	100	0	Product 1	100	0	0
Product 2	200	0	Product 2	200	100	50
Product 3	0	300	Product 3	300	0	0
Product 4	0	150	Product 4	200	100	0
Product 5	0	0	Product 5	0	0	0
Week 2						
Demand	Sawmill 1	Sawmill 2	Production	Harvest 1	Harvest 2	Harvest 3
Product 1	200	0	Product 1	0	100	100
Product 2	300	0	Product 2	0	0	300
Product 3	0	400	Product 3	0	200	400
Product 4	0	0	Product 4	0	0	0
Product 5	200	0	Product 5	0	0	400

Now, the new total cost for the objective function is $ 269,000; 4.98% more expensive than the results obtained in the example 1.5, where the shipper do not impose predeterminated allocation decision. The detail of the result appears in Table 6. The table shows that are 6 direct tours and 5 backhauls to fulfil the demand of clients.

Table 6: Demand and production per period and product.

Direct tour	**Product**	**Sawmill**	**Harvest**	**Week**	**Quantity**
1	2	1	1	1	50
2	3	2	1	1	200
3	1	1	3	2	100
4	2	1	3	2	300
5	3	2	3	2	300
6	5	1	3	2	200
Backhaul tour	Product	Sawmill	Harvest	Week	Quantity
1	2	1	2	1	50
1	3	2	1	1	50
2	2	1	2	1	50
2	4	2	1	1	50
3	2	1	3	1	50
3	3	2	1	1	50
4	1	1	1	1	100
4	4	2	2	1	100
5	1	1	2	2	100
5	3	2	3	2	100

Implementation

For computer results, the implementation of the forest transportation method was done with AMPL modeling system, solving the problem instances by CPLEX solver. The computer used is a 4 core i7 7^{th} generation with 2.6 MHZ of processing speed.

The input data necessary to generate the optimal solution in the transportation process of this case is the following:

1. Distance: The distance between origin (supply) and destination (client) in kilometers.
2. Time: Time between origin and destination with the assumptions of average speed in primary road, secondary road and on the road within 5 km distance from supply or client location.
3. Transactions every week, with the detail of origin, destination, product transported and carrier which made the transportation.

4. Cost of direct tours and backhauls in every route.
5. Name of: products, clients, carriers, harvest zones.
6. Contract between shipper and carriers, stipulating the payment formulas with the price of fuel and the ratio of payment per minute of transportation, and key assumptions as the time of loading/unloading per route, truck speed in primary and secondary road, truck speed on the road within 5 km distance from supply or client location and truck fuel consumption.

3 Case study

The case study of this research corresponds to a shipper, pulp and paper mill located in south of Quebec, Canada. The shipper manages a forest land located within a radius of 200 km from the mill. This investigation works with the historical forest transportation data provided by the shipper. Data include:

- Transportation zone: south of Québec, that span west to east over 160 kms.,
- Distances in primary and secondary routes between harvest zones and mills,
- Time of transportation between origin and destination,
- Name of carriers and harvest zones,
- Truck speed assumptions and ratio of payments made by shipper to carriers.

In the case of products' movement, the shipper provided a list of movements for 2016, with data of every transaction: quantity of product transported, client, harvest zone, carrier and date of transaction. Every client receives only one kind of product from an harvest zone that was pre-determined by shipper. Therefore, the origin, destination, product and route for every demand of logs were pre-determinated according to shipper decision, even though there are opportunities of less costly allocation.

3.1 Cost structures

The following subchapters review different transportation costs structured, as well as shipper payments to carriers. It is important to understand and measure the influence of every transportation cost on the objective function of transportation. Fuel, time, operation cost are part of the costs to be analyzed in this chapter. The cost structures that will review in detail are: cost structure 1, cost structure 2, cost structure 3A,3B,3C, cost structure 4, cost structure 5 and cost structure 6.

First, in cost structures 1, 2, 3A, 3B, 3C the analysis uses the shipper payment to understand what is the most convenient scenario for all the stakeholders. Also, to analyze how close every cost structure is to the minimum transportation time and minimum transportation distance.

Second, cost structure 4 measures the operation cost of carriers and how this cost is influenced by fuel and time costs. Also, cost structure 4 allows the analysis of decision behavior of carriers, and if such behavior is coherent with the shipper allocation.

Finally, cost structure 5 show the minimum transportation time and the cost structure 6 show which is the minimum transportation distance. This analysis allows checking what is the difference between operating times and distances with the optimal ones.

Cost structure 1

In cost structure 1, the objective function is minimizing the cost of transportation using only direct tours as a basic solution for forest transportation. Therefore, backhauls are not a part of solutions for transportation in this cost structure. Cost structure 1 is the basic solution of product flow and at the same time, the most expensive. In this case, payment is for all the fuel and time spent in round trips between origin and destination, including 90 minutes for loading/unloading. Payment for every minute spent is $1.34 dollars. In the case of fuel there is a surcharge tax of $0.288/liter, with a truck performance of 1.6 km/liter. Figure 7 shows the system of transportation used in cost structure 1.

The transport of products is from harvest to sawmill and at the return trucks are empty, achieving only a 50% of loading distance efficiency. The payment system pays the total time and operation distance, that means round trip between harvests and sawmill.

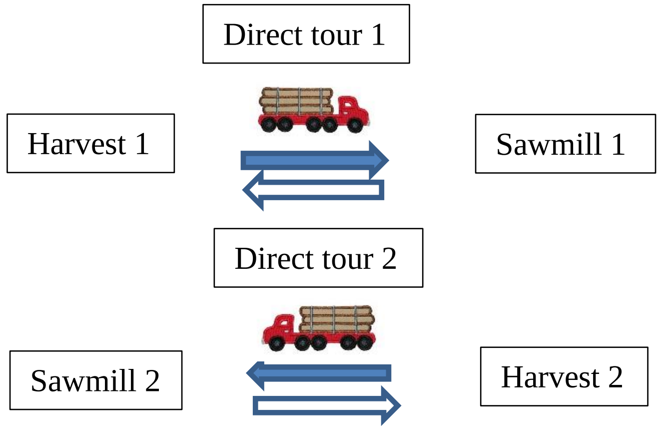


Figure 7: Direct tour system used in cost structure 1.

Cost structure 2

Cost structure 2 is the executed transportation scenario by the shipper in 2016. This cost structure uses direct tours and backhauls as a transportation system. The objective function is to minimize the cost of transportation using backhauls and direct tours. The shipper payment system pays for the fuel and time used as a round trip between origin and destination in all direct tours.

In a backhaul tour, the shipper pays two times the fuel and time spent between origin1 (harvest 1) and destination 1 (sawmill 1). The route between origin1 and destination 1 is designated as the linehaul. In addition, shipper pays the time spent between origin 2 and destination 2 (backhaul) and all the time of loading/unloading in the linehaul and the backhaul routes. The time for loading/unloading is fixed in 90 minutes, so that in a backhaul tour it is 180 minutes. Payment for every minute spent is $1.34 dollars. In the case of fuel, there is a surcharge tax of 0.288 $/liter, with a truck performance of 1.6 km/liter. Figure 8 shows the backhaul route used in cost structure 2.

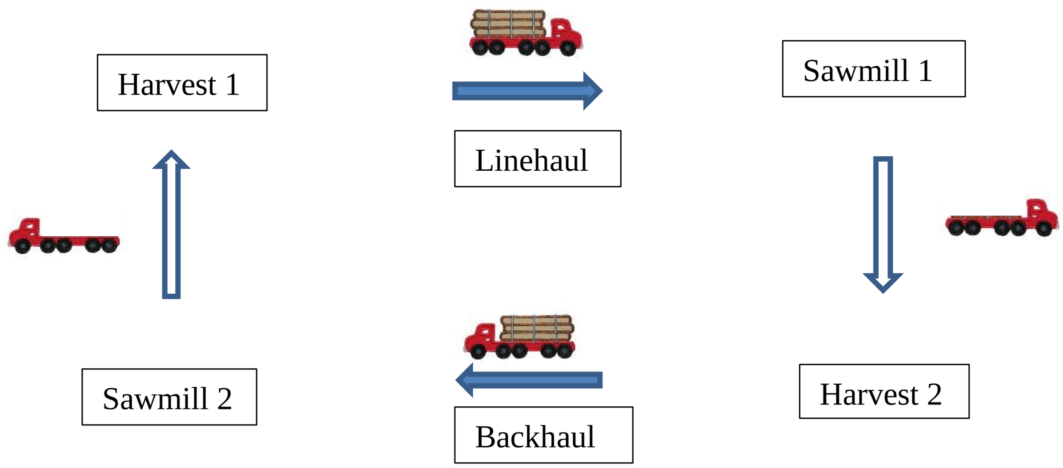


Figure 8: Backhaul route used in cost structure 2

Cost structure 3A, 3B, and 3C

In cost structure 3A, 3B and 3C the same payment system of cost structure 2 is used but, a restriction of maximum time of tour is added. This restriction is of 600 minutes (10 hours) as a maximum time per tour. The limit of 600 minutes is fixed as a form of limiting the allowed work time limit for drivers per day. This time includes the loading/unloading time per route. The objective function is minimizing the cost of transportation, based on direct tours and backhauls. Figure 9 shows backhaul route used in cost structure 3A, 3B and 3C.

Cost structure 3A achieves the lowest cost among structures 3A, 3B, 3C, however, without restriction in unloading distance, the solution can include backhauls where overall empty truck distances are greater than overall loading distance. This cost structure is very attractive for shipper, but not for carriers, since some tours generate high operation cost for carriers, because of overall empty truck distances are bigger than overall full truck distances.

In the case of cost structure 3B a new restriction is added, the total unloading distance in backhaul must be less than 99% of the total loading distance in a route.

Finally, cost structure 3C increases the restriction on unloading truck routes by establishing that unloading routes cannot exceed 90 % of loading routes. This restriction improves the quality of the allowed backhaul, because reduce the distances where the truck is empty.

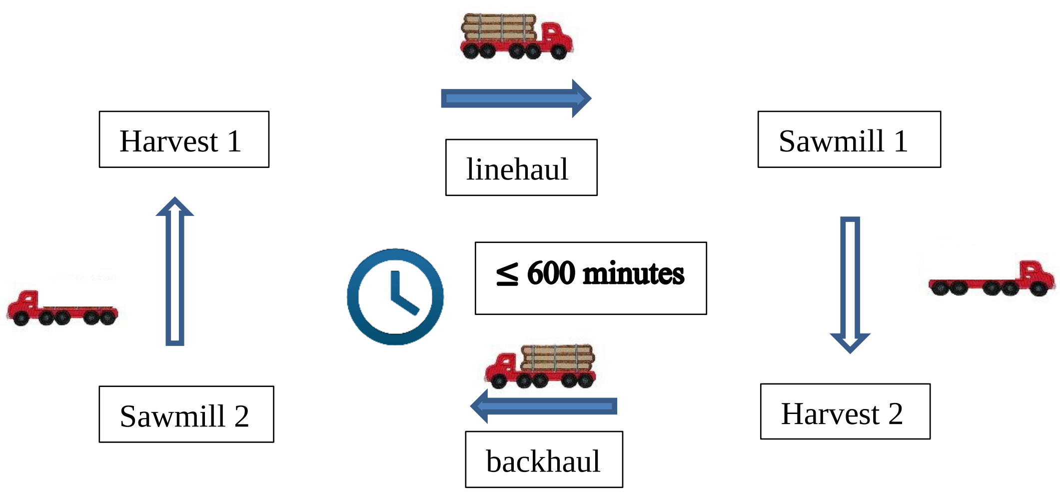


Figure 9: Backhaul route used in cost structure 3, with the restriction of 600 min.

Cost structure 4

In cost structure 4, the objective function is minimizing the operating cost of carriers. In this case the cost is per kilometers travel and the time spending by travel with or without a load, and the minutes spent in all trucks loading/unloading process. This cost structure gives us a good view of carrier costs, and how attractive the transportation opportunity is for them.

Operating costs of carriers include:

- Driver salary,
- Fuel liters.

The driver salary is composed for time of work and kilometers driving the truck. The ratio of payment is the following: $14.17 per hour of work and $ 0.17 per kilometer driven [15]. This salary is used for heavy truck drivers (road train) on Quebec regions . In the case of fuel, the carrier cost is $ 0.97 per liter, with an unloading truck performance of 1.8 km/liter and 1.6 km/liter when the truck is loading.

