Selection of Wood Supply Contracts to Reduce Cost in the Presence of Risks in Procurement Planning

Thèse

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Résumé

Les activités d'achat dans l'industrie des pâtes et papiers représentent une part importante du coût global de la chaîne d'approvisionnement. Les décideurs prévoient l'approvisionnement en bois requis jusqu'à un an à l'avance afin de garantir le volume d'approvisionnement pour le processus de production en continu dans leur usine. Des contrats réguliers, flexibles et d'options avec des fournisseurs de différents groupes sont disponibles. Les fournisseurs sont regroupés en fonction de caractéristiques communes, telles que la propriété des terres forestières. Cependant, lors de l'exécution du plan, des risques affectent les opérations d'approvisionnement. Si les risques ne sont pas intégrés dans le processus de planification des achats, l'atténuation de leur impact sera generalement coûteuse et compliquée. Des contrats ad hoc coûteux supplémentaires pourraient être nécessaires pour compenser le manque de livraisons. Pour aborder ce problème dans cette thèse, dans un premier projet, un modèle mathématique déterministe des opérations d'approvisionnement est développé. L'objectif du modèle est de proposer un plan d'approvisionnement annuel pour minimiser le coût total des opérations relatives. Les opérations sont soumises à des contraintes telles qu'une proportion minimale de l'offre par chaque groupe de fournisseurs, des niveaux cibles des stocks, de la satisfaction de la demande, la capacité par la cour à bois et la capacité du procédé de mise en copeaux. Les décisions sont liées à la sélection des contrats d'approvisionnement, à l'ouverture de cour à bois et aux flux du bois. Dans un deuxième projet, une évaluation du plan d'approvisionnement à partir du modèle déterministe du premier projet est effectuée en utilisant une approche de simulation Monte Carlo. Trois stratégies contractuelles différentes sont comparées : fixes, flexibles et une combinaison des deux types des contrats. L'approche de simulation de ce projet évalue la performance du plan par la valeur attendue et la variabilité du coût total, lorsque le plan est exécuté pendant l'horizon de planification. Dans un troisième projet, une approche de programmation stochastique en deux étapes est utilisée pour fournir un plan d'approvisionnement fiable. L'objectif du modèle est de minimiser le coût prévu du plan d'approvisionnement en présence de différents scénarios générés en fonction des risques. Les décisions lors de la première étape sont la sélection des contrats dans la première période et l'ouverture des cours à bois. Les décisions de la deuxième étape concernent la sélection des contrats commençant après la première période, les flux, l'inventaire et la production du procédé de la mise en copeaux.

L'étude de cas utilisée dans cette thèse est inspirée par Domtar, une entreprise des pâtes et papiers située au Québec, Canada. Les résultats des trois projets de cette thèse aident les décideurs à réduire les contraintes humaines liées à la planification complexe des achats. Les modèles mathématiques développés fournissent une base pour l'évaluation de la stratégie d'approvisionnement sélectionnée. Cette tâche est presque impossible avec les approches actuelles de l'entreprise, car les évaluations nécessitent la formulation de risques d'approvisionnement. L'approche de programmation stochastique montre de meilleurs résultats financiers par rapport à la planification déterministe, avec une faible variabilité dans l'atténuation de l'impact des risques.

Abstract

Procurement activities in the pulp and paper industry account for an important part of the overall supply chain cost. Procurement decision-makers plan for the required wood supply up to one year in advance to guarantee the supply volume for the continuous production process at their mill. Regular, flexible and option contracts with suppliers in different groups are available. Suppliers are grouped based on common characteristics such as forestland ownership. However, during the execution of the plan, sourcing risks affect procurement operations. If risks are not integrated into the procurement planning process, mitigating their impact is likely to be expensive and complicated. Additional expensive ad hoc contracts might be required to compensate for the lack of deliveries. To tackle this problem, the first project of this thesis demonstrates the development of a deterministic mathematical model of procurement operations. The objective of the model is to propose an annual procurement plan to minimize the total cost of procurement operations. The operations are subject to constraints such as the minimum share of supply for each group of suppliers, inventory target levels, demand, woodyard capacity, and chipping process capacity. The decisions are related to the selection of sourcing contracts, woodyards opening, and wood supply flow. In the second project, an evaluation of the procurement plan from the deterministic model from project one is performed by using a Monte Carlo simulation approach. Three different strategies are compared as fixed, flexible, and a mix of both contracts. The simulation approach in this project evaluates the performance of the plan by the expected value and variability of the total cost when the plan is executed during the planning horizon. In the third project, a two-stage stochastic programming approach is used to provide a reliable procurement plan. The objective of the model is to minimize the expected cost of the procurement plan in the presence of different scenarios generated based on sourcing risks. First-stage decisions are the selection of contracts in the first period and the opening of woodyards. Second-stage decisions concern the selection of contracts starting after the first period, flow, inventory, and chipping process production.

The case study used in this thesis was inspired by Domtar, which is a pulp and paper company located in Quebec, Canada. The results of three projects in this doctoral dissertation support decision-makers to reduce the human limitation in performing complicated procurement planning. The developed mathematical models provide a basis to evaluate the selected procurement strategy. This task is nearly impossible with current approaches in the company, as the evaluations require the formulation of

sourcing risks. The stochastic programming approach shows better financial results comparing to deterministic planning, with low variability in mitigating the impact of risks.

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To my loved ones…my wife and son…my parents and brothers

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Foreword

This thesis is prepared as an article insertion thesis comprising five chapters starting with the introduction and ending with a conclusion. Chapters 1, 2 and 3 regroup accepted and submitted articles. Here is the information on the mentioned articles:

1. A. Rahimi, M. Rönnqvist, L. Lebel, J.F. Audy, "An optimization model for selecting wood supply contracts." Canadian Journal of Forest Research 50.4 (2020): 399-412.

2. A. Rahimi, M. Rönnqvist, L. Lebel, J.F. Audy, “Evaluation of Wood Supply Procurement Planning in the Presence of Sourcing Risks”, revised on 16 March 2020, International Transactions in Operational Research.

3. A. Rahimi, M. Rönnqvist, L. Lebel, J.F. Audy, “Selecting Wood Supply Contracts under Uncertainty using Stochastic Programming”, revised on 08 April 2020, Informational Systems and Operations Research.

Furthermore, in addition to the above-mentioned papers, the results of this work were presented by me at the following conferences:

- Rahimi, M. Rönnqvist, L. Lebel, J.F. Audy, “Planification des processus d’approvisionnements en présence de risque”, Comité de suivi et d'orientation (CSO)-Université Laval, March 28, 2017, Quebec, Canada.

- Rahimi, M. Rönnqvist, L. Lebel, J.F. Audy, “Prise en compte du risque pour le développement d'une stratégie d‘approvisionnement en bois”, Expo conference, 2017, Quebec, Canada.

- Rahimi, M. Rönnqvist, L. Lebel, J.F. Audy, “Wood procurement planning under sourcing uncertainties”, 21st Conference of the International Federation of Operational Research Society, July 17-21, 2017, Quebec, Canada.

- Rahimi, M. Rönnqvist, L. Lebel, J.F. Audy, “Evaluation of wood procurement plan under sourcing uncertainties”, Optimization Days, May 7-9, 2018, Quebec, Canada.

- Rahimi, M. Rönnqvist, L. Lebel, J.F. Audy, “Wood procurement planning under sourcing uncertainties”, CIRRELT conference, May 10, 2018, Quebec, Canada.

- Rahimi, M. Rönnqvist, L. Lebel, J.F. Audy, “sélection du portefeuille des sources d’approvisionnement pour une entreprise de pâtes et papiers”, Expo Conference, Jan 29, 2019, Quebec, Canada.

Introduction

Procurement operations for a pulp and paper company (PPC) involve activities to provide wood supply for the production units. The wood procurement in Quebec accounts for an important portion of total cost in the PPC supply chain, between 30% (Domtar 2017) and 50% (Sfeir et al. 2019). Planning for procurement operations is usually performed through contracts. The selected set of supply contracts provides the monthly wood supply deliveries for the planning horizon, called the "forecast plan". Procurement decision-makers seek a forecast plan to minimize procurement costs.

Production at PPCs requires continuous wood supply to avoid shutdowns related to the lack of material. To ensure the availability of wood supply, procurement managers engage in contracts with suppliers for usually one year. As a result, an annual forecast plan is determined to secure sufficient wood supply. In the presence of sourcing risks inherent to the operations of procurement, it is unlikely that the execution of real deliveries conforms to the schedule of the forecast plan. The variations between the characteristics of real and forecasted deliveries lead to re-adjustments in the operations. Additional, often more expensive, contracts might be required to compensate for the lack of wood supply, while extra deliveries may result in higher inventory than the target level. Managing the re-adjustments, as well as finding the proper mitigation strategy is challenging, time consuming, and requires the review of a large set of available options. Therefore, it is important for procurement decision-makers to specify a procurement plan that mitigates the impact of sourcing risks with the least cost.

Traditionally, holding a minimum level of inventory (safety stock) has been a common strategy practiced by PPC managers to mitigate the risk of shortage (Carlsson et al. 2014). In our case, however, a target level of inventory is determined intuitionally based on the historical data of sourcing risks and the duration of their impact. The decision-makers opt for the target level to monitor the maximum upward and downward variations from the target level. The maximum downward variation from the target level corresponds to the safety stock level. In the presence of cyclical deliveries, the target level and allowable variations in each period differ accordingly. In our case, it is determined to fulfill the fiber demand by the production unit between one or two months.

In addition, acquiring a large number of contracts with distinct suppliers is a common strategy for a PPC to share the supplier-related risks (Merzifonluoglu 2017) such as supplier bankruptcy, delayed deliveries or equipment breakdown (Sawik 2011). To ensure lowering risks, decision-makers typically dedicate a portion of the wood fiber demand to each supplier, creating a portfolio of suppliers. The advantage of having a portfolio is to avoid the allocation of large portions of the supply to a few suppliers. An exclusive partnership with a supplier necessitates a significantly higher reserved capacity from that supplier compared to multiple sourcing (Serel et al. 2001). The problem is the optimal determination of the wood supply allocation to suppliers.

In selecting the best contracts, several characteristics have to be considered such as the schedule of deliveries, volume in each delivery, the price per unit of delivery, and volume flexibility. Based on the characteristics, different types of contracts have emerged to satisfy the transaction requirements between buyers and sellers. Some of the most common types were described by Lienhoop and Brouwer (2015) as regular, flexible and option.

In Hellion (2013) regular contracts are modeled by fixed price, discount, and fixed duration contracts. For portfolios with regular fixed characteristics, a lack of flexibility was the main issue addressed by Martel and Klibi (2016). As a result, in mitigating the risk of expensive purchases, the risk of extra inventory may increase. Thus, adding flexibility to contracts can be an efficient way to address this problem (Martínez-de-Albéniz and Simchi-Levi 2005). Flexible contracts allow the buyer to change the order level with a usually higher unit cost than fixed contracts (Blanco et al. 2018). Options contracts give the opportunity to the buyer to pay a small fraction of a contract up-front and in return reserves the capacity from the supplier up to a certain level (Bansal et al. 2007). In this way, when necessary, the buyer can pay to receive extra volume up to the option level. This will prevent unnecessary inventory costs for the buyer. It was demonstrated by Peleg et al. (2009) that under various conditions a trade-off between contracts of different duration should be favorable and no specific types of contracts dominate others.