Cost structure 5

The objective function in cost structure 5 intends to minimize the operating time of transportation. The operating time includes the time to loading/unloading trucks and the time when the empty truck is travelling. This cost structure gives the best operating time to cover all the demand of clients during a year. Also, this cost structure is a good reference to compare with the total transportation time of other cost structures and measure the time gap. In this cost structure there are 2 type of costs, carrier operational cost and time shipper cost. The carrier operational cost includes the driver salary and fuel consumption cost and the shipper cost include only the time spent in allover forest transportation. The carrier operational cost pays the same ratios used in cost structure 4 and the shipper cost is $1.34/min.

Cost structure 6

Cost structure 6 intends to minimize the distance of transportation operation fulfilling clients' demand over the year. With this cost structure it is possible to compare with others cost structures and measure the difference with the minimum distance of transportation operation. This comparison supports strong analysis to reduce fuel consumption, at a time of high diesel prices. This cost structure includes 2 types of cost, carrier operational cost and distance shipper cost. The carrier operational cost pays the same ratios used in cost structure 4 and 5. The distance shipper cost is fuel spent in the total distance travelled in the route with $0.97/liter and a truck performance of 1.6 km/liter.

Table 7 summarizes the six cost structures:

Table 7: Summary of cost structures.

	Shipper Cost		**Carrier Cost**		
Cost Structure	Operation time cost ($/min.)	Fuel Cost ($/L)	Labour Cost ($/hr.)	Distance Cost ($/km.)	Fuel Cost ($/L)
1	1.34	0.288	14.17	0.17	0.97
2	1.34	0.288	14.17	0.17	0.97
3A, 3B, 3C	1.34	0.288	14.17	0.17	0.97
			Labour Cost ($/hr.)	Distance Cost ($/km.)	Fuel Cost ($/L)
4			14.17	0.17	0.97
	Operation Time Cost				
	Operation time cost ($/min.)		Labour Cost ($/hr.)	Distance Cost ($/km.)	Fuel Cost ($/L)
5	1.34		14.17	0.17	0.97
	Distance Cost				
	Fuel Cost ($/L)		Labour Cost ($/hr.)	Distance Cost ($/km.)	Fuel Cost ($/L)
6	0.97		14.17	0.17	0.97

3.2 Input data for case study

This information is used as a basis to simulate the transportation of all the cost structures during 52 weeks of the year, only changing the system of forest transport or the objective function according to the cost structure. Table 8 shows an example of summary data for the first week of transaction provided by the shipper. The information contains the following:

- Transaction: number of transactions.
- Week: time period of transaction in 2016.
- Origin zone code: is the harvest zone of logs demanded by the client.
- Destination client name: name of the client that demands the logs.
- Demand: quantity of product demanded in dry metric tons.
- Carrier: name of the carrier that transports the products between origin and destination.
- Products: name of log species transported.

Table 8: Summary data of transactions of the first week in 2016.

Transactio	Week	Origin	Destinatio	Demand (TMA)	Products	Carrier
1	w01	S38	C21	114.819	sciage feu	Carrier 1
2	w01	S59	C13	456.03	pâte feu	Carrier 1
3	w01	S37	C15	113.181	sciage res	Carrier 2
4	w01	S59	C18	85.691	sciage res	Carrier 1
5	w01	S38	C04	8.918	sciage cèdre	Carrier 1
6	w01	S38	C14	20.442	déroulage feu	Carrier 1
7	w01	S41	C11	250.934	sciage res	Carrier 3
8	w01	S51	C11	53.621	sciage res	Carrier 3
9	w01	S37	C13	47.777	pâte feu	Carrier 1
10	w01	S38	C02	134.983	sciage feu	Carrier 1
11	w01	S36	C13	16.323	pâte feu	Carrier 1
12	w01	S16	C04	31.712	sciage cèdre	Carrier 4
13	w01	S41	C13	324.406	pâte feu	Carrier 3
14	w01	S51	C13	568.466	pâte feu	Carrier 3
15	w01	S38	C13	796.103	pâte feu	Carrier 1
16	w01	S33	C18	17.283	sciage res	Carrier 2
17	w01	S06	C13	60.307	pâte feu	Carrier 5
18	w01	S38	C03	49.012	sciage feu	Carrier 1
19	w01	S16	C12	26.333	sciage cèdre	Carrier 4
20	w01	S16	C03	57.668	sciage feu	Carrier 4
21	w01	S38	C11	34.85	sciage res	Carrier 1
22	w01	S16	C13	1340.541	pâte feu	Carrier 4
23	w01	S13	C15	32.743	sciage res	Carrier 2
24	w01	S16	C06	502.836	sciage feu	Carrier 4
25	w01	S13	C13	275.356	pâte feu	Carrier 2
26	w01	S33	C13	502.51	pâte feu	Carrier 2
27	w01	S14	C13	498.356	pâte feu	Carrier 2
28	w01	S14	C15	85.992	sciage res	Carrier 2

3.3 Clients, suppliers and carriers

This research considers 23 clients located in the province of Quebec. The clients are sawmills and pulp and paper companies. The harvest zones are 65 points of extraction of logs that are a part of shipper’s property. The service of 6 carriers is used for the products’ transportation, previously chosen by the shipper. The annual volume of product that moves each carrier during the studied year is the following:

- Carrier 1: 71,899 (dry metric tons)
- Carrier 2: 40,546 (dry metric tons)

- Carrier 3: 5,372 (dry metric tons)
- Carrier 4: 80,351 (dry metric tons)
- Carrier 5: 9,582 (dry metric tons)
- Carrier 6: 3,719 (dry metric tons).

3.4 Periods, trucks and products

This research considers 52 periods that represent the weeks of the year. Every week has transactions that are movements of trucks with products between origin and destination. Some weeks have more movements that others, and there are other without transactions. Whether and some holidays are part of the reason for the absence of movement in some weeks.

For products' movements, only one volume capacity of truck is considered in this transportation process. This capacity is measured in DMT (dry metric tons). This capacity change depending on the transported product. Table 9 shows the values used by species of tree on the basis of a full truck load.

Table 9: Conversion table between product units and DMT based on a full truck load.

Unit	Quantity (DMT)
Dry metric tonne	19
Green metric tonne	17.9
mlv	15.1
mlv - cedar	7.4
Green metric tonne	8.9
Thousand foot board measure-deciduous	18.4
Thousand foot board measure-cedar	13.9
Thousand foot board measure-resinous	19.1
cord 8 feet - resinous and cedar	13.5
cord 8 feet- deciduous	18.1

The transportation of the logs from origin to destination is done in consolidated loads. That means using all the volume of the truck for transporting the products. The total trucks that are working in the transportation is not relevant for this research.

Regarding fuel consumption per truck, the operating cost of carriers considers 1.8 km/liter when the truck is empty, and 1.6 km/liter when the truck is loaded [17]. However, the agreement between shipper-carrier and the corresponding payment considers 1.6 km/liter as the truck consumption in both cases: loaded or empty.

Regarding the products, the clients request different types of product, depending on the companies' necessities regarding the final product. The transportation process uses the pre-determinated allocation from the shipper, supplying different types of wood required by clients. This research uses the following products' division, provided by the shipper:

- Deroulage Feuilleux
- Pate Feuilleux
- Sciage Cedre
- Sciage Feuilleux
- Sciage Resineux

This division is based on two big groups, Feuilleux and Resineux and subdivided into subgroups that represent the final use in the industry: sciage, pate and deroulage.

3.5 Routes and time restrictions

The routes are arcs that join nodes of index i with nodes of index j into the network. The nodes of index i are all the harvest places and the nodes of index j are all sawmills, or pulp and paper factories.

There are primary roads and secondary roads. Highways and paved routes are primary roads. All the forest roads, internal roads, gravel or unpaved road are classified as secondary routes. Approximately 30% of the distances between origin and destination were determined with the support of Google Maps. The other 70% is come from shipper data.

The average speed on primary roads is 75 km/h and on secondary roads is 25 km/h. Also, when the truck is 5 km from arriving to destination, the speed is 30 km/h. These are conditions of the truck speed that were accorded between shipper and carriers.

The cost of transportation in the model is related to the traveling and the time spent between the nodes. The cost is the same for one way or the other (symmetric). There are two cases of cost. First case is the ratio payment of shipper to carriers. The second case is the operating cost of carriers in relation to time and fuel. In the first case, shipper pays to carriers $ 0.288 per liter of fuel and $ 80.44 per hour of service. In the second case, operation cost of carriers, the price associated to diesel is the average between two regions: Estrie and Beauce [14]. For the purpose of this research, it is $ 0.97/liter. In the case of time and distance, cost is the salary of the driver with a ratio of $ 14.17 per hour of service and $ 0.17 per kilometer travel [15].

Regarding restrictions, one used in the model is the maximum time for every route. For this research, the maximum time per turn was fixed at 600 minutes, related to the maximum time designated that every driver can work per day. That means, the time per backhaul or direct tour can’t exceed that limit of time. This time includes the minutes used to load and unload the trucks (90 minutes per action). In the case of backhauls, it is 180 minutes and in the case of direct tour, 90 minutes.

Finally, the information for a week transaction is entered to the AMPL program and process to identify the result of every cost structure.

4 Results and data analysis

This chapter analyzes the results of every cost structure, describing the advantage of every cost structure, and what are the best values for operating cost, minimum distance, time and fuel consumption for products transported.

In the case study, the impact of backhauls is a reduction in unload distances of up to 8 % (104,840 km) and a reduction of spending times up to 2.25% (84,495 min.). When there is a collaboration between carriers, the impact of backhauls is stronger than in scenarios where carriers work alone.

From cost structure 1 to cost structure 3C are utilized direct tours and backhauls as systems of forest transportation. All these cost structures utilize the shipper payment form but, differ in the system of product transportation.

Cost structure 4 gives the minimum carrier operational cost, so this cost structure is a baseline of comparison for operating cost with cost structure 1 to 3C.

Cost structure 5 is the minimum operation time for all products transported that satisfied client's demand. The minimum working time allows analyzing the behavior of time in all cost structures and which is the difference between the cost structure and the minimum time of product transportation.

Finally, cost structure 6 is the minimum traveling distance for transporting all the products from harvest zones to clients. This cost structure allows comparing the transportation distances of other cost structures with the minimum forest transportation distance.

4.1 Comparison of costs for all cost structures

The cost structures reviewed in this subsection support an analysis that clarify the cost of every cost structure, advantages/disadvantages, and the cost structure that improves the transportation costs of stakeholders.

The starting point of cost comparison of every cost structure is done with cost structure 1 as a basis (only direct tours). Cost structure 1 is the most expensive cost structure, with the highest cost for carriers and shipper, with longest distances for products movement.

Going on with other cost structures, it is important to mention that the shipper spent $ 5,625,980 dollars in forest transportation in 2016 (cost structure 2) for moving products from harvest zones to clients. The shipper used direct tours and backhauls as a system of transportation of logs. The shipper worked with 6 different companies of carriers.

Table 10 shows the shipper and carrier transportation cost for the different cost structures. Cost structure 1 is used as a basis for comparing. Also, in Table 10, the shipper cost showed in cost structure 6 include only fuel cost.

Table 10: The shipper cost, operational cost of carriers and percentage of shipper cost reduction with direct tours as a basis of comparison.

Cost Structure	Shipper cost	Carrier operational cost	Shipper cost reduction	Carrier cost reduction
1	5 632 255	2 818 389	0.00%	0%
2	5 625 980	-	0.11%	-
3A	5 424 387	2 792 167	3.69%	0.90%
3B	5 471 479	2 738 068	2.96%	2.85%
3C	5 497 413	2 739 707	2.46%	2.79%
4	-	2 724 107	-	3.34%
5	4 927 052	2 724 128	2.01%	3.34%
6	1 512 668	2 724 115	0.54%	3.34%

The results show that cost structure 2 is only 0.11% less than cost structure 1, where backhauls represent only 1% of overall DMT transported. That means that almost all the forest transportation used in 2016 was based on direct tours. Therefore, it is important to review the cost structure 3A, 3B and 3C, and understand what opportunities are being lost with the current form of operating.

Cost structure 3A reduced the shipper cost by 3.69% and carrier operating cost by 0.9%. This cost structure reduces the costs for both parts but, include some backhauls where empty distances are bigger than loaded distances. Such backhauls are not attractive for carriers, because they cover long distances without receiving a payment for that displacement. Their costs are only 0.9% less than before, but their payment is reduced by 3.69%.

In the same line of cost structure 3A, cost structure 3B reduces the costs of shipper by 2.96% and decreases the operating cost of carriers by 2.85%. This cost structure is more attractive for carriers than 3A. First, cost structure 3B eliminates all backhauls that have more overall empty distance than overall loaded distance, and secondly, they reduce the operating costs. On the other hand, the shipper has a better cost structure than cost structure 1 and 2, but a little less attractive than cost structure 3A.

Revising cost structure 3C, the shipper cost appeared reduced by 2.46% in relation with cost structure 1, but 0.5% and 1.23% higher than cost structure 3B and 3A, respectively. The operating cost of carriers is 2.79% less than base case, but a little bit higher than cost structure 3B.

Reviewing the results of Table 11, backhauls represent only 1% of overall DMT transported in 2016. Also, cost structure 3A increment the percentage of backhauls representing 35% of the total tons transported. Cost structure 3A, 3B and 3C show that when is incremented the percentage of backhauls the cost of transport is reducing.

Table 11: Shipper cost and movement by direct tours and backhauls with carrier collaboration.

	Cost Structure				
	1	2	3A	3B	3C
Total shipper cost	5 632 255 $	5 625 980 $	5 424 387 $	5 471 479 $	5 497 413 $
Direct tour movement (DMT)	211469	209358	137852	163289	174359
Direct Tour/Total DMT transported	100%	99%	65%	77%	82%
Backhaul Movement (DMT)	0	2111	73617	48180	37110
Backhaul/Total DMT transported	0%	1%	35%	23%	18%
Total (DMT)	211469	211469	211469	211469	211469
Cost per ton. transported (Ton)	11.82 $	11.81 $	11.38 $	11.48 $	11.54 $

Regarding collaborative transportation, operating cost of carriers needs to be controlled so that working together has sense for carriers as well. Cost structure 4 shows the minimum operational cost for carriers, being a good point of comparison with other operating costs that are between cost structures 1 to 3C. As shown in Table 10, cost structure 4 offers an operating cost lower than other cost structures. The difference in percentage is the following:

- Cost structure 4 is 3.35% less than operating cost in cost structure 1
- Cost structure 4 is 2.43% less than operating cost in cost structure 3A
- Cost structure 4 is 0.51% less than operating cost in cost structure 3B
- Cost structure 4 is 0.57% less than operating cost in cost structure 3C

Therefore, cost structure 3B presents the most convenient operating cost for carriers, with 0.51% higher than cost structure 4.

Finally, when comparing carrier's operating cost structure 5 (minimum time of transportation) and cost structure 6 (minimum distance of transportation) with cost structure 4, the difference between cost structures is $21 and $8 respectively (Table 10). Hence, when minimized the total transportation distance and total transportation time, the carrier operating cost is almost the minimum.

4.2 Comparison of time for all cost structures

Part of the goals searched by shipper, clients and carriers altogether is complete the total forest transportation in a minimum time. In the cost structures show in Table 12, cost structure 5 has the minimum time of forest transportation. The cost structure 3C is the minimum shipper cost between cost structures 1 to 3C. Also, Table 12 shows that cost structure 3B and 3C have almost 3 times more percentage of savings than cost structure 3A.

Table 12: Operating time for all cost structures with time savings.

Operation time (Min.)					
Cost structure	Direct tour	Backhaul	Total	Savings	Savings %
1	3761400	0	3761400	0	0.00%
2	3719890	-	-	-	-
3A	2412546	1325015	3737561	23839	0.63%
3B	2828908	860552	3689460	71940	1.91%
3C	3023482	665000	3688482	72918	1.94%
4	2861970	814941	3676911	84489	2.25%
5	2861712	815193	3676905	84495	2.25%
6	2874888	802147	3677035	84365	2.24%

4.3 Comparison of distances for all cost structures

The minimum distance in all cost structures is cost structure 6, with 2,495,122 km. Between cost structures 1 to 3C, cost structure 3C offers the minimum total transportation distance with a 3.48% of reduction in distance compared to cost structure 1, as shown in Table 10.

Also, it is important to show that not necessarily a high quantity of backhauls implies the minimum cost of transportation. Going over the data in Table 13, cost structure 3A has more traveling distance in backhauls than other cost structures, but it only reduces the total distance of transportation by 1.12 %.

In addition, to analyze empty distances in backhauls for understanding the overall distance of full truck loading of each backhaul route. Table 14 shows that cost structure 3A has more empty distances than other cost structures, being less effective. Furthermore, cost structure 3C is less than 50 % of backhauls distance from cost structure 3A, but it reduces the total transportation distance by 3.48 %.

Table 13: Operational distances for all cost structures with distance savings.

Distances Traveled (Km.)					
Cost Structure	Direct Tour	Backhaul	Total	Savings	Savings %
1	2600024	0	2600024	0	0.00%
2	2568988	-	-	-	-
3A	1696336	874634	2570970	29054	1.12%
3B	1964496	546173	2510669	89355	3.44%
3C	2090256	419188	2509444	90580	3.48%
4	1991146	504006	2495152	104872	4.03%
5	1991006	504178	2495184	104840	4.03%
6	1999910	495212	2495122	104902	4.03%

Table 14: Summary of loading/unloading distances, time and fuel consumption for all cost structures.

		Distance (Km)	Time (Min)	Unload distance (Km)	Fuel consumption (L)
3A	Direct tours	1696336	2412546	848168	1001309
	Backhauls	874634	1325015	422790	517286
	Total	2570970	3737561	1270958	1518595
3B	Direct tours	1964496	2828908	982248	1159598
	Backhauls	546173	860552	228409	325496
	Total	2510669	3689460	1210657	1485095
3C	Direct tours	2090256	3023482	1045128	1233832
	Backhauls	419188	665000	164304	250583
	Total	2509444	3688482	1209432	1484414
4	Direct tours	1991146	2861970	995573	1175329
	Backhauls	504006	814941	199567	301145
	Total	2495152	3676911	1195140	1476474
5	Direct tours	1991006	2861712	995503	1175247
	Backhauls	504178	815193	199669	301245
	Total	2495184	3676905	1195172	1476492
6	Direct tours	1999910	2874888	999955	1180502
	Backhauls	495212	802147	195155	295955
	Total	2495122	3677035	1195110	1476458

4.4 Comparison of fuel surcharge for all cost structures

Cost structure 6 has the minimum total transportation distance and has the minimum consumption of fuel among all cost structures. Also, it is worth mentioning that cost structure

3C has the lowest fuel consumption among cost structures with objective function to minimize the shipper cost function a 3.28 % reduction. Table 15 shows these results. Respect of fuel consumption of case structure 2, there is not information on shipper's report about of routes connection between linehauls and backhauls. For that reason, is not possible calculate the total fuel consumption of cost structure 2.

Table 15: Fuel consumption for all cost structures with fuel savings.

Fuel consumption (L)					
Cost structure	Direct tour	Backhaul	Total	Savings	Savings %
1	1534736	0	1534736	0	0.00%
2	1605618	-	-	-	-
3A	1001309	517286	1518595	16141	1.05%
3B	1159598	325496	1485095	49642	3.23%
3C	1233832	250583	1484414	50322	3.28%
4	1175329	301145	1476474	58262	3.80%
5	1175247	301245	1476492	58244	3.80%
6	1180502	295955	1476458	58279	3.80%

4.5 Comparison of average transportation cost for all cost structures

The average transportation cost analysis for cost structures are shown in Table 16, indicating that the best average transportation cost for the shipper and the minimum average operating cost for carriers, with the current system of payment is 11.38 $/ton and 5.75 $/ton respectively. The objective function in cost structure 4 minimize the cost of carriers with an average cost of 5.72 $/ton. For cost structure 5 the shipper cost is only the operation time without include fuel costs. In this cost structure the shipper average cost is the 10.34 $/ton, and the carriers average operational cost is 5.72 $/ton. In cost structure 6 the shipper average cost is 3.17 $/ton.

Finally, the cost column of table 16 shown an average cost where both total fuel and total time spent are calculated for each cost structure with unit cost of 0.288 $/liter and 1.34 $/min respectively.

Table 16: Average transportation cost for the 6 cost structures.

Cost Structure	Shipper Average Cost ($/ton.)	Carrier Average Cost ($/ton.)	Average Cost ($/ton.)
1	11.82	5.92	11.82
2	11.81	-	11.81
3A	11.38	5.86	11.38
3B	11.48	5.75	11.48
3C	11.54	5.75	11.54
4	-	5.72	11.23
5	10.34	5.72	11.23
6	3.17	5.72	11.23

4.6 Analysis of important routes in backhauls

Backhauls is a transportation system that improves the results of transportation using loading returns, but it is important to choose a good backhaul to avoid cases of high operating cost and empty routes with greater distances than loading routes.

This case study requires attention. Shipper's form of payment doesn't pay distances in backhauls where the truck is unloading. Therefore, it is important to review all the backhauls, because there could be routes chosen at a minimum cost of transportation by the shipper, but with a big cost for carriers when the empty routes are greater than the loading routes.

For example, in cost structure 3A, the distance in empty routes could be greater than in loading routes, with a bigger cost for carriers. That means, the trucks could be driving more time without load than transporting products in some backhauls routes. In cost structures 3B and 3C, the empty routes are restricted to 99% and 90% of the total distance in loading routes. Cost structure 3A reduces only by 0.63% the transportation time in relation to direct tours system, as show in Table 12, meanwhile in cost structures 3B and 3C the percentage is of 1.91% and 1.94% respectively. Also, the total distance transported covered by cost structure 3A is only a 1.12% reduction in relation with direct tour transportation system, meanwhile for cost structure 3B and 3C it is 3.44% and 3.48% respectively, as shown in Table 13. In addition, Cost structure 3A spent more quantity of fuel than cost structures 3B and 3C, reducing with respect to direct tours transportation only by 1.05%, while 3B and 3C were 3.23% and 3.28% respectively, as shown in Table 15. When bad backhauls are chosen, the impact is not only for couriers, but also for the shipper as happens in the case of operating time.

Another important point to analyze is the quantity of savings for every backhaul in contrast with direct tours. Figures 10, 11, and 12 show that in cost structures 3A, 3B, and 3C less of 27% of backhauls represented 75% of the total savings. That means, it is essential to go through all the backhauls and classify the best quarter of them, ensuring that these routes are done during the operation.

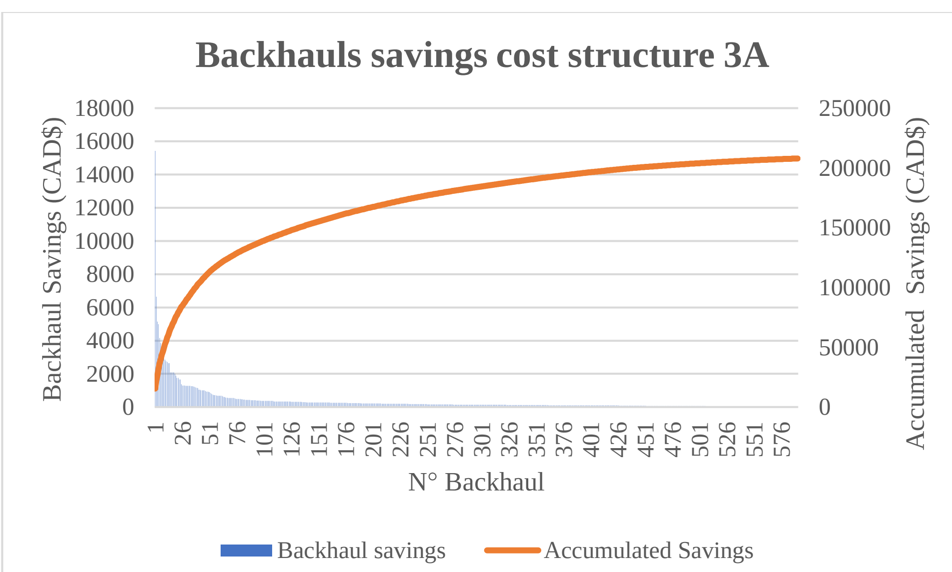


Figure 10: Backhaul savings in cost structure 3A.