In addition to different types of contracts, suppliers can be organized also in different groups where the characteristics of each group have a direct impact on the characteristics of their contracts. A supplier group is characterized by the common business status of its suppliers, which is determined based on their working environments, such as forestland ownership or the assortment they supply for PPC. Assortments are different tree segments sorted based on the requirements of forest industries and the difference in species, dimension, and quality (Fuente et al. 2017) (e.g., softwood wood chips or hardwood pulp logs). Suppliers' business status determines their relationship with other companies (Drolet and LeBel 2010). For example, contracts with some supplier groups tend to be less flexible, while the business status of other groups may allow for contracts that are more flexible.

Considering the aforementioned aspects of the wood supply procurement, a typical PPC uses a manual planning approach. Manual planning has limitations to consider all details related to large procurement operations. The necessity of developing tailor-made decision support tools for the PPC is addressed by Carlsson et al. (2009). Considering the characteristics of each contract, in addition to supplier groups, procurement planning demands extreme efforts and attention when using the manual approach. Nevertheless, no evaluation can be made to ensure the efficiency of the selected plan, since the comparison of different sourcing options is too complicated for human perceptions. In addition, dealing with such real-world applications with inherent risks and uncertainties could result in erroneous decisions. The size of the problem becomes too large to analyze the performance of the plan considering future realizations of random events.

In order to address the aforementioned planning complexities and provide an advanced analytical approach to decrease the errors during manual planning, three main research questions are raised:

1. What is the optimal procurement plan for the PPC by selecting a portfolio of sourcing contracts?
2. What is the impact of sourcing risks on procurement operations when executing the forecast plan?
3. What is the procurement plan that is expected to have minimum costs when executed in presence of sourcing risks?

Considering these questions, we develop tools in three projects that support the decision-making process. These tools lead to facilitate analyzing the sourcing options and provide insights into the selection of optimal portfolio and its performance in a relatively short time. In this regard, mathematical modeling as a powerful tool enables the optimal solution for such a complex problem in deterministic assumptions and in the presence of uncertainty (Shishegar, et al. 2019).

The case study used in these projects is inspired by a real PPC located in Quebec, Canada. The PPC has one production mill supplied by hundreds of suppliers. Procurement operations in this company are planned based on data and charts in Excel spreadsheets. Decisions are taken based on the experience of decision-makers without using any advanced analytical tool. In addition, risks are integrated intuitively into the planning, which is a complicated task to be done in the presence of thousands of sourcing options. Currently, the target inventory level is the main mitigation tool at the company. In this Ph.D. thesis, the main objective is to provide decision support tools to suggest a reliable procurement plan in the presence of a constraint for maximum variations from the target stock level. In order to fulfill this objective, three projects are defined. The first project is the development of a mathematical model based on the current operations in the procurement department of the PPC. This provides a standard and flexible tool for performing the second project, in which a Monte Carlo simulation approach is adapted to evaluate the performance of the proposed plan by the deterministic model. In the third project, the proposition of a reliable plan based on stochastic programming is the objective.

Problem description

Procurement operations include wood supply purchases, harvesting, transportation, and reception at the mill (Uusitalo and Pearson 2010). By outsourcing some of these operations, overhead costs are transferred from direct labor supervision to management of the outsourcing contracts (Meixell et al. 2014). Management of these costs is important since they account for a large portion of the total cost to produce pulp and paper. For a PPC in India, it can reach 57% of the total cost (Jain 2016) while for our case in Canada, it is nearly 30% (Domtar 2017). Considering the size of the operations, their management is a difficult task and any variations from the procurement plan could become expensive due to costs related to either the lack of wood supply or extra inventory volume.

Outsourcing has also resulted in a new business interface for the wood supply chain and has created a customer-supplier relation between PPC and its suppliers. It created new challenges, as the suppliers were no longer under PPC’s direct control. For example, it has been addressed that a majority of small or medium-sized suppliers pay little attention to strategic planning (Wang et al. 2011). This is in contrast with the PPCs’ procurement planning for continuous raw material, months in advance. Besides, the perception of suppliers from their business status variates and this might complicate the customer-supplier integration (Drolet and LeBel 2010).

To fulfill the demand of the production process, hundreds of suppliers are involved, each with one or more contracts in different types, comprising thousands of available sourcing options. This creates a complex procurement network for the PPC, with thousands of deliveries performed on a monthly basis. Deliveries are also planned according to the inventory target level of the mill’s woodyard and remote woodyards (satellite stockpiles). Inventory target levels are used to mitigate the risk of shortage and they are determined by the procurement manager based on historical data, to mitigate procurement risks.

Suppliers-related risks such as delayed deliveries and risks originated from external sources such as the start of the thawing are inherent to wood procurement operations. Because of these risks, characteristics of suppliers' deliveries may be different from forecasted deliveries in the contract or their deliveries may not continue from a time period completely.

Although contracts create a commitment between suppliers and the PPC, market variations may affect the operations. Suppliers may delay in delivering the required volume or revise their production of wood. In such situations, suppliers deliver the wood supply to other better-paying clients to maximize their profit. Suppliers may not be able to fulfill their contracts due to reasons such as fire or infestation in their harvesting zones. Although with low probability, the impact of such events can be large. The conditions in the market have forced many suppliers to shut down their operations, consequently breaching the contract with the PPC. For example, several closures occurred around 2008 when international market changes forced companies to lay off shifts or close their operations (Pinkerton and Benner 2013).

The spring thaw for regions subject to winter season like our case, is when the frozen ground starts to melt. This refers to the impact of warmer temperatures on road structure after the winter season. During thawing, ice melts, water permeate the road infrastructure, lowering the bearing capacity. The forest industries during this period face limitations on the harvesting and transportation and therefore, a reduction in its capacity to produce and deliver wood fiber. A similar effect is observed in countries with long rain seasons, where heavy rain causes instability in the forest road structure. The challenge is to plan for these periods, given that their beginning is uncertain. The intensity of procurement operations is usually increased before the forecasted start of these periods to harvest and stock sufficient wood supply and hedge against the risk of shortage during these periods. This strategy may cause high inventory costs, if the start date is delayed, or force expensive mitigation actions to avoid shortages, in case of an early thawing. High costs are due to the mitigation initiatives that the company must take to adapt the plan. Therefore, when thawing is delayed, the inventory level should remain higher for a longer period compared to the forecast. In the occurrence of an early thawing, the inventory level has not still reached the target level and the early decrease in deliveries requires additional purchases of wood supply or re-negotiating the actual contracts to avoid shortage.

In the eventuality of unwanted events, a large portfolio of suppliers can provide opportunities for necessary modifications in the order volume. This is referred to as a portfolio strategy practiced by the procurement of the PPC. The risk is perceived to be lower with such a portfolio, although this may come at a relatively higher cost than the sole sourcing strategy. It is necessary to evaluate the trade-off between the cost and the reliability that is provided by the selected portfolio.

In addition to purchasing wood assortments, the procurement of a PPC may sell some assortments. The assortment is sold to its suppliers or other clients in the market. The assortments are harvested from the forestland of the PPC and is more profitable to be sold rather than being consumed by the mill. Therefore, the procurement of the PPC makes profits by selling them.

Some suppliers also have the possibility to provide their wood supply in the spot market. The availability of wood supply in the spot market supports the mitigation of the supply shortage, however, imposing a risk of expensive purchases. Typically, decision-makers are looking after a reliable procurement plan to avoid such purchases.

Figure 0-1 provides a schematic description of the context of this study. In this figure, numerous production mills are shown, served by suppliers and woodyards. Each supplier or woodyard can serve more than one mill. The network of suppliers delivers wood supply either directly to the mills or to the woodyards. As shown in the figure, supplier-related risks, as well as the risk related to the start of the spring thaw are considered to have an impact on the volume of deliveries from suppliers to mills and woodyards, without impact on deliveries from woodyard to mills.

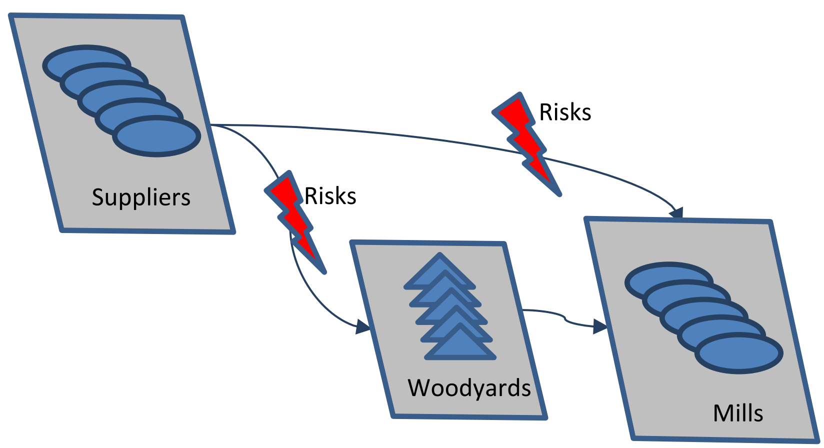

Figure 0- 1. The illustration of the network of the procurement considered in our study

Case study

The current case study is based on a PPC in Quebec, Canada. The procurement plan is determined for one year ahead with monthly reviews and updates on the status of the inventory and wood flows. In our case, the PPC includes one production mill (a fully integrated pulp and paper mill) with two internal wood yards, one for logs and the other for chips. Logs are processed into chips by chippers at the mill and transferred to the internal wood chips yard. It also benefits from several available external woodyards (terminals) for pulp logs. Although the number of available external woodyards may vary, two of them are included in our case, to highlight their availability. External woodyards are operated jointly with suppliers. They are situated between suppliers (harvesting areas) and the production mill. The main advantage is to decrease transportation costs by using higher capacity trucks from forest to woodyards and also holding inventory for delivering during the periods with low deliveries from suppliers. However, the financial impact of using external woodyards should be analyzed in integrity with other procurement activities.

Having hundreds of suppliers, the PPC has categorized them into five main groups; pulp log from PPC's forest land, pulp log from the public forest, pulp log from forest association of domestic wood producers, pulp log from private suppliers, and wood chips from private suppliers. Our developed model can integrate individual suppliers or groups of suppliers, each with specific types of contracts. For clarity and better representing the decision-making process observed in our case study, procurement planning is formulated considering groups of suppliers. Each group has in average 300 contracts available (total number of contracts is 1500), half being fixed and half being flexible contracts. In Figure 0-2, groups and their deliveries are illustrated.