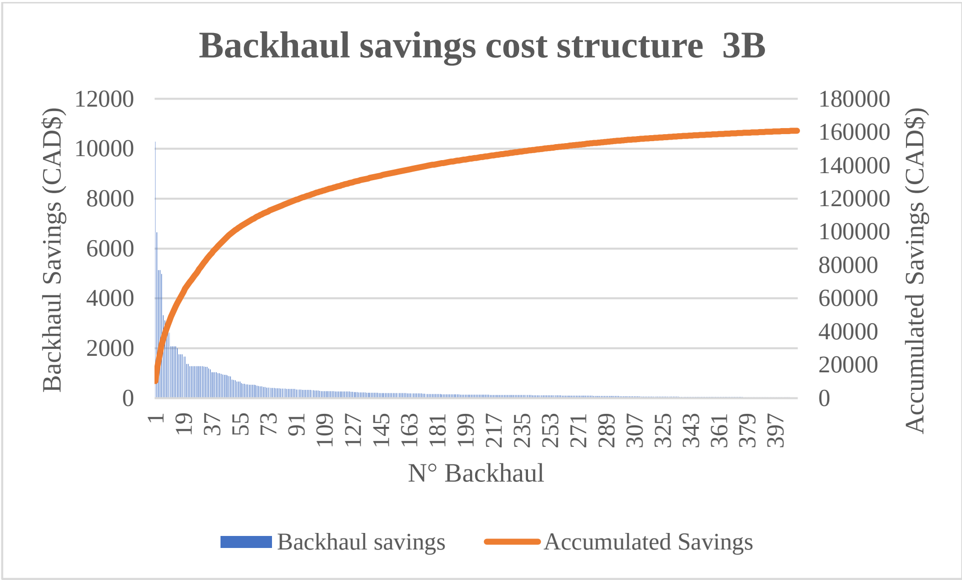


Figure 11: Backhaul savings in cost structure 3B.

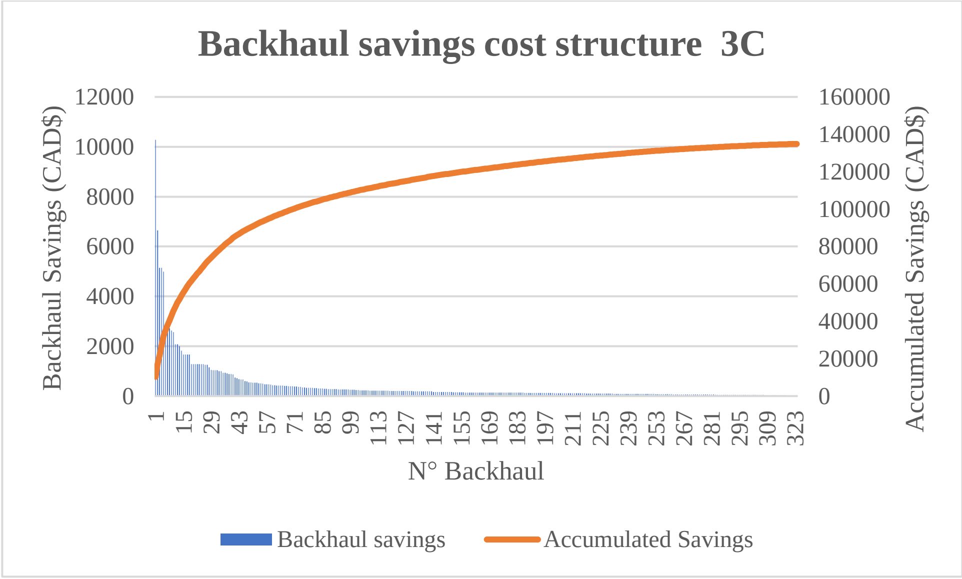


Figure 12: Backhaul savings in cost structure 3C.

When the operational cost of carriers is analyzed, the trend of savings is built up in a small quantity of the backhauls. This is shown in Figure 13, where 28% of the total backhauls accumulate 75% of the total savings. There is a similar result when analyzing the minimum total transportation time and the minimum total distance of transportation, shown in Figures 14 and 15 respectively. Both cost structures 5 and 6 build up to 75% of total savings only in 28% of backhauls.

The importance of this analysis rests on collaboration and common objectives between the shipper and carriers. Both parties' objective is to reduce costs, but this goal could not be achieved without collaboration. In a "working together" relationship, companies ensure the best cost structures to improve results. The alliance of companies should ensure that the best backhauls will be done.

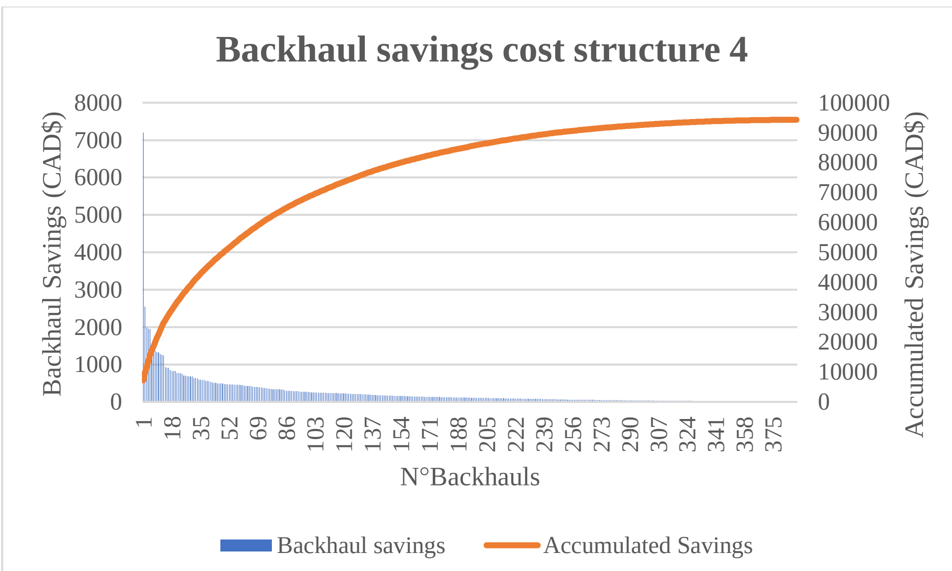


Figure 13: Backhaul savings in cost structure 4.

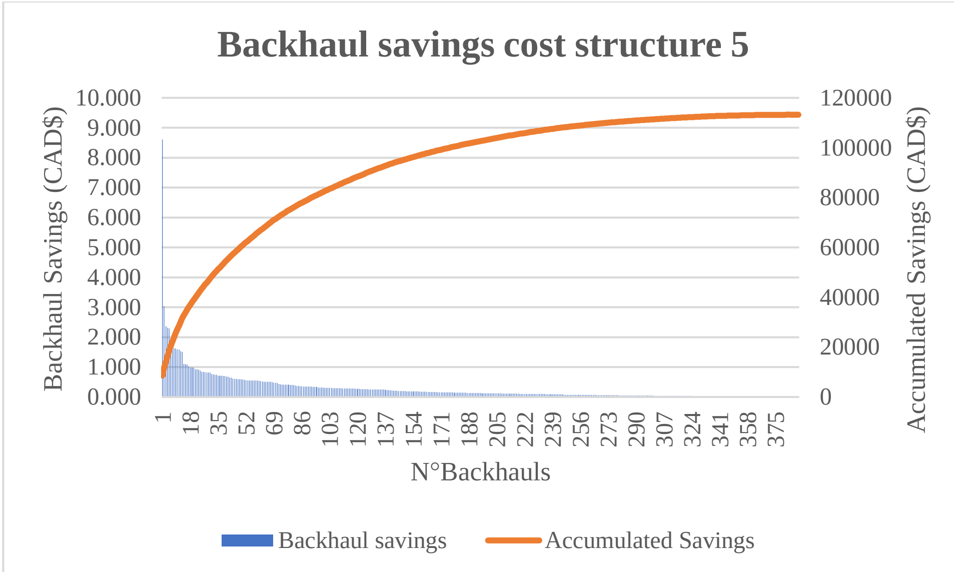


Figure 14: Backhaul savings in cost structure 5.

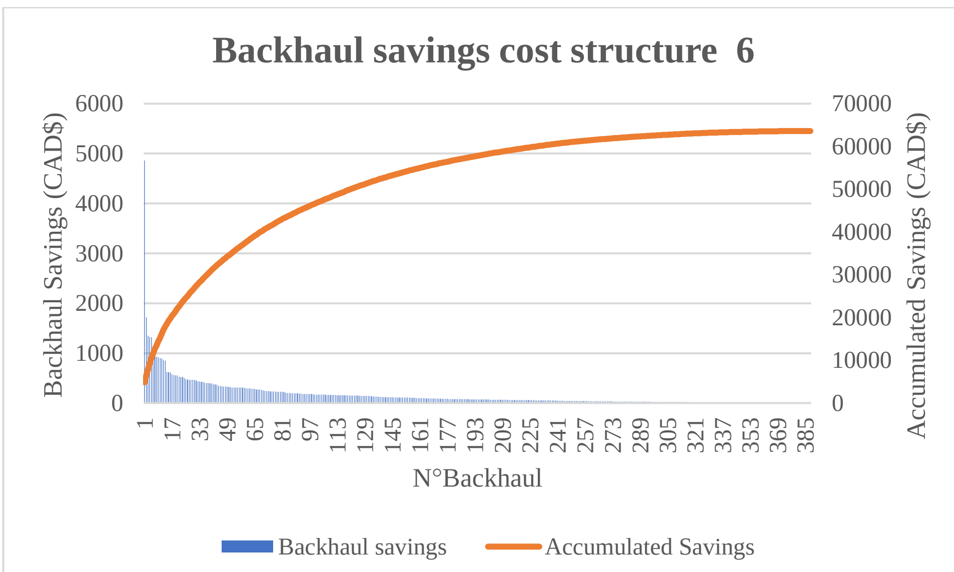


Figure 15: Backhaul savings in cost structure 6.

With the previous analysis the reduction of cost is only in some backhauls but also, it is interesting to know if these backhauls corresponding only some routes of backhauls or all these routes of backhauls have almost the same cost reduction. In detail, Figure 16 shows that in cost structure 3A, 8% of routes, that means, 29 types of backhauls savings at least 10 times more than the other routes. Also, in cost structure 3B (Figure 17) and 3C (Figure 18), 11% and 13% of types of backhaul routes respectively, savings of at least 10 times more than other backhaul routes. Therefore, these backhauls are part of the key backhauls for the shipper.

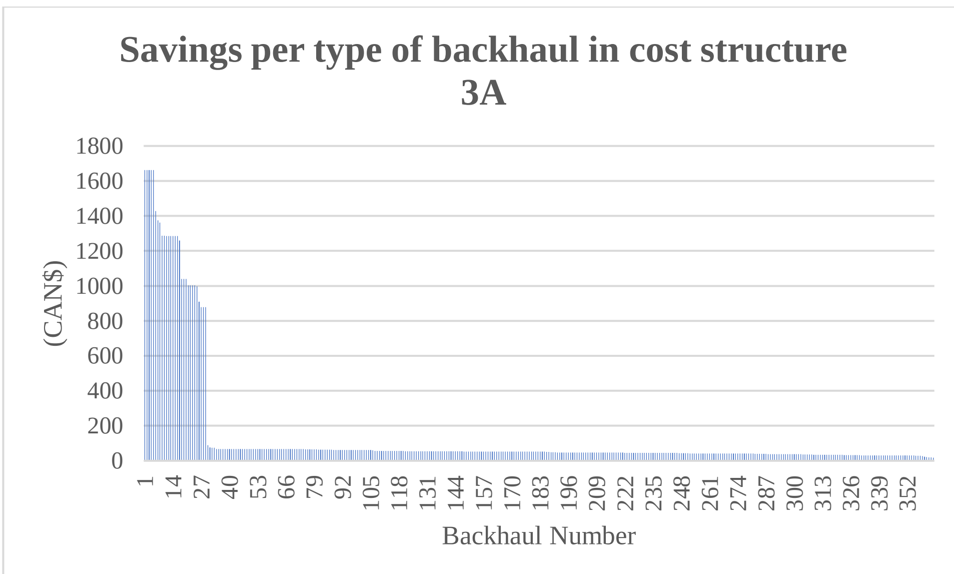


Figure 16: Backhaul savings in cost structure 3A.

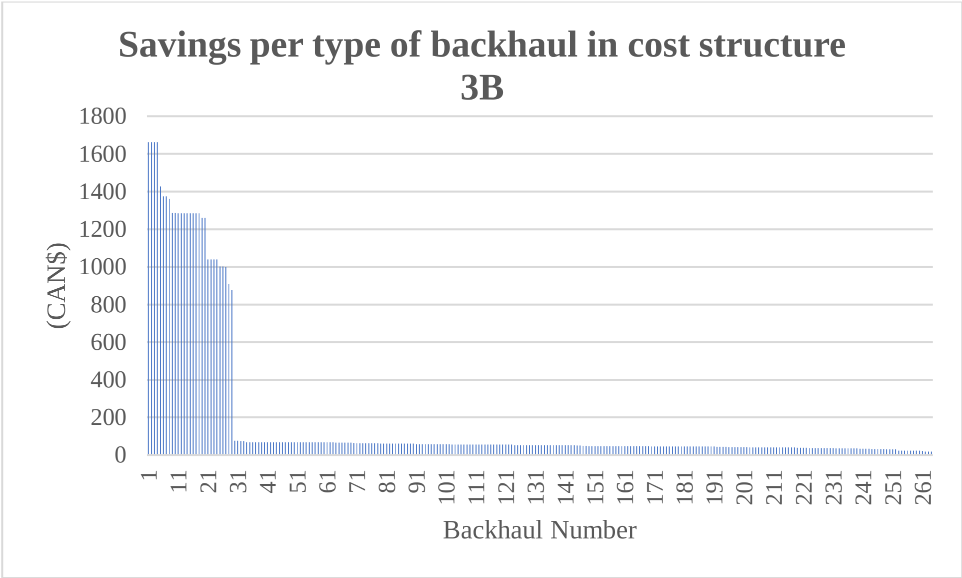


Figure 17: Backhaul savings in cost structure 3B.

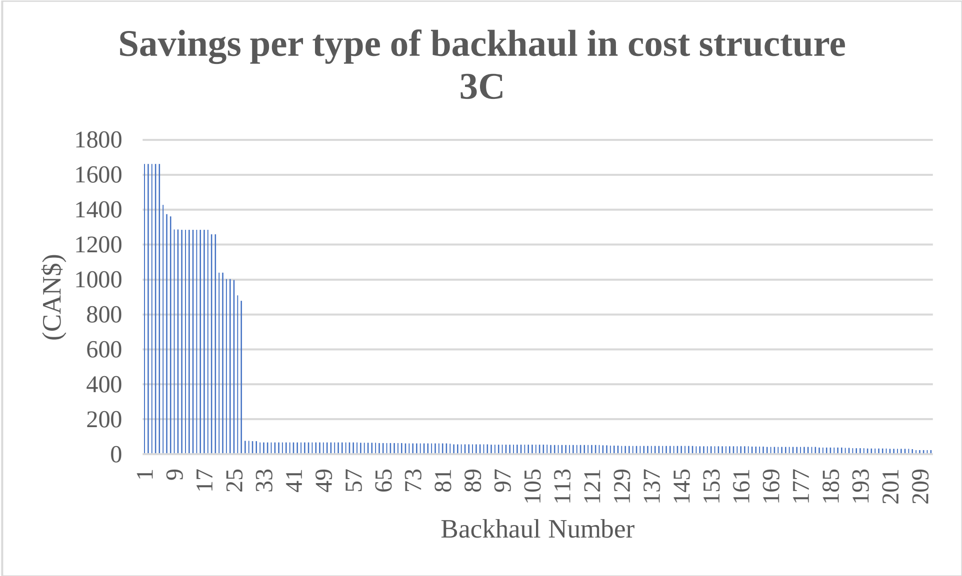


Figure 18: Backhaul savings in cost structure 3C.

Now, it is important to go over the data of cost structure 4 and realize if the big part of savings are located in some types of backhauls or dispersed in different types of backhauls. Figure 19 shows that in the case of cost structure 4, there is not a type of backhauls which contain high quantity of savings. In effect, the highest quantity of saving performed by a backhaul is $249, far away from $1,662, as the highest backhaul in cost structure 3C. Also, in carrier operating cost, the savings are more dispersed than in the shipper cost, hence carriers need to put the focus on a bigger quantity of savings at backhaul routes.

Going through types of backhauls, they can be classified in the following savings groups:

- $250- $200: 2 % backhauls type
- $200- $150: 2 % backhauls type
- $150- $100: 13 % backhauls type
- $100- $50: 25 % backhauls type
- $50- $0: 57% backhauls type

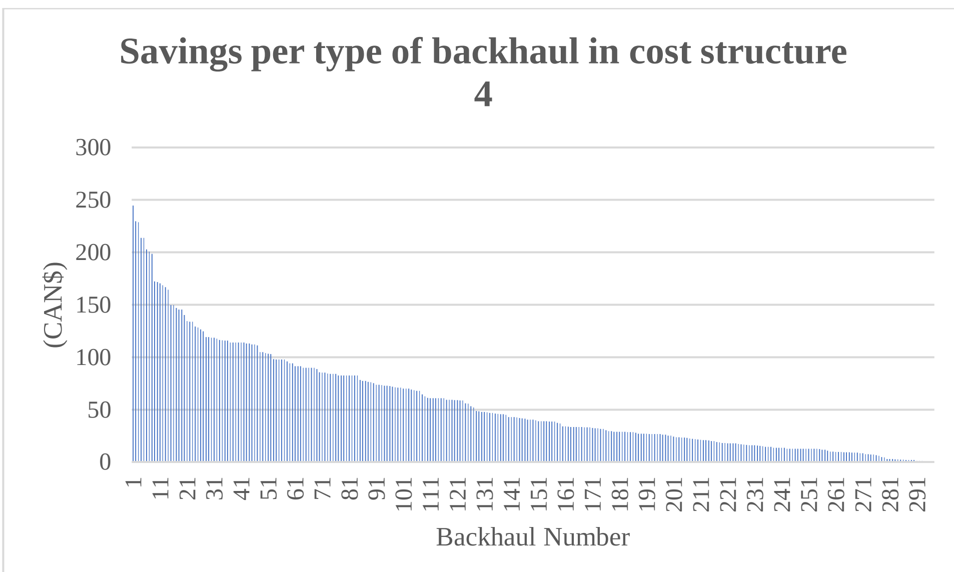


Figure 19: Backhaul savings in cost structure 4.

Going over Figures 20 and 21, is possible to verify that there is not a high quantity of savings per type of backhauls when the objective function is minimizing the time and the distance of forest transportation.

For example, Figure 20 shows 389 types of backhauls when the operating time is minimized. The best savings of backhaul is $300, with a similar dispersion of backhauls savings as cost structure 4.

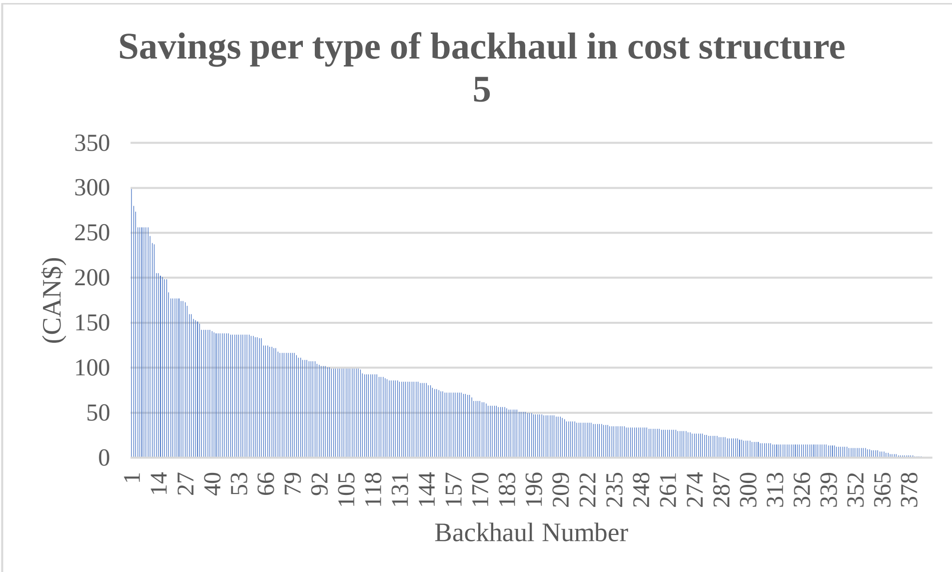


Figure 20: Backhaul savings in cost structure 5.

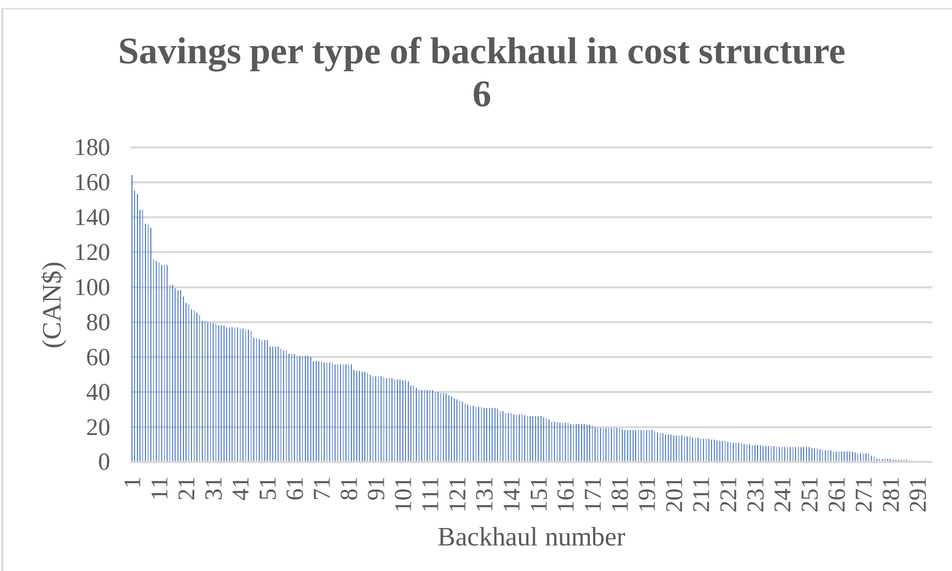


Figure 21: Backhaul savings in cost structure 6.

4.7 Analysis over all time periods

This section shows the savings achieved by backhauls by period (week), in all the cost structures that were calculated.

For cost structures 3A, 3B, 3C, (Figure 22, 23 and 24) there are two weeks (5 and 25) where the savings are the highest of the year, representing 16.4%, 20%, and 23.9% of the total annual savings respectively. On the other hand, for cost structures 4, 5, and 6, (Figure 25, 26 and 27) week 28 represents 9.9% of the total saving of the year.

Reviewing week 5 and 25, in cost structures 3A, 3B and 3C, the big quantity of savings is due to the following routes:

- Cost structure 3A, week5: S57-C13-S37-C04; week 25: S43-C18-S59-C04, and S60-C02-S59-C04.
- Cost structure 3B and 3C, week 5: S15-C09-S37-C04 and S12-C13-S37-C04. Week 25: S43-C18-S59-C04 and S06-C15-S59-C04.