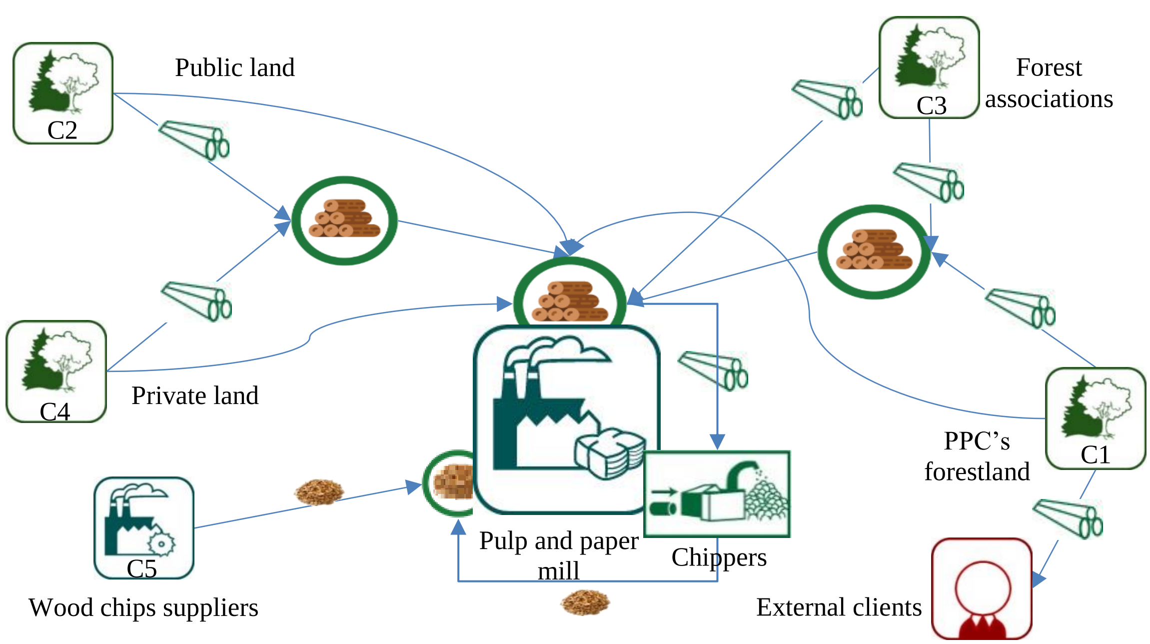

Figure 0- 2.The wood supply flow from groups of suppliers in the case study

As shown in the figure, pulp logs from suppliers are either directly delivered to the internal woodyard or indirectly through external woodyards. Wood chips are delivered to the wood chips yard at the mill, added to the chips produced by chippers. Each group is described depending on its landownership or type of assortment delivered to the mill. Below the description of each group of suppliers is followed.

1. *Pulp log from PPC's forest land (C_1):*

This category includes the forest contractors working on the PPC's private forestland. These are strategic and long-term contractors with fixed and flexible contracts. These suppliers provide relatively high flexibility in deliveries as the land they operate on is owned by the PPC. They continuously exchange information with the PPC and can adapt their production.

2. *Pulp log from the public forest(C_2):*

This category includes suppliers working on public forests. In addition, the PPC has its own share of the public forest through timber licenses (TL). Contracts are established with contractors working on PPC's TL or with other suppliers holding their own TLs. More information on this organizational approach can be found in (Direction de la gestion des stocks ligneux 2016).

3. *Pulp log from forest association of domestic wood producers(C_3):*

This category includes purchases from forest associations of private wood producers in Quebec (Foretprivee.ca 2019). A forest association is an aggregation of private forest landowners. The forest association organizes the process of selling and buying wood supply and is the sole negotiating agent for its members.

4. *Pulp log from private suppliers (C_4):*

This category is associated with purchases from private suppliers, mainly located outside of Quebec in the USA and neighboring Canadian provinces such as Ontario. Some suppliers that are located in Quebec (without being represented by forest associations) include individuals, families, organizations, First Nations groups or corporations.

5. *Wood chips from private suppliers (C_5):*

This category includes wood chip purchases from sawmills and chip producers. Wood chips are moved to the PPC with different transportation modes than pulp logs. In general, approximately 70% of the wood chips used for a PPC production process in Quebec are produced by sawmills (Grubıi et al. 2019).

Different contracts are defined for each group of suppliers, as shown in Table 0-1. In addition to traditional contracts with fixed characteristics, flexible and option contracts are included. The three mentioned types can be categorized as being short-term or long-term, and exclusive. Therefore, types of contracts are defined collectively, meaning that a specific contract can be categorized for example as an exclusive long-term fixed contract.

Table 0- 1. Types of contracts

Contract types	Definition
Exclusive	Contracts with contractors working on PPC's forestland or with suppliers located near the PPC
Regular long-term	Contracts that are scheduled to deliver during one year
Regular Short-Term	Contracts with a delivery schedule of a maximum of six months
Fixed	Traditional contracts with fixed order volume at each given period
Option	Contracts with the possibility to reserve supply capacity of supplier for later periods
Flexible	Contracts which have a certain level of flexibility, enabling upward or downward modifications in the order volume

Exclusive contracts are solely between the PPC and the associated supplier group. They are more reliable in providing the order volume since they do not impose risks related to market price variations. The PPC also has direct control over the operations of exclusive suppliers. Short-term contracts are usually more expensive, but with more volume flexibility. They usually cover purchases outside of Quebec, e.g. Ontario or the US. To hedge against price and exchange rate variations.

The characteristics of contracts are determined based on the group of suppliers and the type of contract, as defined in Table 0-2. Contract characteristics are negotiated beforehand and they are available as potential sourcing options. The procurement department of PPC has the discretion to select among them to minimize costs with respect to improving the reliability. Reliability in different applications has similar definition which is the probability of maintaning the forecasted state for system (Tavakkoli-Moghaddam, et al. 2016).

Table 0- 2. Contract characteristics

Characteristic	Definition
Nominal volume	Agreed volume written in the contract stated in dry metric tonne (DMT)
Volume flexibility	The negotiated ratio of the nominal volume to determine the maximum allowable upward and downward variations for order volume (0 for fixed contracts)
Assortment	Wood chips or pulp logs, from either softwood or hardwood species
Wood supply unit price	Cost per volume unit of the wood assortment for each time period
One-time fixed cost	The cost associated with initiating the contract
Start, end	The first and the last period of deliveries
Schedule	The detailed plan for volume of assortment to be delivered in each period
Origin, destination	Respectively: where the wood supply has been produced and the location it is being delivered

The unit price of wood supply includes material, labor, overhead, logistics charges and profits of the supplier (Meixell et al. 2014). Depending on the contract, it may be the same or not in each period. The fixed cost of a contract is usually higher for flexible contracts and includes the costs of necessary equipment, permits, or facilities that have to be established for the execution of its deliveries. The destinations include three pulp log yards and one wood chip yard. Wood chip yard, as well as one pulp log yard, are located at the production mill. The origin is important, especially for identifying the associated risks, such as the beginning of thawing for different geographical zones. Data related to the determination of these characteristics are provided separately in the following chapters of the thesis, depending on the required details.

Since this study focuses on the procurement department of the PPC, the starting point is at the beginning of the financial year, when the procurement department receives the demand for wood supply from the production department. Each group of suppliers is expected to have a total volume of deliveries between a minimum and a maximum limit, to emphasize on maintaining a diverse supply portfolio.

Literature review

At first, some related reviews and articles on pulp and paper related studies and the procurement process of PPC are provided. Then, sourcing strategies with contract and supplier selection are reviewed. Next, risk management and the existing frameworks in different applications, as well as in forestry will be reviewed. In all cases, developing optimization models is shown to be benefitial to achieve an optimal system performance with respect to the constraints (Shishegar, et al. 2018).

Pulp and paper value chain

One of the first pulp and paper supply chain problems was addressed by Benders et al. (1981) which contributed to the design of production/distribution networks by utilizing a mathematical programming model to suggest network design decisions. Decisions in the deterministic approach concerned continuous production processes in this industry. Since then, many studies have worked in detail to manage PPC's operations.

Regarding the position of PPC in the forest value chain, Figure 0-3 shows the relationship between PPC and other industries. The wood flow starts from harvest areas and goes to terminals, sawmills, pulp mills, and panel mills. The lower part of the tree has a higher value and it is used typically for sawmill operations. The upper part, with characteristic unfit for the sawmill process, is sent to pulp and paper mills.

In addition to final products, sawmills produce co-products and by-products. Co-products are demand-driven, while by-products are usually produced from primary processing and usually have a lower market value. In Quebec, a PPC procures a large volume of wood chips from the co-products of sawmill production. Sawmills co-products include approximately 60% of wood chips, 22.5% barks, and 17.5% wood shavings and sawdust (Gouvernement du Québec 2016).

The wood supply in the form of logs or chips is transformed into pulp to produce paper at the pulp mill. The mixture depends on the produced pulp grade or the used manufacturing process. Examples of final products are newsprint, fine paper, and packaging materials. A PPC might own many production mills, each having a specific demand for wood supply (D'Amours et al. 2008).

Pulp and paper production was studied more recently by Alayet et al. (2016) in a supply chain in conjunction with several independent business units. They considered a network including sawmilling operations, pulp and paper production, and energy production. The decision included the harvesting volume of wood and their allocation to business units, as well as stock volume. They illustrated the importance of price, demand, and wood freshness variations in order to increase supply chain benefit. In Ben Daya and Nourelfath (2019), the authors developed a multi-objective optimization model motivated by the integrated biorefinery and the pulp and paper business model. The case study was in Canada. They simultaneously minimized greenhouse gas emissions and maximized the financial value of the integrated model. Economic and environmental such as the cash return on capital invested, the internal return rate, the emission rate, the internal integration rate, and the waste recycling rate were used to compare Pareto optimal investment road-maps.

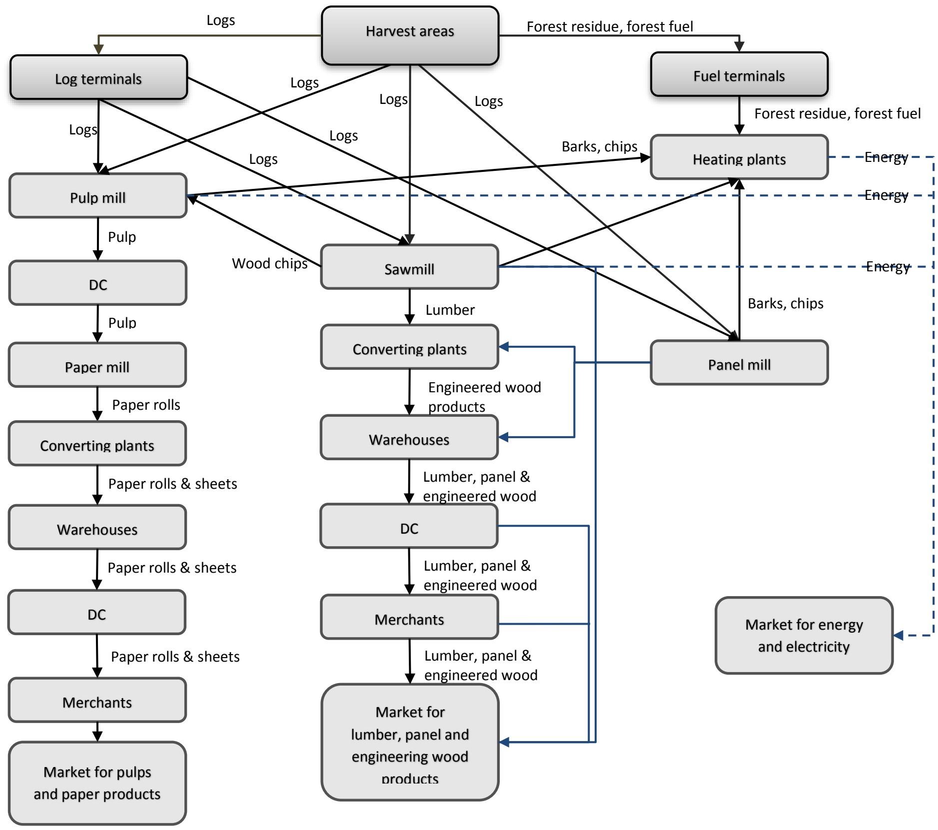

Figure 0- 3. Different supply chains for forest products (D'Amours et al. 2008)

Procurement operations

At the beginning of the procurement planning, before determining the sourcing strategy, details of the available sourcing options are drafted (Tittler et al. 2001). By determining the sourcing strategy among available sources, a wood procurement plan is prepared. In a procurement plan, operational decisions are identified regarding harvesting, inventory handling, and transporting material to mills (Beaudoin et al. 2007). Such decisions determine the harvesting areas for procuring wood fiber, as well as the allocation of wood to each production mill, either a sawmill or a pulp and paper mill or other industries (D'Amours et al. 2008).