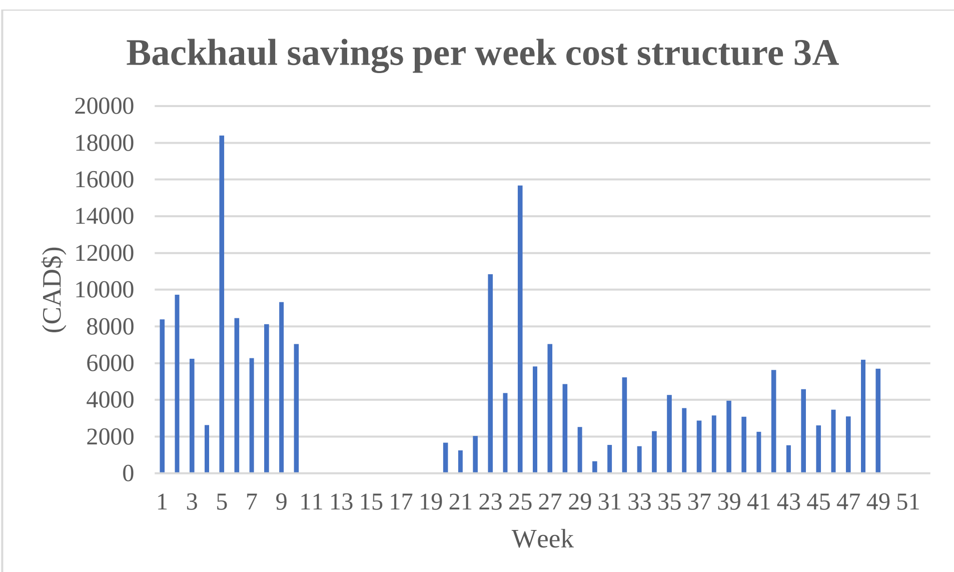


Figure 22: Backhaul savings per week in cost structure 3A.

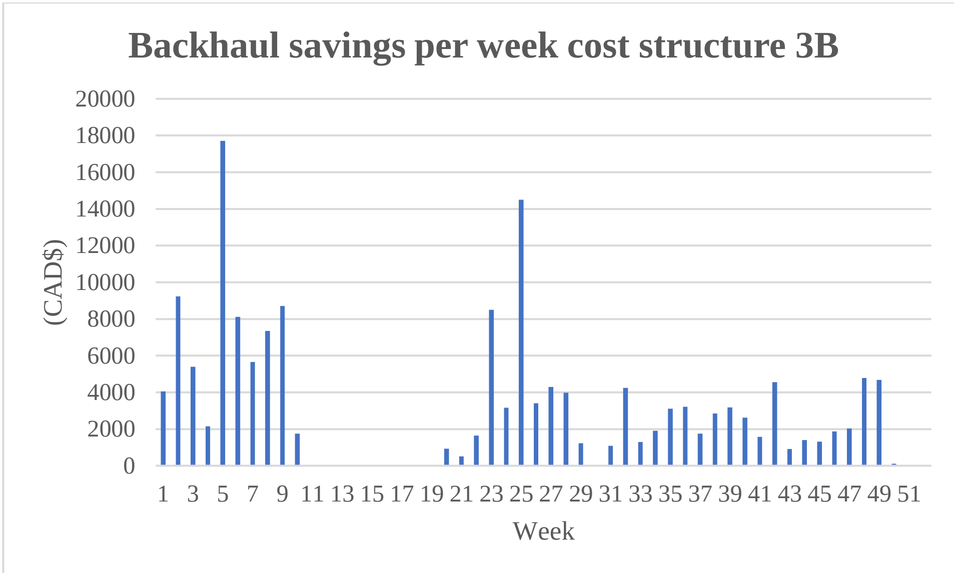


Figure 23: Backhaul savings per week in cost structure 3B.

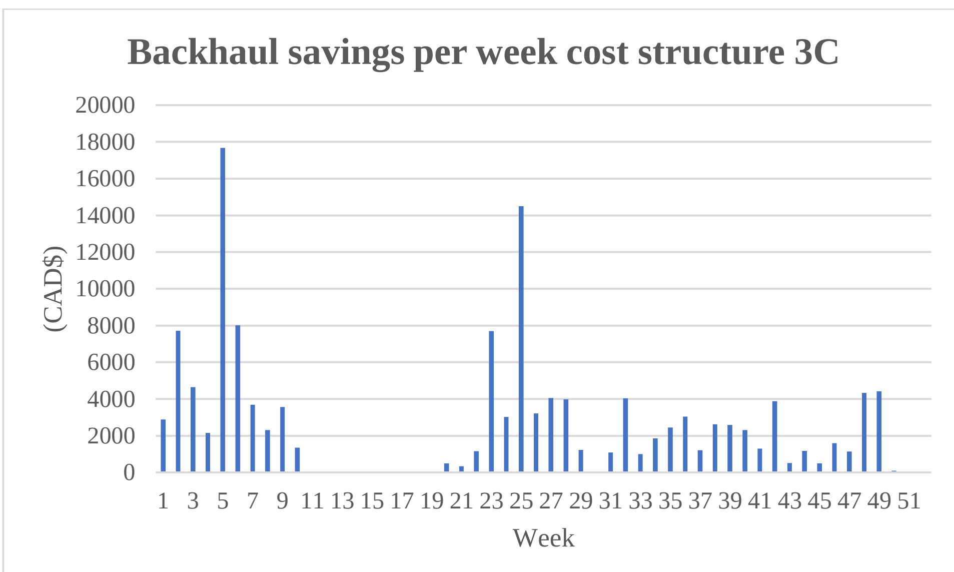


Figure 24: Backhaul savings per week in cost structure 3C.

In cost structures 4, 5 and 6, Figures 25, 26, and 27 respectively, the bigger quantity of savings is in week 28, due to high movements of products in the same backhaul route. In total, 42 times the same route in week 28: S16-C13-S43-C07.

On the other side, there are weeks without transportation of product. There are different factors that influence a low level of transportation: holidays, weather, less demand by clients. In the case study, the weeks that show a null level of transportation are: 11, 13, 14, 15, 16, 17, 18, 19, 51 and 52.

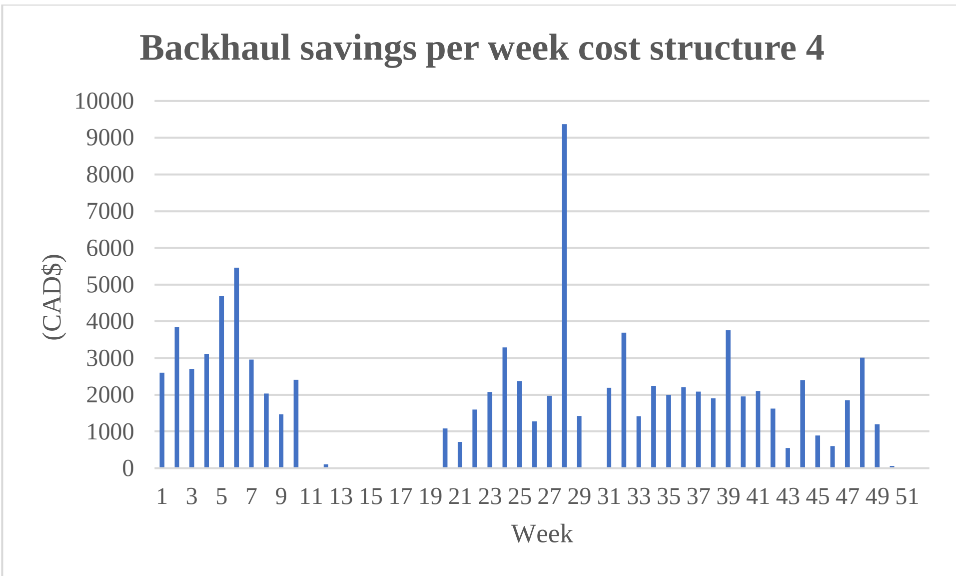


Figure 25: Backhaul savings per week in cost structure 4.

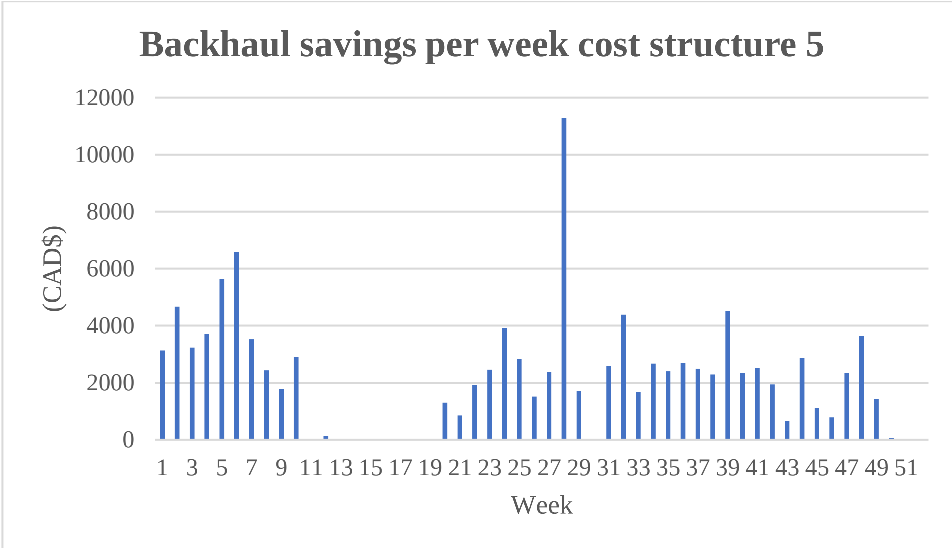


Figure 26: Backhaul savings per week in cost structure 5.

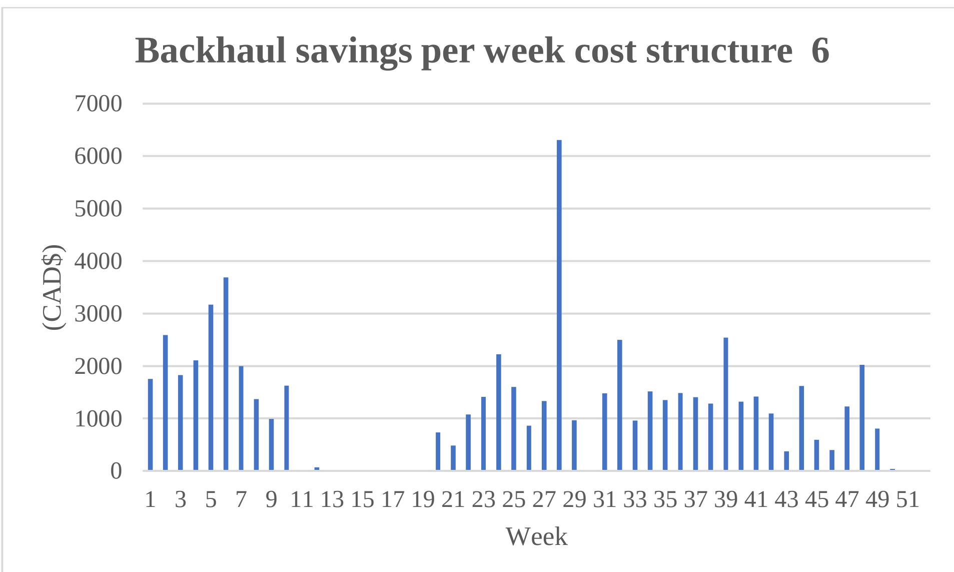


Figure 27: Backhaul savings per week in cost structure 6.

4.8 Analysis over several carriers

Another important point for reviewing is the cost of carriers and the shipper, when carriers act alone, without collaboration among them. In this scenario, carriers transport one product in linehaul, and without collaboration with other carriers, transport a second product at backhaul. This system of no-collaboration dismisses opportunities of cost reduction not only for carriers, but also for the shipper. In Table 17 appears a summary of results when carriers work independently from one another. Cost structure 1 and 2 do not experience modification, because they are the same when carriers act in a collaborative form or not. In cost structure 2 the historical backhauls tours that have been executed, include tours where the two delivered full truck load are coming from different carriers. However, the shipper costs increase in cost structure 3A, 3B and 3C, by 1.29%, 1.47% and 1.53%, respectively. The reason for that change is because the percentage of TMA moved by backhauls decreases by the following figures: Cost structure 3A from 73,617 to 53,851 TMA; 3B from 48,180 to 29,414 TMA; and 3C from 37,110 to 20,204 TMA. This reduction is due to less combination alternatives of line hauls/backhauls between carriers. So, in some cases the best opportunity of transportation is with direct tours.

Table 17: Shipper cost and movements by direct tours and backhauls, when carriers work without collaboration.

	Cost Structures				
	1	**2**	**3A**	**3B**	**3C**
Total shipper cost	5 632 255 $	5 625 980 $	5 495 045 $	5 552 866 $	5 582 634 $
Direct tour movement (DMT)	211469	209358	157618	182054	191265
Direct Tour/Total	100%	99%	75%	86%	90%
Backhaul movement (DMT)	0	2111	53851	29414	20204
Backhaul/Total	0%	1%	25%	14%	10%
Total (DMT)	211469	211469	211469	211469	211469
Cost per ton. transported (Ton)	11.82 $	11.81 $	11.53 $	11.65 $	11.72 $

Also, the operating cost of carriers increases. When collaboration is present among carriers, Table 10, the operating costs in cost structure 4 is $ 2,724,107 and without collaboration, as shown in Table 18, is $ 2,777,887 (increment of 1.93 %)

Without collaboration among carriers, distance and time of transportation increase. The minimum total distance of transportation (cost structure 6, Table 13) raises from 2,495,122 km to 2,554,987 km, representing 2.4% of distance increase. In addition, it represents an increase of 1.3% in the cost of fuel for carriers.

Table 18 shows the details of carriers and the shipper costs of 6 cost structures in a non-collaboration scenario.

Also, Table 18 shows that some carriers have a better results (percentage) after operating cost than others, as is the case of: carrier 1, carrier 2, and carrier 6. By contrast, some others as carrier 3, carrier 4, and carrier 5 show results with less profit percentage than other transportation companies.

Table 18 shows that more than 75% of the transportation movement is done by two of the six carriers, however without transportation collaboration the percentage of profit of one is better than that of the other.

Table 18: Details of cost per carrier in every cost structure.

		Shipper cost (1)	Op. Cost (2)	Direct tour cost	Backhaul cost	% Tot. shipper cost	Savings	Dif (1)- (2)	%
Cost Structure 1	Carrier 1	1 746 282 $	829 005 $	1 746 282 $	0	31.01%	0	917 277 $	32.60%
	Carrier 2	860 266 $	377 064 $	860 266 $	0	15.27%	0	483 202 $	17.17%
	Carrier 3	137 510 $	72 897 $	137 510 $	0	2.44%	0	64 613 $	2.30%
	Carrier 4	2 530 469 $	1 348 882 $	2 530 469 $	0	44.93%	0	1 181 587 $	41.99%
	Carrier 5	295 808 $	162 950 $	295 808 $	0	5.25%	0	132 858 $	4.72%
	Carrier 6	61 920 $	27 591 $	61 920 $	0	1.10%	0	34 329 $	1.22%
	Total	5 632 255 $	2 818 389 $	5 632 255 $	0	100.00%	0	2 813 866 $	100.00%
Cost Structure 2	Carrier 1	1 746 282 $	-	1 746 282 $	0	31.04%	- $	-	-
	Carrier 2	859 637 $	-	854 427 $	5 210 $	15.28%	629 $	-	-
	Carrier 3	137 510 $	-	137 510 $	0	2.44%	- $	-	-
	Carrier 4	2 528 136 $	-	2 505 930 $	22 206 $	44.94%	2 333 $	-	-
	Carrier 5	292 774 $	-	264 065 $	28 709 $	5.20%	3 034 $	-	-
	Carrier 6	61 641 $	-	58 242 $	3 399 $	1.10%	279 $	-	-
	Total	5 625 980 $	-	5 566 456 $	59 524 $	100.00%	6 275 $	-	-
Cost Structure 3A	Carrier 1	1 664 438 $	828 893 $	896 411 $	768 027 $	30.29%	81 844 $	835 545 $	31.16%
	Carrier 2	848 993 $	375 695 $	634 849 $	214 144 $	15.45%	11 273 $	473 298 $	17.65%
	Carrier 3	134 704 $	72 929 $	89 485 $	45 219 $	2.45%	2 806 $	61 775 $	2.30%
	Carrier 4	2 489 296 $	1 345 871 $	2 246 240 $	243 056 $	45.30%	41 173 $	1 143 425 $	42.65%
	Carrier 5	295 694 $	162 917 $	294 066 $	1 628 $	5.38%	114 $	132 777 $	4.95%
	Carrier 6	61 920 $	27 591 $	61 920 $	- $	1.13%	- $	34 329 $	1.28%
	Total	5 495 045 $	2 813 897 $	4 222 971 $	1 272 074 $	100.00%	137 210 $	2 681 148 $	100.00%
Cost Structure 3B	Carrier 1	1 704 504 $	803 974 $	1 271 004 $	433 500 $	30.70%	41 778 $	900 530 $	32.47%
	Carrier 2	852 856 $	368 506 $	720 800 $	132 056 $	15.36%	7 410 $	484 350 $	17.46%
	Carrier 3	135 888 $	72 336 $	108 345 $	27 543 $	2.45%	1 622 $	63 552 $	2.29%
	Carrier 4	2 502 004 $	1 344 031 $	2 351 887 $	150 117 $	45.06%	28 465 $	1 157 973 $	41.75%
	Carrier 5	295 694 $	162 917 $	294 066 $	1 628 $	5.33%	114 $	132 777 $	4.79%
	Carrier 6	61 920 $	27 591 $	61 920 $	- $	1.12%	- $	34 329 $	1.24%
	Total	5 552 866 $	2 779 356 $	4 808 022 $	744 844 $	100.00%	79 389 $	2 773 510 $	100.00%
Cost Structure 3C	Carrier 1	1 715 976 $	805 835 $	1 418 275 $	297 701 $	30.74%	30 306 $	910 141 $	32.50%
	Carrier 2	854 158 $	368 671 $	744 962 $	109 196 $	15.30%	6 108 $	485 487 $	17.33%
	Carrier 3	137 222 $	72 727 $	132 679 $	4 543 $	2.46%	288 $	64 495 $	2.30%
	Carrier 4	2 517 550 $	1 344 001 $	2 402 121 $	115 429 $	45.10%	12 919 $	1 173 549 $	41.90%
	Carrier 5	295 808 $	162 950 $	295 808 $	- $	5.30%	- $	132 858 $	4.74%
	Carrier 6	61 920 $	27 591 $	61 920 $	- $	1.11%	- $	34 329 $	1.23%
	Total	5 582 634 $	2 781 775 $	5 055 765 $	526 869 $	100.00%	49 621 $	2 800 859 $	100.00%
Cost Structure 4	Carrier 1	803 156 $	n/a	600 513 $	202 643 $	28.91%	943 126 $	n/a	n/a
	Carrier 2	368 066 $	n/a	313 018 $	55 048 $	13.25%	492 200 $	n/a	n/a
	Carrier 3	72 336 $	n/a	58 430 $	13 906 $	2.60%	65 174 $	n/a	n/a
	Carrier 4	1 343 821 $	n/a	1 274 087 $	69 734 $	48.38%	1 186 648 $	n/a	n/a
	Carrier 5	162 917 $	n/a	162 097 $	820 $	5.86%	132 891 $	n/a	n/a
	Carrier 6	27 591 $	n/a	27 591 $	- $	0.99%	34 329 $	n/a	n/a
	Total	2 777 887 $	n/a	2 435 735 $	342 151 $	100.00%	2 854 368 $	n/a	n/a
Cost Structure 5	Carrier 1	1 507 316 $	803 157 $	1 129 912 $	377 404 $	30.20%	238 966 $	704 159 $	31.81%
	Carrier 2	774 953 $	368 066 $	664 798 $	110 155 $	15.53%	85 313 $	406 887 $	18.38%
	Carrier 3	124 414 $	72 336 $	98 348 $	26 066 $	2.49%	13 096 $	52 078 $	2.35%
	Carrier 4	2 259 339 $	1 343 821 $	2 123 452 $	135 887 $	45.26%	271 130 $	915 519 $	41.36%
	Carrier 5	267 748 $	162 917 $	266 183 $	1 565 $	5.36%	28 060 $	104 831 $	4.74%
	Carrier 6	57 765 $	27 591 $	57 765 $	- $	1.16%	4 155 $	30 174 $	1.36%
	Total	4 991 535 $	2 777 888 $	4 340 458 $	651 077 $	100.00%	640 720 $	2 213 647 $	100.00%
Cost Structure 6	Carrier 1	438 188 $	803 156 $	335 371 $	102 817 $	28.30%	n/a	n/a	n/a
	Carrier 2	188 056 $	368 067 $	160 579 $	27 477 $	12.15%	n/a	n/a	n/a
	Carrier 3	41 150 $	72 336 $	33 562 $	7 588 $	2.66%	n/a	n/a	n/a
	Carrier 4	772 099 $	1 343 823 $	734 018 $	38 081 $	49.87%	n/a	n/a	n/a
	Carrier 5	94 510 $	162 917 $	94 066 $	444 $	6.10%	n/a	n/a	n/a
	Carrier 6	14 220 $	27 591 $	14 220 $	- $	0.92%	n/a	n/a	n/a
	Total	1 548 224 $	2 777 891 $	1 371 816 $	176 407 $	100.00%	n/a	n/a	n/a

5 Discussion

5.1 Cost structures discussion

Going over the results and the cost structures presented, it is possible to review their advantages and disadvantages. Also, to emphasize the importance of choosing the best backhauls to avoid problems as: overall loading distances smaller than overall empty distances, trips with more time than the maximum permitted by the authority, high operating carrier cost and planning no attractive routes for carriers.

At the current scenario used by the shipper and accepted for the carriers by contract, cost structure 3B is the best cost structure, because it reduces shipper cost as well as the carrier's operating costs, being more convenient than other cost structures. In addition, it reduces distances and time of transportation in relation to the scenario of shipper payment in 2016. This scenario expresses in a best form a win-win relation between carriers and the shipper.

Reviewing cost structures 1 to 3C, the best cost structure for the shipper is 3A, but this cost structure is not a good cost structure for carriers, due to the long distance in which they travel empty. Also, cost structure 3A reduces, with respect to cost structure 1, only by 0.63% the transportation time below cost structures 3B and 3C which reduce total transportation time by 1.91 % and 1.94% respectively. The fuel consumption is another point against cost structure 3A, because the reduction in comparison to cost structure 1 is only 1.05% meanwhile, cost structures 3B and 3C by 3.23 % and 3.28 % respectively.

Cost structure 3C has better time and distance indicators than cost structure 3B, but 3C is less attractive for shipper due to higher cost than 3B. From a carrier perspective, 3B and 3C have almost the same operating cost, as is possible to see in Table 2, therefore both cost structures are positive for carriers.

After reviewing cost structure 1 and 2, there are not doubts that cost structure 3B presents better figures and results than 1 and 2. Cost structure 3B improves performance while reducing distances, transportation times, fuel consumption, shipper costs and operating cost of carriers.

Also, cost structure 3B reduces the distance and operating time compared to cost structure 1, 2 and 3A, hence it is a cost structure which reduces the quantity of CO_2 emissions as well as the use of roads and tires.

Cost structure 3B is a good cost structure not only because it improves the results of the shipper, but also improves the results of carriers. But, the collective benefit of this cost structure demands sacrificing some individual benefits, such as more cost for the shipper or higher operational cost for carriers. The benefit is possible to share as long as carriers and shipper work together, giving up some own benefits to achieve a better result for all stakeholders.

Finally, to ensure that every carrier works in a collaborative form with other carriers. That means, to open the opportunity that two carriers work in the same tour for avoiding loses: one in linehaul, the second in backhaul.

5.2 How to implement

First, to review the current situation of the shipper, including the data of 2016 and the result of cost structure 2. Although it is true that the shipper transportation system is based on backhauls and direct tours, at present only 1 % of the transportation is in backhauls.

Second, review the direct tour model and the results of cost structure 1. Afterwards, compare with cost structure 2 (2016 shipper forest transport scenario) and verify the differences between both costs.

Third, to go over cost structures 3A to 6 with transport collaboration between carriers and after reviewing the results of cost structures without transport collaboration between carriers and prove how much stakeholders win when they work together with a backhaul system.

Fourth, it is relevant to understand why all actors are not achieving the goal of cost reduction with the current model of transportation and to improve all the weakness of the process.

Finally, once stakeholders understand the weakness of the current scenario, they should work in improving shortfalls and results according to the new model program and its implementation in the computer system of the shipper.

5.3 Future work

In the future works would be interesting, with the same model, including cases where the shipper doesn't design specific suppliers for fulfilling some requirements of the clients. That alternative would help shipper to make better decision of allocation.