In the presence of uncertainty related to the PPCs' procurement operations, Bergman and Löfgren (1991) provided three common strategies practiced by PPC managers. First is to have many supply sources to neutralize the impact of stochastic sources. Second is by holding a minimum level of inventory (safety stock), and use it in case of shortage. The third is to deal with the consequences and to apply mitigation solutions (e.g. spot market purchase, production stoppage…).

The first two use a proactive strategy, while the third one uses a reactive one. In a study by Yin et al. (2002), it is shown that the proper inventory policy has benefits for the company in case of uncertainty. Controlling the level of inventory prevents stock out. In the study by Chopra and Sodhi (2004) benefits of multiple sourcing strategies and controlling supply risks were mentioned. Risks in procurement were introduced by causing fluctuations in the price of deliveries from suppliers or transportation costs. Drivers of these risks were the exchange rate and duration of contracts. In Dulmin and Mininno (2003) and Sarkis et al. (2007), it is addressed that selecting suppliers is the most important task, as it has a high impact on quantity, quality, time and price of purchased material.

Everett et al. (2000) formulated the optimal allocation of suppliers to mill by a mixed-integer programming model. Their proposed model has determined decisions in tactical and strategic levels. The sourcing options consist of pine and eucalyptus logs from several suppliers, chips from sawmills, and recycled papers. Philpott and Everett (2001) presented a stochastic programming model for a PPC for a planning period of ten years. Their stochastic model presented three scenarios for the market forecast, as expected, optimistic, and pessimistic forecasts. However, the size of the problem was too large to achieve optimal results. Nevertheless, the results of the model for the three scenarios showed considerable variability.

Sawik (2013) has developed a decision-support tool for selecting suppliers to respond to customer orders. In that study, the objective function consists of the cost of back-ordered, purchasing and lost orders, to decide the optimal schedule for customer orders. It is concluded that suppliers with high disruption risks hold the lowest share of supply or they are not selected at all.

In a study by Bansal et al. (2007) the problem is defined as selecting both contracts and suppliers for a multinational company. In order to do that, contracts are classified based on characteristics such as their types, prices, durations, and suppliers. Their deterministic model suggested the optimal sourcing strategy by minimizing the costs. In the study by Talluri and Lee (2010), the authors investigated the optimal selection of contracts in manufacturing firms by mixed-integer programming approach. They presented insights to manufacturing managers on choosing the right contracts (short, long or mid-term), in the presence of market price uncertainty, supplier discounts, investment costs, and supplier capacity restrictions. An important conclusion of their study was that the long-term contract strategy might not be superior to short-term strategy. This was also concluded that no strategy systematically dominated others.

Groups of suppliers

Kaufman et al. (2000) proposed a typology based on the collaboration capacity and technology of the suppliers and classified them. Four distinct groups for suppliers were identified in their typology. In the first group, the company and its suppliers have low dependency because switching costs are low. Suppliers in the second group are attractive for the company, as they reduce internal monitoring (administrative) costs. The third group represents suppliers that are mutually dependent on the company, where trust reduces the uncertainty. Finally, in the last group, suppliers are technology-oriented and have weak relations with the company.

Similar to the previously mentioned groups, in Canada, suppliers can be classified into different groups. A large proportion of forestlands is in public ownership. The allocation of timber licenses to private companies is an important decision since it is associated with the uncertainty of supply in those forests (Niquidet and O'Kelly 2010). In British Columbia, a study by Pinkerton and Benner (2013) was conducted to examine the resilience of sawmills in the presence of economic shocks. The authors concluded that more access to publicly owned timber supply is required to increase the benefit. In Quebec, it was decided to allocate 25% of government-owned lands to be sold through an auction system, while the rest is allocated through long-term contracts (Gouvernement du Québec 2013). More information about different groups of suppliers can be found in Lehoux et al. (2012). The authors have mentioned forest business units to address different stakeholders in providing wood products, such as private landowners, forest contractors, forest companies, and forest management groups.

Supply contracts

Traditionally, long-term contracts have been used to eliminate the risk of price variations for the procurement operations (Martínez-de-Albéniz and Simchi-Levi 2005). Long-term contracts are also called forward buy contracts or fixed commitment contracts in the literature. In these contracts, characteristics are fixed, i.e. fixed volume and fixed price for the supply. Therefore, the buyer is not exposed to the risk of price variations. However, the risk of high inventory levels is more likely in this case, as well as the risk of shortage, due to the inability to modify the contract.

Option contracts were introduced to reduce the above-mentioned risks. In these contracts, the buyer pre-pays a fraction of the total value of the contract up-front while reserving the capacity of a supplier up to a certain level (Bansal et al. 2007). The capacity is usable in case the buyer pays an additional price. The average unit price of such contracts is typically higher than a traditional long-term contract.

Option contracts shift inventory risks from the buyer to the supplier, since the supplier should develop the flexibility in its operations to provide the buyer with the options. Thus, a different contract has been emerged to share risk between suppliers and buyers, called flexible contracts. In these contracts, the amount of supply is fixed but have a possibility of modification at the time of order, by a given percentage. As described, flexible contracts are referred to as a combination of long-term and options contracts (Martínez-de-Albéniz and Simchi-Levi 2005).

In some PPCs, a clause is added to contracts as "right of first refusal". In these contracts, the supplier holds the ability to seek bids to maximize its return. In this case, the PPC can decide whether to match or exceed the bid. Otherwise, this contract gives the right to suppliers to sell the wood in the spot market (Behavior et al. 2009). Roise (2016) has reviewed the usage of long-term contracts in the forest industry. Interviews with professionals and an extensive literature review were done. It was concluded that the landowners could benefit by adding the right of first refusal clause to certain silvicultural and harvesting activities, to reduce concerns about losing control over their land. However, the usage of this phrase is in tight connection to market variations and spot market price volatility, which is not considered in our study.

Another contract, which is widely used, is the quantity discount contract. It provides price incentives for quantities above a certain level to maximize the profit of suppliers and provide economies of scale to the buyer. Discount contracts are most effective in coordinating different stakeholders in supply chains (Hezarkhani and Kubiak 2010).

Risk and uncertainty

Mason and Mitroff (1973) have categorized problems as being either structured or unstructured. In structured problems, considering the relationships between an event and its environment, all the outcomes are known based on three forms: certainty (known deterministic relationship), risk (probabilistic and known relationships) or uncertainty (probabilities are not known but the possible states of the relationship are known), while in unstructured problems absolutely no information is available. Structured problems are repetitive in nature and do not require subjective inputs, while all or some terms in unstructured problems must be extracted by extensive analysis based on opinions and judgments of experts.

Miller (1977) stated, "Risk occurs where the future is not known, but the probability distribution of possible futures is known". In Kersten et al. (2006) it was denoted that "risk is the damage - assessed by its probability of occurrence - that is caused by an event within a company, its supply chain or its environment". These definitions suggest that the term "risk" can be adapted for an event in the future that is not known in advance, but where its occurrence can be estimated with a probability. The more risks are involved in one domain, the more volatile it would be the profitability. Three tasks have been proposed for risk mitigation by Li (2004). First, to quantify the risk into numerical data, then design certain tools and measures to control it, and at last, since as ideal can never be reached, an acceptable risk level be justified.

However, as stated by Gadow (2000), “uncertainty” represents known expected damage from a risk. For example, for a buyer, there is a probability that its supplier delivers less supply than the order amount. In the case where the probability and variation from the order volume is known, the delivery volume becomes an uncertain parameter and there is a risk of a supply shortage.

A few studies have incorporated uncertainty into supply chain optimization of forest industries such as biomass power plants (Shabani and Sowlati 2016a), pulp mill (Shahi et al. 2017), wood remanufacturing mill (Rafiei et al. 2015), chemical industries (Gupta and Maranas 2003), and sawmill (Kazemi Zanjani et al. 2013).

In the domain of forestry, Brumelle et al. (1990) provide a framework to recognize risks, based on definitions by Mason and Mitroff (1973). They were the first to categorize sourcing risks as production, timber prices, fire, insects and salvage prices in forest management and silvicultural investment. Risks affecting energy efficiency in the Swedish pulp and paper industry were recognized by Thollander and Ottosson (2008) as technical risks such as the risk of production disruptions. They used questionnaires to determine the ranking of the risk elements. The results showed that not all risks are market-related and thus firm-specific risks can be more important such as lack of staff awareness or long decision processes.

In Cunico and Vecchietti (2015), the authors have considered uncertainty in the characteristics of deliveries from suppliers. The selection of suppliers and contract types was performed by including decisions related to the purchase quantities involved and the stock of materials. In addition, the uncertainty in the supply was represented as an interval for the upper and the lower limit of the delivery volume. In their study, there was no distinction made between different sourcing risks causing short-term or long-term variations in the supply.

Common solution methods

Traditionally, deterministic models including safety stock at distribution centers are considered to take into account uncertainty. The problem is to decide the level of the stock in each distribution center, while its advantage is the small size of the planning problem. By identification of the sources of data, a suitable method or hybrid of methods can be decided. In addition to safety stock, other solution methods have been proposed such as stochastic optimization (Birge and Louveaux 2011) and robust optimization approach (Mulvey et al. 1995).

Robust optimization

Using Robust Optimization (RO) is common when the focus is on obtaining a solution that will be feasible for any realization taken by the unknown coefficients within a small, “realistic” set, called the uncertainty set (Gabrel et al. 2012). Uncertainty set is centered around the nominal values of the uncertain parameters. The approach in RO is to make the worst-case solution as good as possible. Hence, any realization of the uncertain parameters is feasible in a robust solution (Bertsimas, 2010 and Ben-tal et al. 2009). The deficiency of RO lies in over-conservative (Thiele 2010) and costly solutions (Bredström et al. 2013). These drawbacks can be addressed by adding practical considerations in the uncertainty description (Carlsson et al. 2014). For achieving this purpose, historical information and characteristics of uncertain parameters in practice are entered into the model, such as setting the total uncertainty over a certain period to zero.

Stochastic programming

Stochastic Programming (SP) approach is based on the knowledge about distributions of the uncertain data or probable scenarios. Solutions from the SP approach are expected to be optimal on average.

Sawik (2014) formulated a mixed-integer SP to integrate supplier selection decisions with customer order scheduling. Disruption risk was considered with either a single or a dual sourcing strategy. Risks were considered as affecting individual suppliers or a set of suppliers in the same region at once. Local suppliers were more reliable but more expensive than foreign suppliers, who were more exposed to risks. It was concluded that the supplier reliability is the key factor for their selection, whether in maximizing service level or minimizing costs.

A more general model for wood procurement decisions is presented by Beaudoin et al. (2007) in the form of mixed-integer SP. Two types of decision variables were presented, first-stage and second-stage. The planner is responsible for instantiating first-stage variables, such as the binary decision on whether harvesting a block and if so, the proportion of the harvested block. Second-stage variables coordinate tactical decisions with operational decisions, such as flow variables. Their method fulfills the shortcomings of the manual planning process, mainly in proposing alternative plans and evaluating their performances under uncertainty. The authors used Monte Carlo simulation to generate scenarios randomly for the problem based on the key factors of uncertainty, such as standing inventory and production capacity.