Also, it could be interesting testing different capacities of trucks and after verifying the impact on the transportation cost, using backhauls in a transportation model.

Could be interesting to research scenarios where clients and suppliers are located at more than 500 km of distance to include another mode of transportation, such as train and intermodal transportation.

The next research could be working in the reduction of loading/unloading time. Time reduction is relevant, because every load/unload of truck means $121 dollars of cost ($1.34/min x 90 min) for the shipper. That means approximately 1.5 million dollars of cost per year for the shipper. Also, it is a cost for carriers, because they must pay $14.17 dollars per hour of driver. The time of loading/unloading can be reduced with some implementation.

To reduce the time when trucks pass for lorry weighbridge zone. In that place the truck needs to stop and to show the products that they transport. There is a system that uses a bar code for transferring the information to the computer system at the site. That system can show you all this information only in some seconds, without the necessity to stop the truck and scan a transportation card. That system utilizes only a big port where through laser scanners an IP HD camera determines the dimensions of the product [19], and other important characteristics that will be online in less than 2 minutes. If the camera in the future can recognize the species of the log, this will be a big progress, because the system could be replacing a lorry weighbridge, with a big reduction of time.

Conclusion

In this master thesis was reviewing different models of forest transportation and investigation of transport planning. The investigations are aimed to reduce the cost of transportation, improve the collaboration between hauling companies and in some cases, find a form of cost allocation.

This investigation worked with backhaul model and added characteristics of multi-period, multi products, multi clients, and multi suppliers. The results showed that backhaul model presented better values than direct tour models, achieved reduction of cost transportation up to 3.69%.

Among backhaul cost structures which were reviewed and with the current system of payment, one cost structure (3B) achieved better results, because it reduces shipper cost as well as carrier's operating costs, being more convenient than similar cost structures (3A and 3C). Cost structure 3B reduces, with respect to a situation without backhaul, the total transportation time by 1.91 % and fuel consumption by 3.23%.

When comparing cost structure 3B with 1 and 2, there are not doubts that cost structure 3B shows better figures and results than 1 and 2. Cost structure 3B improves performance while it reduces distances, transportation times, fuel consumption, shipper costs and operating cost of carriers. Due to reduction of distances and transportation times, cost structure 3B reduces the quantity of CO_2 emissions, as well as the use of roads and tires.

Another point reviewed was the cost in carriers and shipper, when carriers act alone, without collaboration among them. This system of no-collaboration dismisses opportunities of cost reduction. Without collaboration, shipper costs increased in cost structure 3A, 3B and 3C, by 1.29%, 1.47% and 1.53%, respectively.

Forest transportation represents approximately one-third of total cost in logistics planning [9], therefore developing transportation models and mechanisms of transportation collaboration between carriers will support the reduction of transportation costs. To emphasize the importance of inter-company collaboration to improve the companies' results would be an interesting point to work on in the next research on forest transportation.

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Annex :AMPL model alternative 3A

```
#-------------------
# Model file: Shipper3A.mod
#--------------------------
    set HARVEST;
    set SAWMILL;
    set PRODUCTS;
    set POSITION;
    set TRANSACTION;
    set WEEK;
    set CARRIER;


    param ncols integer >=0;

    set COLS:=1..ncols;

    param Demand {TRANSACTION} >= 0;
    param DH {HARVEST,PRODUCTS,WEEK,COLS,POSITION} >=0 binary, default 0;
    param DS {SAWMILL,PRODUCTS,WEEK,COLS,POSITION} >=0 binary, default 0;
    param BH {HARVEST,PRODUCTS,WEEK,COLS,POSITION} >=0 binary, default 0;
    param BS {SAWMILL,PRODUCTS,WEEK,COLS,POSITION} >=0 binary, default 0;
    param cost_Direct_Tour {COLS} >=0, default 0;
    param cost_Backhaul {COLS} >=0, default 0;
    param operational_cost_direct {COLS} >=0, default 0;
    param operational_cost_back {COLS} >=0, default 0;
    param km_Backhaul {COLS} >=0, default 0;
    param empty_km_Backhaul {COLS} >=0, default 0;
    param fuel_consumption {COLS} >=0, default 0;
    param time_Backhaul {COLS} >=0, default 0;
    param backhaul_savings {COLS} >=0, default 0;
    param tauxreg {SAWMILL,HARVEST} >=0, default 0;
    param tauxback {SAWMILL,HARVEST} >=0, default 0;
    param routetime {SAWMILL,HARVEST} >=0, default 0;
    param distance {SAWMILL,HARVEST} >=0, default 0;
    param production_quantity {TRANSACTION} >= 0;
    param Time {TRANSACTION} symbolic within WEEK;
    param Destiny {TRANSACTION} symbolic within SAWMILL;
    param Origin {TRANSACTION} symbolic within HARVEST;
    param Products {TRANSACTION} symbolic within PRODUCTS;
    param Carrier {TRANSACTION} symbolic within CARRIER;
    param Ton {TRANSACTION}>=0;
    param quantity_average {TRANSACTION}>=0;
    param km_directour {COLS} >=0, default 0;
    param time_directour {COLS} >=0, default 0;
   param empty_km_directour {COLS} >=0, default 0;
   param fuel_consumption_directour {COLS} >=0, default 0;
  var direct_tour {n in COLS} >=0 integer;
   var backhaul {n in COLS} >=0 integer;

    minimize cost:
```

```
       sum {n in COLS} (cost_Direct_Tour[n]*direct_tour[n] +
       cost_Backhaul[n]*backhaul[n]);



    subject to assign1 {w in TRANSACTION}:
       sum {n in COLS,s in POSITION}
       (DH[Origin[w],Products[w],Time[w],n,s]*direct_tour[n]
       + BH[Origin[w],Products[w],Time[w],n,s]*backhaul[n])
       = production_quantity[w];

     subject to assign2 {w in TRANSACTION}:
       sum{n in COLS,s in POSITION}
       (DS[Destiny[w],Products[w],Time[w],n,s]*direct_tour[n]
     + BS[Destiny[w],Products[w],Time[w],n,s]*backhaul[n])
     = Demand[w];



#--------------------------
# Command file: Shipper3A.run
#--------------------------
reset;
model Shipper3A.mod;
data Shipper3A.dat;


table tauxreg IN "ODBC" "Transport Shipper 2016-Nov 2017 alt 3 (Shipper
Payment).xlsx":
[j ~ tauxreg], {i in SAWMILL} < tauxreg [i,j] ~ (i) >;
read table tauxreg;

table tauxback IN "ODBC" "Transport Shipper 2016-Nov 2017 alt 3 (Shipper
Payment).xlsx":
[j ~ tauxback],{i in SAWMILL} < tauxback [i,j] ~ (i) >;
read table tauxback;


option solver cplex;
let ncols:=0;
for{w1 in TRANSACTION}{
                          let ncols:=ncols+1;

                   let DH[Origin[w1],Products[w1],Time[w1],ncols,1]:=1;
                   let DS[Destiny[w1],Products[w1],Time[w1],ncols,2]:=1;

                   let cost_Direct_Tour[ncols]:=
tauxreg[Destiny[w1],Origin[w1]];
                   let operational_cost_direct[ncols]:=
0.97*(distance[Destiny[w1],Origin[w1]]/ 1.6)+
0.97*(distance[Destiny[w1],Origin[w1]]/ 1.8)
                   + 0.17*(2*distance[Destiny[w1],Origin[w1]])
                   + 0.236*(2*routetime[Destiny[w1],Origin[w1]]+90);
```

```
                              let km_directour[ncols]:= 2*
distance[Destiny[w1],Origin[w1]];
                       let
time_directour[ncols]:=(2*routetime[Destiny[w1],Origin[w1]])+90;
                              let empty_km_directour[ncols]:=
distance[Destiny[w1],Origin[w1]];
                              let fuel_consumption_directour[ncols]:=
(distance[Destiny[w1],Origin[w1]]/ 1.6)+(distance[Destiny[w1],Origin[w1]]/
1.8);}

       for{w2 in TRANSACTION, w3 in TRANSACTION: w2<>w3}{



                       if   Time[w3]=Time[w2] and tauxreg[Destiny[w3],Origin[w3]] >
tauxback[Destiny[w3],Origin[w3]] and Origin[w3]<>Origin[w2] and
Destiny[w3]<>Destiny[w2] and
(routetime[Destiny[w3],Origin[w3]]+routetime[Destiny[w2],Origin[w2]]+routetime[D
estiny[w3],Origin[w2]]+routetime[Destiny[w2],Origin[w3]]+180)<= 600

                       then {

                       let ncols:=ncols+1;
               let BH[Origin[w2],Products[w2],Time[w2],ncols,1]:=1;
                       let BS[Destiny[w2],Products[w2],Time[w2],ncols,2]:=1;
               let BH[Origin[w3],Products[w3],Time[w3],ncols,3]:=1;
               let BS[Destiny[w3],Products[w3],Time[w3],ncols,4]:=1;

               let cost_Backhaul[ncols]:=
tauxreg[Destiny[w2],Origin[w2]]+tauxback[Destiny[w3],Origin[w3]];

               let km_Backhaul[ncols]:=
distance[Destiny[w2],Origin[w2]]+distance[Destiny[w3],Origin[w3]]+distance[Desti
ny[w2],Origin[w3]]+distance[Destiny[w3],Origin[w2]];
               let
time_Backhaul[ncols]:=routetime[Destiny[w2],Origin[w2]]+routetime[Destiny[w3],Or
igin[w3]]+routetime[Destiny[w2],Origin[w3]]+routetime[Destiny[w3],Origin[w2]]+18
0;
                              let empty_km_Backhaul[ncols]:=
distance[Destiny[w2],Origin[w3]]+distance[Destiny[w3],Origin[w2]];
                              let backhaul_savings[ncols]:=
tauxreg[Destiny[w3],Origin[w3]]-tauxback[Destiny[w3],Origin[w3]];
                              let operational_cost_back[ncols]:=
0.97*(((distance[Destiny[w2],Origin[w2]]+distance[Destiny[w3],Origin[w3]])/1.6)+
((distance[Destiny[w2],Origin[w3]]+distance[Destiny[w3],Origin[w2]])/1.8))
                              + 0.17*
(distance[Destiny[w2],Origin[w2]]+distance[Destiny[w3],Origin[w3]]+distance[Dest
iny[w2],Origin[w3]]+distance[Destiny[w3],Origin[w2]])
                              + 0.236 *
(routetime[Destiny[w2],Origin[w2]]+routetime[Destiny[w3],Origin[w3]]+routetime[D
estiny[w2],Origin[w3]]+routetime[Destiny[w3],Origin[w2]]+180);

                              let fuel_consumption[ncols]:=
((distance[Destiny[w2],Origin[w2]]+distance[Destiny[w3],Origin[w3]])/1.6)+((dist
ance[Destiny[w2],Origin[w3]]+distance[Destiny[w3],Origin[w2]])/1.8);}}
```

```
   let ncols:= ncols;
   solve;
   option omit_zero_rows 1;



      table directour1 OUT "ODBC" "ShipperF.xlsx":
    {n in COLS,s in POSITION,w in TRANSACTION:
DS[Destiny[w],Products[w],Time[w],n,s] * direct_tour[n]} ->
[DIRECT_FLOW_N,POSITION,TRANSACTION],
      DS[Destiny[w],Products[w],Time[w],n,s] * direct_tour[n] ~
Full_Trucks,Time[w] ~ WEEK, Destiny[w]~ DESTINY ;
      write table directour1;

      table directour2 OUT "ODBC" "ShipperF.xlsx" :
      {n in COLS ,s in POSITION,w in TRANSACTION:
DH[Origin[w],Products[w],Time[w],n,s] * direct_tour[n]} ->
[DIRECT_FLOW_N,POSITION,TRANSACTION],
      Origin[w] ~ ORIGIN,Ton[w] ~ TMA, quantity_average[w]~ QTY_AVE_TRUCK,
km_directour[n] ~ KM_DIRECT,time_directour[n]~ TIME_DIRECT ,
empty_km_directour[n]~ EMPTY_KM, fuel_consumption_directour[n]~
FUEL_LT,cost_Direct_Tour[n]~ COST,operational_cost_direct[n]~ OP_COST;
      write table directour2;
```