Simulation approach

Besides solution approaches, evaluations of the solution in the presence of uncertainty is also very well addressed in the literature. Usually, simulation is used to evaluate the performance of the plan. In a study by LeBel and Carruth (1997), they analyzed the cost of inventory in the presence of variability in procuring wood supply for a mill. Uncertainty was related to the failure in loggers operations and the recovery time, mainly due to weather conditions. After the simulation, metrics were presented on the production and capacity utilization of loggers, inventory levels, and production of by-products. It was concluded that setting two days buffer of production between trucking and harvesting decreases the risk of shortage at the mill significantly. Through this evaluation, the company was able to save time and money on avoiding expensive trials in practice.

Production planning has been coupled with an inventory management problem in the work by Shahi et al. (2017). They considered a PPC in Northern Ontario by including demand and supply uncertainty using a simulation-optimization approach. The optimization model aimed at maximizing the net annual profit of the pulp mill. It was concluded that merchandizing yards could absorb supply and demand shocks. Therefore, yards could improve customer satisfaction by ensuring the continuous production of the pulp mill.

Contributions

Three projects are defined in this Ph.D. thesis. Each project is presented briefly below as there is a full paper on each of them.

Chapter 1: An Optimization Model for Selecting Wood Supply Contracts

The procurement planning of a PPC in the presence of different sourcing contracts is a large and complex problem. Characteristics of contracts and suppliers, in addition to practical constraints such as portfolio strategy limits, inventory target levels, and capacities of woodyards are difficult to be consider for manual planning approaches. According to the literature review, no work has been found to develop an analytical model for addressing such complexities of the PPC procurement process. Thus, as the first project of this Ph.D. thesis, a novel mixed-integer linear programming model is developed. The model takes into account the procurement network including suppliers, woodyards and a production mill. This project contributes to the literature by including different types and characteristics for contracts among multiple groups of suppliers. Decisions concern the selection of contracts with groups of suppliers, external woodyards openings, the flow of material and inventory level of woodyards, and lastly the chipping volume in each period. The deterministic model minimizes the total cost of procurement and select the best set of contracts. Evaluations were made for this project by using sensitivity analysis on different sets of contracts (regarding flexibility) and portfolio limits for groups of suppliers.

Chapter 2: Evaluation of Wood Supply Procurement Planning in the Presence of Sourcing Risks

Although a deterministic model provides an optimal plan with minimization of costs, it is complicated to evaluate the performance of the proposed plan from the deterministic model in the presence of risks. Sourcing risks are inherent to the procurement operations of the PPC. To propose a better evaluation of the portfolio strategy and measuring the potential impact of sourcing risks the second project is performed. This project is based on a simulation of the procurement operations. Several random events are generated using a Monte Carlo approach. The performance of the plan in the presence of different problem setting is evaluated by monitoring the statistical distribution of results. In practice, the PPC can benefit from the findings to test the selected procurement plan beforehand, avoiding high costs of the wait-and-see approach or time-consuming evaluations of individual contracts and suppliers. Instead, the PPC can update any changes or new information into the selected portfolio and generate the output of the simulation approach in terms of expected values and variations. This project contributes to the academic literature by providing a Monte Carlo simulation approach of the procurement operations embedded in an optimization model in the presence of contract unreliability, contract breach, and the stochastic start of the thawing.

Chapter 3: Selecting Wood Supply Contracts under Uncertainty using Stochastic Programming

There is a lack of an analytical approach to propose a procurement plan taking into account sourcing risks. Previous projects do not optimize the performance of the proposed plan in consideration of sourcing risks. Developing a decision support tool for proposing such a plan is the objective of this study. Sourcing risks and related uncertainties are integrated into the planning before the execution phase. This way fewer modifications and less total cost are expected after the execution of the proposed plan. The resulted plan from the SP approach will have an average optimal performance in the presence of different realizations of risks. To test the efficiency of the plan it is compared with the proposed plan by the deterministic model. Based on the developed scenarios, the solution from each approach is generated for individual scenarios. Then, the average value of objective function and variation of results for all scenarios are compared. The SP model is the first to integrate the sourcing risks in the context of contract selection for procurement operations of a PPC. A two-stage approach is used to divide decision variables. First stage variables are selected contracts in the first period and woodyards opening decisions, while the decision for selecting future contracts as well as flow, inventory and chipping volume is second stage and dependent on the realization of different scenarios. This project contributes to the gap of an SP model for PPC procurement operations. In practice, the consideration of uncertainty and sourcing risks during the planning was nearly impossible and no advanced analytical tool was available. By the use of the SP model, the decision-maker can save on average $1 million dollars comparing to deterministic planning.

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Chapter 1 An Optimization Model for Selecting Wood Supply Contracts

Résumé

L'approvisionnement des entreprises forestières avec des usines de pâtes et papiers vise à garantir qu'un volume suffisant du bois entre dans le processus de production. De nombreux fournisseurs et types de contrats sont disponibles; Cependant, leur sélection est une décision complexe pour les responsables des achats. De plus, les gestionnaires divisent généralement leur demande en bois à plusieurs groupes de fournisseurs, ce qu'on appelle une stratégie de portefeuille. Malgré la documentation disponible sur la sélection des contrats, la prise en compte des types de contrats et de leurs caractéristiques n'a pas été abordée dans la literature pour tel processus d'approvisionnement complexe. Dans cette étude, un modèle d'optimisation à nombres entiers est proposé pour sélectionner au mieux les contrats d'achat de pâtes et papiers. Le défi était de planifier les livraisons à chaque période afin de satisfaire la demande de matières premières des usines. Le potentiel de ce modèle est démontré par une étude de cas basée sur les caractéristiques d'une entreprise forestière du Québec, Canada. Une comparaison entre les contrats traditionnels fixes et flexibles est présentée. Différentes stratégies de portefeuille sont également évaluées pour des groupes de fournisseurs afin d'étudier les améliorations potentielles.

Mots-clés: Sélection de Contrat, Approvisionnement, Programmation en Nombres Entiers, Pâtes et Papiers, Stratégie de Portefeuille de Fournisseurs

Abstract

Procurement for forest companies with pulp and paper mills aims to ensure that a sufficient volume of wood supply enters the production process. Numerous suppliers and contract types are available; However, their selection is a complex decision for procurement managers. In addition, managers typically dedicate a portion of their wood fiber demand to each group of suppliers, referred to as a portfolio strategy. Despite the available literature in contract selection, the consideration of contract types and their characteristics have not been addressed for the complex procurement process. In this study, a mixed-integer optimization model is proposed to best select contracts for pulp and paper procurement. The challenge was to plan deliveries in each time period to satisfy the demand of raw material at the mills. The potential of this model is demonstrated with a case study based on characteristics from a forest company in Quebec, Canada. A comparison between traditional fixed and flexible contracts is presented. Different portfolio strategies are also evaluated for groups of suppliers to investigate potential improvements.

Keywords: Contract Selection, Procurement, Mixed-integer Programming, Pulp and Paper, Supplier Portfolio Strategy

1.1 Introduction

Procurement planning for a pulp and paper company (PPC) includes the selection and management of a set of supplier contracts. Many challenges in the relationship between PPC and its suppliers have previously been addressed (Eriksson, 2016). Entering into contracts between suppliers and the PPC support the management of challenges by guarantying the supply for the PPC (Kimmich and Fischbacher, 2016). For a large PPC, hundreds of suppliers, possessing one or several contracts, are available to meet the production demand. Any PPC is interested in establishing the best set of procurement contracts with suppliers to minimize procurement costs (Martínez-de-Albéniz and Simchi-Levi, 2005).

In the forest sector, suppliers operate differently depending on land ownership. The characteristics of a company, based on its working environment, determine its business status and relationship with other companies (Drolet and LeBel, 2010). Each supplier functions according to the regulations surrounding the forest land they own or the land they are working on. In a PPC's own forest land, a common practice in harvesting operations is to sell the extra harvested wood to other clients. This is performed with contractors working under the direct control of the PPC. The revenue from selling extra wood belongs to the procurement department of the PPC. The distribution of multi assortments from the forest has been addressed by Kong et al. (2012). By diversifying the supply sources and implementing a portfolio strategy, a company reduces the impact of risks (Merzifonluoglu, 2017, Shishehgar et al., 2014)) such as supplier bankruptcy, delayed deliveries or equipment breakdown (Sawik, 2011). Having such a diverse portfolio, the allocation of the wood supply to production mills is important to prevent wood supply failure (Paradis et al., 2017). Each supplier, depending on its business status, may be associated with a variety of contracts simultaneously. Thus, it is important that procurement decision-makers consider the selection of contracts among its suppliers respecting the portfolio requirements.

A contract is a binding agreement that states that the seller should provide a volume of a specified product while the buyer should pay for it under agreed terms (Park et al. 2006). Both PPC and its suppliers use contracts as a common tool to maintain procurement operations under control (Sauvageau and Frayret, 2015). Each contract has a set of characteristics including price, flexibility, duration, quality, quantity, terms and conditions, and can be classified into different types such as regular, flexible and options (Lienhoop and Brouwer, 2015).

Fixed contracts are often used in most practical cases. However, there is no possibility of adjusting order levels after entering into contracts (Park et al., 2006). Therefore, option contracts have emerged where a small fraction of a contract is paid in advance and in return, the supplier reserves the capacity for the buyer up to a certain level (Bansal et al., 2007). Flexible contracts allow the buyer to change the order level; However, they are usually more costly than fixed contracts (Blanco et al., 2018).

A typical PPC has a tradition of using manual planning (Carlsson et al., 2009). Considering the characteristics of each contract, in addition to its associated supplier and business status, procurement planning demands extreme efforts and attention for manual approaches. The comparison of different sourcing options for making decisions is too complicated for human perception. The size of the problem becomes too large for analyzing these aspects and testing the efficiency of the selected portfolio. This is due to the inability of evaluating all possible combinations of contracts manually. Therefore, it is not possible to confirm whether the selected portfolio is optimal. Regarding the high costs associated with this process, the precision of the selected supply portfolio is essential.

Analytical approaches are useful in finding an optimal portfolio strategy by saving time and avoiding human errors. Mathematical modeling has been widely used as a powerful tool in the literature and provides an optimal solution in a relatively reasonable amount of time (Troncoso et al., 2015,Abasian et al., 2017, Shishegar et al., 2018 and Tavakkoli-Moghaddam et al., 2016). However, limited studies have integrated different types of contracts into procurement models in forest-related activities. Blanco et al. (2018) recently developed a framework for selecting biomass contracts with a set of 13 potential contracts. They used fixed and flexible contracts for supply in the long term and developed a mathematical model for the biomass contract selection. However, it was found that for a complex network of suppliers for a PPC, a larger set of contracts is needed.

In a study by Feng et al. (2013), the authors decided on the best sourcing contracts for the oriented strand board industry. Several mathematical models were developed in their study to test the efficiency of the integrated sales and operations system compared to the decoupled management of procurement, distribution, production, and sales. The consideration of contracts and structure of the network is similar to our study; however, the focus is mostly on the sales-order part of the planning and less on the procurement. Also, contracts are detailed with a minimum and maximum level for order quantity. In our study different contract types are formulated by fixed, flexible, and option. We also use short term contracts to ensure a good overall mix of contracts. In addition to the order volume, other characteristics of contracts such as the schedule, which reflects the annual procurement planning, are also studied. The schedule determines specific time periods that each contract delivers specific volumes accordingly. Moreover, we include explicit consideration in how to balance and provide a predetermined level of contracts to each of a set of supplier groups. In addition, the simultaneous consideration of different types of suppliers and detailed portfolio constraints for each group are not evaluated in the study by Feng et al. (2013).

In this study, a contract selection mixed-integer programming model is proposed. The proposed model integrates different supplier groups and their preferences related to the portfolio strategy. This is followed by a demonstration of the ability to select contracts in this environment. In allocating wood supply, the PPC has minimum and maximum requirements for each group of suppliers. The selected contracts and their corresponding order volume must respect the portfolio limits, which prevent exclusive partnerships with few groups. The present paper includes a case study of a large size procurement operation with hundreds of contracts and contributes new knowledge to the current literature by:

1. Developing a new contract selection model for wood procurement planning;
2. Embedding characteristics of different groups of suppliers and different types of contracts such as option and flexible;
3. Considering the strategic supply portfolio related to groups of suppliers.

What distinguishes contract selection in this study from typical supply chain optimization models is the focus on contracts and the requirement of more explicit modeling of material flows such as extra wood from PPC's forest land sold in open market, and strategic managerial factors such as constrained portfolio strategy. Three main sets of contracts regarding the flexibility to analyze the impact of this feature on the inventory and procurement costs will be compared. Further analysis concerning the portfolio strategy is performed to understand the impact on costs associated with varying portfolio minimum and maximum limits for each group of suppliers.

In the current study, first, the materials and methods are introduced. In this section, the background of procurement activities is presented. Then, the planning problem is described with the development of its mathematical formulation. The case study is presented at the end of the section. Then, the next two sections provide a presentation of the results and discussion. Finally, concluding remarks are provided and future directions are proposed for the current work.

1.2 Materials and methods

1.2.1. Background to procurement activities

1.2.1.1. Outsourcing of procurement processes

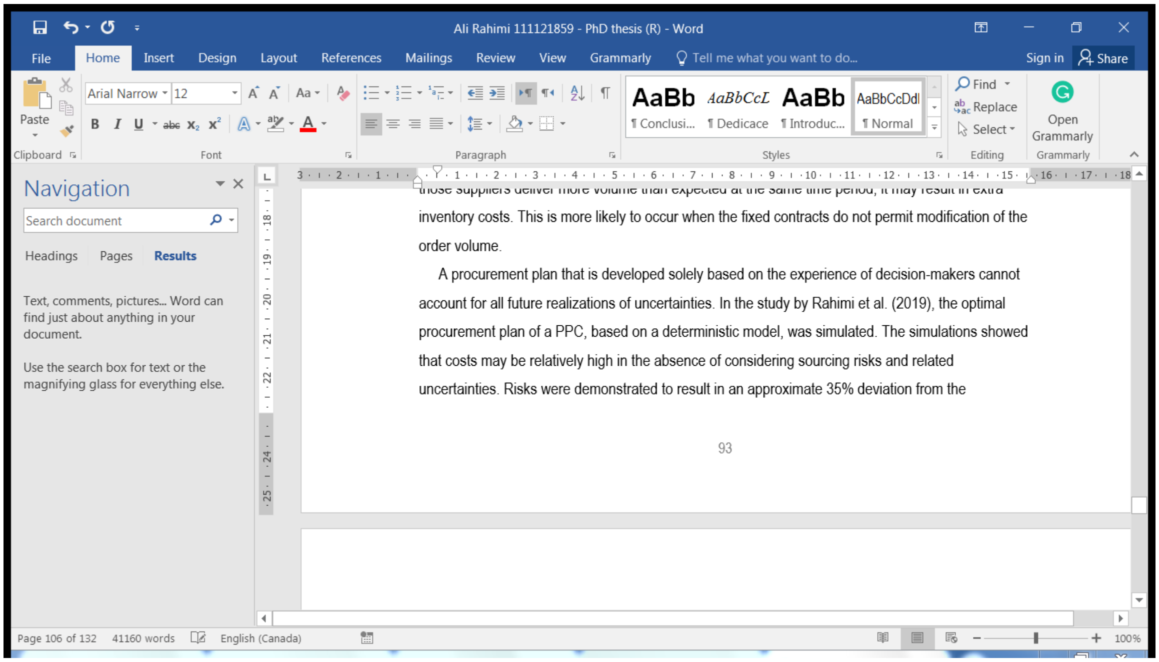
The procurement process in a PPC is defined as "a process where the wood supply as a raw material used by the industry is harvested from the forest and delivered to the mill or another production plant" (Onali, 2017). Typically, procurement operations are outsourced, including the purchase of the wood supply, transportation, and reception at the mill (Uusitalo and Pearson, 2010 and Kelle et al., 2012). By outsourcing procurement operations, overhead costs are transferred from direct labor supervision to management of the outsourcing contracts (Meixell et al. 2014).

The ratio of procurement costs to total costs of production differs for each country and region. In India, it reaches 57% (Jain, 2016) while for Canada, the ratio is somewhere between 30% for our case study (Domtar, 2017), and may rise to 50% in general (Sfeir et al., 2019). Inventory and transportation costs for PPC can reach up to 20% of company sales (Martel et al. 2005). This highlights the importance of our study and the impact of procurement planning on the costs.

Outsourcing has resulted in a new business interface for the wood supply chain and created a customer-supplier relation between PPC and its suppliers. While the outcome was an increase in the efficiency of operations for PPCs to focus more on the production and reduce unnecessary operations management, it created new challenges, as the suppliers were no longer under PPC's direct control. For example, it has been addressed that a majority of small or medium-sized suppliers pay little attention to strategic planning (Wang et al. 2011). This is in contrast to the PPCs' procurement planning for continuous raw material, months in advance. In addition, the perception of suppliers from their business status varies which may complicate customer-supplier integration (Drolet and LeBel, 2010). For example, market variations may affect the decision of suppliers to revise their production of wood to maximize their profit, while this may have a negative impact on PPC's supply.

1.2.1.2. Groups of suppliers

Due to the high diversity among suppliers, PPCs who wish to maximize their alignment with production demand are advised to engage in active supplier selection (Eriksson et al. 2015). Selecting suppliers has a significant impact on quantity, quality, delivery time and cost of purchased material (Dulmin and Mininno, 2003). PPCs often group suppliers based on their business status to facilitate the selection of contracts and portfolio strategies. Characteristics of each group of suppliers directly affect the characteristics of associated contracts respectively.



In general, forest ownership is divided into two categories: public and private (Whiteman et al. 2015). A public owner is a state or a different level of government controlling the land. Throughout the world, approximately 86% of the forests are publicly owned. However, this differs depending on the country. For instance, Russia owns nearly 100% compared to the USA which owns approximately 43% (Available from https://www.pefc.org/forest-issues/who-owns-the-forest). In India, 20% of raw materials for PPCs are supplied from government sources, and the remaining from areas such as farm landowners (Varadha Raj et al., 2014).

Private forest owners may be individuals, families, business entities or other private institutions and communities. Half of the forest land in Sweden is owned by private owners, which is either an individual or many individuals who have come together and jointly manage the land. For the remaining forest lands in Sweden, approximately 25 percent is owned by forest companies, 20 percent by the Swedish state and the rest by other owners such as municipalities and the church (Available from https://www.forestindustries.se/forest-industry/statistics/swedish-forests/).

In Canada, a great proportion of the forest lands is publicly owned although there may be differences between provinces. In Quebec, commercially operated forest zones account for nearly 3.8 billion cubic meters of timber, of which 82.4% belong to the province as public forests. The remaining is owned by a large number of small private woodlot owners and a few of the zones are owned by large industrial owners (Gouvernement du Québec, 2016). Similar to many countries, forest associations exist in different regions of Quebec. Their mission is to perform operations in the interest of members to increase profitability (Available from https://www.foretprivee.ca/a-propos/mission-et-mandats/).

1.2.1.3. Procurement contracts

Contracts that are well designed can enhance the efficiency of the supply chain (Cachon, 2003). They have aided in reducing transaction costs in forestry (Furness-Lindén, 2013). Traditionally, long-term contracts have been the most popular to eliminate price risk. In these contracts, fixed characteristics, such as fixed-price or volume, have been the common practice. The PPC can choose to have a sole long-term supplier to mitigate its risk of purchasing cost (Moreira 2018). Although in this case, the switching cost is high as a result of too much investment in expanding relationships with a single supplier (Mizgier et al. 2017). One example of this occurs in cases where the volume replenishment is required from a spot market with an expensive price. In a study by Talluri and Lee (2010), the authors provided insight on choosing the right contracts (short, long or mid-term). They concluded that not all long-term contracts are favorable for companies, due to various reasons such as high fixed costs.

An important issue with fixed quantity long-term contracts is the risk of extra inventory for the buyer in case the production at the mill(s) is lowered. To reduce the inventory of the buyer, option contracts were introduced (Bansal et al. 2007). In this type of contract, the buyer reserves a certain volume of delivery upfront with a prepayment. This way, the buyer can pay to receive extra volume up to the option level, if necessary. This will prevent unnecessary inventory costs for the buyer. However, the total price paid for this type of contract is higher than the fixed types. Options may offer additional opportunities for the supplier, as orders can be shifted between different customers (Blanco et al., 2018).

To share the inventory risk between buyer and seller, flexible contracts have been defined, where the nominal quantity of order at the time of signature can be different from the actual delivery, up to a certain level (Lian and Deshmukh, 2009). As shown by Martínez-de-Albéniz and Simchi-Levi (2005), flexibility contracts combine long-term and option contract characteristics. Therefore, the correct trade-off between price and flexibility should be decided.

Another classification of procurement contracts based on two categories has been proposed by Lariviere (1999). The first relates to decisions concerning replenishment policies and concentrates on the characteristics of contracts. The focus is on the optimization of the buyer's procurement strategy. The second category relates to coordination strategies and improving the characteristics of contracts to achieve mutual benefits. Revenue sharing contracts (Cachon and Lariviere, 2005) are in this category. We position our problem in the first category.

1.2.1.4. Portfolio strategy

PPCs are interested in multiple sourcing strategies and controlling supply risks (Chopra and Sodhi, 2004). Previously, Peleg et al. (2009) demonstrated, under various conditions, that a trade-off between contracts of different duration should be favorable and no strategy of selecting specific types of contracts dominate others. It has also been established that an exclusive partnership with a supplier necessitates a significantly higher reserved capacity from that supplier compared to multiple sourcing (Serel et al. 2001).

The portfolio strategy has been widely used in supply management and procurement. It is an approach to diversify supply sources through numerous suppliers (Neumüller et al. 2016) or contracts (Hu et al., 2018). In addition, in the context of the newsvendor problem, Merzifonluoglu (2017) demonstrated the benefits for the company in reducing the risks associated with suppliers by diversifying the sources for supply, known as a portfolio strategy. In applications such as energy systems, Ren and Gao (2010) studied a case where the purchase could not be lower than a certain volume. This was termed a supply share. In some cases, companies decide to deviate the supply share from one supplier to another in order to modify relationships with those suppliers (Pagell et al. 2010). This is mostly based on the operations of suppliers in case their performance varies.

1.2.2. The planning process and optimization model

1.2.2.1. Problem description

The problem in our study is limited to the procurement of wood supply, where the flow of raw material begins from the suppliers and is completed at the production mills of PPC (see Figure 1.1). Different types of wood supply are procured and are commonly known as assortments. Assortments are different tree segments sorted based on the requirements of forest industries and the difference in species, dimension, and quality (Fuente et al., 2017) (e.g., softwood wood chips or hardwood pulp logs). In pulp and paper production, pulp logs and wood chip assortments are converted to pulp and eventually paper. The PPC uses assortments in a different mix of hardwood and softwood for its production processes. Softwood is referred to as coniferous trees such as the SPF (spruce, pine, fir) group, while hardwood is obtained from the deciduous trees such as maple, oak, ash, aspen and white birch (Rönnqvist et al., 2018).

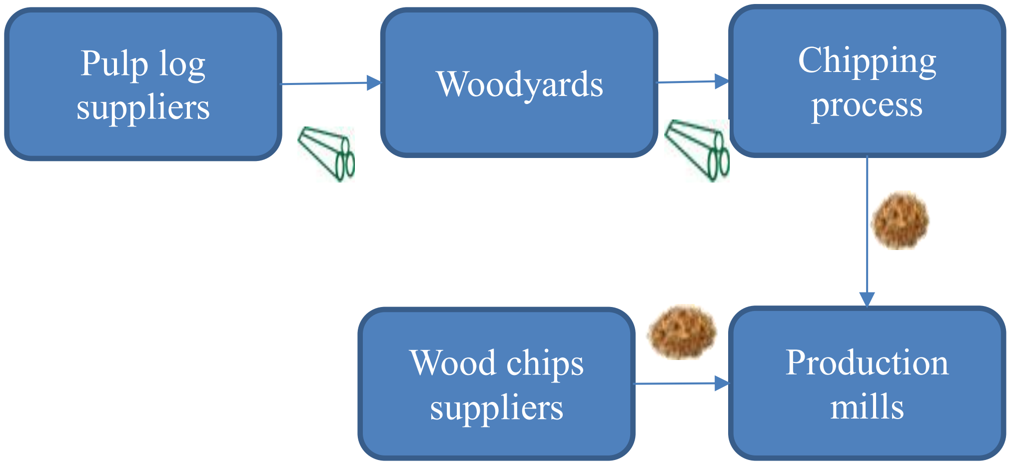


Figure 1.1. The general flow of wood supply for PPC.

Wood chips are the product of chipping purchased pulp logs or a by-product of saw log processing at sawmills, purchased separately by the procurement of the PPC. PPC can take advantage of the co-products from sawmills. Co-products are produced by lumber processing in the form of sawdust, shavings and wood chips. Sawmills can sell them as feedstock to a neighboring PPC (Ghafghazi et al., 2017). Chipping machines are used at the mills to produce wood chips. A certain loss in volume is assumed between the arrival of pulp logs in woodyards and their transformation to wood chips due to different reasons such as debarking operations (LeBel and Carruth, 1997). In general, we consider a conversion rate to address such a volume reduction. Pulp logs are either harvested within forest lands owned by the PPC or granted to PPC through licenses by government, or purchased from suppliers.

Intermediary woodyards are distribution centers that are used to manage transportation operations (Shishehgar et al. 2014). A woodyard (or terminal) is an area that is used as a storage and transshipment point for the wood from different harvesting locations to be hauled to certain mills (Carlsson et al., 2009). Woodyards are of two main types: pulp log yard (PLY) and wood chip yard (WCY). Wood chips are delivered directly to the WCY, whereas PLYs serve as a hub for the harvested pulp logs. WCYs are often in the vicinity of the PPC. In addition, the PLY located at the mill is referred to as internal PLY, while those located upstream toward the harvesting areas are referred to as external PLY. There are inventory control levels established for each woodyard. The possibility to transfer wood between the woodyards is also included. All flow of pulp logs end up in the internal PLY and are transformed into wood chips. Transformation is through the chipping process and the output is stored in the wood chip pile of WCY.

The procurement operation for a PPC follows a sequence of events that leads to contract selection. First, the demand profile of the wood chips is received from the mill production department at the beginning of the planning year. Several mills often use the same assortment. The procurement department ensures that supply is sufficiently provided for all production mills in each month. Depending on the production recipes of the PPC, demand for hardwood and softwood assortments can vary and it is assumed to be provided deterministically in the demand of production mills as well. Then, the inventory control levels at the woodyards (WCY and PLYs) are defined for each month based on factors such as demand for wood supply at production mills and chipping process capacity. In order to realize the available options, procurement decision-maker contacts suppliers and negotiates the contracts. By having the available sourcing contracts, a decision has to be made on the best strategy regarding the total cost of procurement, monthly inventory target levels, and monthly demand profile. Based on their intuition, the procurement decision-maker analyzes the available contracts. Contracts are compared by the use of visualizations of the volume and costs in spreadsheets. An evaluation is done to compare the limited number of portfolios, which should satisfy the constraints of procurement, such as portfolio strategy per group of suppliers.

Portfolio parameters are defined as the percentage of the supply to be allocated to each supplier group. The portfolio parameters are assumed to be provided by the procurement management for the planning year. As in most cases, we include the external suppliers and one group of suppliers for contractors working on PPC's forest land. Contractors on PPC's forest land can sell extra wood harvested and not used by the PPC.

The PPC can choose to sign one or more contracts with each supplier. All contracts have specific characteristics such as wood supply cost, total volume of delivery, monthly schedule of the deliveries, its duration, flexibility, assortment(s), and origin-destination of the deliveries. These are defined in Table 1.1.

Table 1.1. Contract characteristics.

Characteristic	Definition
Nominal volume	The agreed volume that is written in the contract stated in dry metric tonne (DMT)
Assortment	It is either softwood or hardwood, in shape of wood chips or pulp log
Wood fiber price	Cost per unit of the wood assortment for each time period in the contract. The cost includes material, labor, overhead, logistics charges and profits of the supplier (Meixell et al., 2014). It represents the price the client will have to pay

	to obtain the product. Depending on the contract, it may be the same or not in each period.
Fixed cost	The one-time cost associated with the contract construction for initiating the contract.
Start, duration, end	Respectively refers to the starting period of the deliveries, the number of periods that the contract lasts and its ending period.
Schedule	This refers to the distribution of deliveries in the duration of the contract. It determines the volume of assortment to be delivered in each period.
Origin, destination	It determines respectively where the wood supply has been produced and to which location it is being delivered. The destination can be a woodyard or a mill.

As we consider an entire planning horizon, option contracts are defined based on their ability to be signed at the beginning of the planning phase even if they may begin later in the future time periods. In addition, their flexibility also provides the option of a differed order than the nominal volume. In the periods where the preference is to sell the extra wood to external clients, the volume in one period may be different than in the other periods for the same contract.

1.2.2.2. Mathematical model

The objective of our model is to minimize the total procurement costs. The model is a part of a decision support tool to select the procurement contracts that will satisfy the PPC demand for raw material. In this study, we consider contracts by a group of suppliers. Transportation costs and other parameters are considered for each contract. By selecting contracts, the supply provided by each supplier group is decided. Groups may be extended to individual suppliers as well, by considering respective contracts for them. In addition, the volume of each assortment that should be delivered (pulp logs or wood chips) is determined. The model is a time period based model. The wood supply prices and other cost factors are provided as parameters. Furthermore, we assume that each group of suppliers has a shared responsibility to deliver the total contracted volume within the group completely. Below is the definition of sets, parameters and decision variables for the model.

Sets :

R	Set of woodyards
T	Set of time periods
L	Set of assortments

C	Set of suppliers groups
G_c	Set of contracts for supplier group c

Supporting set :

R^E	Set of pulp log yards (PLY)
R^A	Set of wood chip yards at mills (WCY)
L^E	Set of pulp log assortments
L^A	Set of wood chip assortments

Parameters :

D_{lit}	Demand for wood chips for mill i for assortment l at t
S_{rlt}	Target stock level for assortment l in woodyard r at t
C^I_{rl}	Inventory unit cost for assortment l in woodyard r
X^I_{rl}	Initial inventory for assortment l in woodyard r
$C^T_{r'rlt}$	Unit transportation cost for assortment l from woodyard r' to woodyard r at t
C^G_{grlt}	Unit transportation cost for assortment l for contract g to deliver to woodyard r at t
$K_{rll'}$	Conversion rate in woodyard r to convert pulp log assortment l to wood chip assortment l'
$C^C_{rll'}$	Unit cost of chipping process in woodyard r to convert pulp log assortment l to wood chip assortment l'
C^R_r	Fixed cost of opening external woodyard r
P^R_{rl}	Capacity of woodyard r allocated to store assortment l
P^C_{rl}	Capacity of chipping process for transforming pulp log assortment l in woodyard r
C^L_{glt}	Cost per unit assortment l in contract g at t
C^F_g	Initiation fixed cost when contract g is selected
Q_{glrt}	Nominal volume of assortment l to be delivered to woodyard r at t in contract g
Y_l	Unit price of selling extra assortment l from harvesting operations in open market
F^+_{gl}	Maximum ratio of flexibility for the nominal volume of contract g for assortment l

F_{gl}^{-}	Minimum ratio of flexibility for the nominal volume of contract g for assortment l (negative value)
A_c^{+}	Maximum share of supply for supplier group c (%)
A_c^{-}	Minimum share of supply for supplier group c (%)
W_{cl}	Maximum level for extra assortment l to be sold in the open market from supplier group c (%)
P^s	Penalty cost when inventory increases above the target level
P^l	Penalty cost when inventory decreases below the target level
M	A large number equals to the total volume of available deliveries

Variables :

u_{rlt}	Inventory of assortment l in woodyard r at the end of period t
$x_{r'rlt}^{R}$	Flow of assortment l from woodyard r' to woodyard r at t
x_{grlt}^{G}	Flow of assortment l by contract g to woodyard r at t
x_{glt}^{E}	Extra volume of assortment l sold in open market, from contract g at t
U_{rlt}^{s}	Volume of assortment l exceeding the maximum level in woodyard r at t
U_{rlt}^{l}	Volume of assortment l below the minimum level in woodyard r at t
z_g	Binary variable, 1 if contract g is selected, and 0 otherwise
v_r	Binary variable, 1 if external woodyard r is decided to be opened, and 0 otherwise

The primary decisions in this model concern the contracts to be selected as well as the ordered volume from groups of suppliers and the inventory. For flexible contracts, the model decides on their order level based on the flexibility to achieve optimal solutions. It is shown as the difference between the nominal volume in a contract (Q_{glrt}) and the ordered volume from the corresponding supplier group (x_{grlt}^{G}). The portfolio strategy is a limitation that is dependent on PPC's business relationships with different supplier groups. To this aim, we assume that the supply share for each group is bounded between upper and lower bounds as strategically defined by the procurement department.

The objective function minimizes the total procurement cost. This cost includes two types: fixed costs and periodic costs of procurement. Fixed costs relate to the selection of contracts and opening costs of the woodyards, while periodic costs include the purchasing, transportation, transformation of pulp logs to wood chips and inventory holding costs. Aside from the actual costs presented, there are also a number of penalty costs that have been included. These costs are not real monetary and they are used for control aims, related to inventory violations from target levels. These penalties occur periodically.

$$Minimize\ Total\ costs =$$

$$\sum_{t\in T}(\sum_{r'\in R^E}\sum_{r\in R}\sum_{l\in L^E} x^R_{r'rlt}C^T_{r'rlt} \quad (1)$$

$$+\sum_{r\in R}\sum_{c\in C}\sum_{g\in G_c}\sum_{l\in L} x^G_{grlt}(C^G_{grlt}+C^L_{glt}) \quad (2)$$

$$+\sum_{r\in R^A}\sum_{l'\in L^A}\sum_{l\in L^E} \mathrm{C}^C_{rll'}(\sum_{r'\in R^E} x^R_{r'rlt}) \quad (3)$$

$$+\sum_{r\in R^A}\sum_{l\in L} u_{rlt}C^I_{rl} \quad (4)$$

$$-\sum_{c\in C}\sum_{g\in G_c}\sum_{l\in L} x^E_{glt}Y_l \quad (5)$$

$$+\sum_{r\in R}\sum_{l\in L}(U^s_{rlt}P^s + U^l_{rlt}P^l)) \quad (6)$$

$$+\sum_{c\in C}\sum_{g\in G_c} z_g C^F_g \quad (7)$$

$$+\sum_{r\in R^E} v_r C^R_r \quad (8)$$

The first part of the costs relates to periodic costs that have a summation on index t. In (1), the transportation cost between woodyards for pulp logs are calculated. In (2), the purchasing cost is calculated and added to the cost of transportation for the woodyard. In (3), the chipping cost is calculated, which is denoted by the flow from the pulp log yard to the wood chip yard. Inventory cost is then calculated by (4). In (5) the revenue from selling extra wood in the open market is calculated, which is subtracted from the costs. Then we add the penalty costs for deviations from the target inventory level in the woodyards by (6). As far as fixed costs, (7) relates to the selection of contracts and (8) is the opening cost of woodyards. Constraint set (9) represents the inventory maximum limit if the woodyard is opened.

$$u_{rlt} \le P^R_{rl}v_r + U^s_{rlt} \qquad \forall r\in R, l\in L, t\in T \quad (9)$$

Constraint set (10) is the minimum supply share for each pulp log supplier group, while constraint set (11) is for limiting this share to a maximum level. Regarding the demand for wood chips, the converted volume of pulp log is considered in these constraints. Concerning the wood chip supplier group, constraint set (12) and (13) limit their supply share.

$$\sum_{r\in R^E}\sum_{l'\in L^E}\sum_{t\in T}(K_{rl'l}\sum_{g\in G_c} x^G_{grl't}) \geq A^-_c \sum_{r\in R^A}\sum_{t\in T} D_{rlt} \qquad \forall c\in C, l\in L^A \qquad (10)$$

$$\sum_{r\in R^E}\sum_{l'\in L^E}\sum_{t\in T}(K_{rl'l}\sum_{g\in G_c} x^G_{grl't}) \leq A^+_c \sum_{r\in R^A}\sum_{t\in T} D_{rlt} \qquad \forall c\in C, l\in L^A \qquad (11)$$

$$\sum_{r\in R^A}\sum_{g\in G_c}\sum_{t\in T} x^G_{grlt} \geq A^-_c \sum_{r\in R^A}\sum_{t\in T} D_{rlt} \qquad \forall c\in C, l\in L^A \qquad (12)$$

$$\sum_{r\in R^A}\sum_{g\in G_c}\sum_{t\in T} x^G_{grlt} \leq A^+_c \sum_{r\in R^A}\sum_{t\in T} D_{rlt} \qquad \forall c\in C, l\in L^A \qquad (13)$$

The flow of material to and from woodyards is allowed only when a woodyard is opened. It is denoted by constraint set (14).

$$\sum_{r'\in R}\sum_{l\in L}\sum_{t\in T} x^R_{r'rlt} + \sum_{c\in C}\sum_{g\in G_c}\sum_{l\in L}\sum_{t\in T} x^G_{grlt} \leq v_r M \qquad \forall r\in R^E \qquad (14)$$

The balance of flow in PLYs is shown in constraint sets (15) and (16), respectively, for the first period and remaining periods until the end of the planning horizon. It includes the initial inventory and flow from groups of suppliers and between woodyards.

$$X^I_{rl} + \sum_{c\in C}\sum_{g\in G_c} x^G_{grlt} = u_{rlt} + \sum_{r'\in R} x^R_{rr'lt} - \sum_{r'\in R^E} x^R_{r'rlt} \qquad \forall r\in R^E, l\in L^E, t\in\{1\} \quad (15)$$

$$u_{rl,t-1} + \sum_{c\in C}\sum_{g\in G_c} x^G_{grlt} = u_{rlt} + \sum_{r'\in R} x^R_{rr'lt} - \sum_{r'\in R^E} x^R_{r'rlt} \qquad \forall r\in R^E, l\in L^E, t\in T\setminus\{1\} \qquad (16)$$

The wood chip flow balance is also required for WCYs, considering the flow from the wood chip supplier group and the output of chipping processes, while satisfying the demand of production mills. This is shown by constraint sets (17) and (18).

$$X^I_{rl} + \sum_{c\in C}\sum_{g\in G_c} x^G_{grlt} + \sum_{l'\in L^E}(K_{rl'l}\sum_{c\in C}\sum_{g\in G_c} x^G_{grl't}) = u_{rlt} + D_{rlt} \qquad \forall r\in R^A, l\in L^A, t\in\{1\} \qquad (17)$$

$$u_{rl,t-1} + \sum_{c\in C}\sum_{g\in G_c} x^G_{grlt} + \sum_{l'\in L^E}(K_{rl'l}\sum_{c\in C}\sum_{g\in G_c} x^G_{grl't}) = u_{rlt} + D_{rlt} \qquad \forall r\in R^A, l\in L^A, t\in T\setminus\{1\} \qquad (18)$$

The volume of chipping process production is limited by constraint set (19). The capacity of chippers is expressed by the maximum volume of wood supply entering the chipping process in each period.

$$\sum_{r' \in R^A} x^R_{rr'lt} \leq P^C_{rl} \qquad \forall r \in R^E, l \in L^E, t \in T \qquad (19)$$

In constraint set (20) the minimum level as a target stock is denoted.

$$u_{rlt} + U^l_{rlt} \geq S_{rlt} v_r \qquad \forall r \in R, l \in L, t \in T \qquad (20)$$

Constraint sets (21) and (22) define contract flexibility. For contractors working on PPC's forest land, the flow is a trade-off between the deliveries to the woodyards of the PPC and the volume of extra wood sold in the open market. In case no such contracts are available for the specific group, only deliveries to the PPC's woodyards will be considered in this constraint.

$$(F^+_{gl} + 1) Q_{grlt} z_g \geq x^G_{grlt} + x^E_{glt} \qquad \forall c \in C, g \in G_c, r \in R, l \in L, t \in T \qquad (21)$$

$$(F^-_{gl} + 1) Q_{grlt} z_g \leq x^G_{grlt} + x^E_{glt} \qquad \forall c \in C, g \in G_c, r \in R, l \in L, t \in T \qquad (22)$$

The model decides on the variation from the nominal volume. The order volume, therefore, varies between $(F^-_{gl} + 1) Q_{grlt}$ and $(F^+_{gl} + 1) Q_{grlt}$. In making revenue, there is a limit on the proportion of the sold material to the total order level from the related contractors. Conclusively, greater than this proportion is not allowed to be sold in the open market, as shown in (23).

$$W_{cl} \sum_{r \in R} x^G_{grlt} \geq x^E_{glt} \qquad \forall c \in C, g \in G_c, l \in L, t \in T \qquad (23)$$

Finally, the non-negativity and integer variables are defined in constraint sets (24) and (25).

$$x^G_{grlt}, x^R_{rr'lt}, x^E_{glt}, u_{rlt}, U^s_{rlt}, U^l_{rlt} \geq 0 \qquad \forall r' \in R, l \in L, t \in T \qquad (24)$$

$$v_r, z_g \in \{0,1\} \qquad \forall c \in C, g \in G_c, r \in R \qquad (25)$$

1.2.3. Case study

Our case study is based on data from a PPC located in Quebec, Canada. For the case study, the same size was retained compared to the real case. Our case concerns an integrated pulp and paper production line. Data for parameters such as the contract's information is estimated based on discussions with experts. Information about capacities and costs is extracted from interviews with PPC's staff, the literature or technical reports. It is important to note that all the numbers related to the volume of woods are stated in Dry Metric Tonne (DMT) and that time periods are monthly. The costs are provided in Canadian dollars ($CAD). Table 1.2 summarizes the case:

Table 1.2. Case dimension and key characteristics.

Abbreviation	Set	Dimension	Description
PLY	R^E	3	1 internal: R^I 2 Externals: R_1^E, R_2^E
WCY	R^A	1	Internal
Assortments	L^A	2	Hardwood - wood chips Softwood - wood chips
	L^E	2	Hardwood - pulp log Softwood - pulp log
Supplier groups	C	5	*See Figure 1.2 below*
Contracts	G	1500	*See Table 1.3 below*
Time periods	T	12	Month

Total supply is divided between five groups of suppliers for the whole planning year, following the supply portfolio strategy. The procurement network is illustrated in Figure 1.2 and explained below.

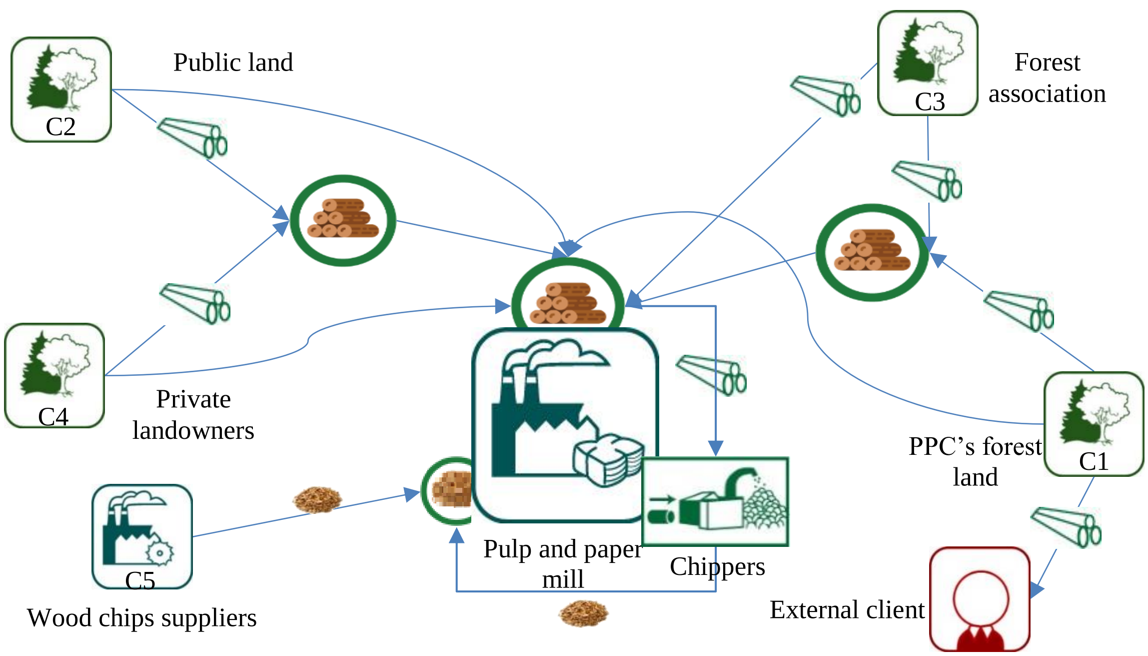


Figure 1.2. The flow of wood supply from different supplier groups to the pulp and paper mill for the case study.

1. *Pulp log from PPC's forest land (C_1):*

This category represents the forest contractors working on the PPC's private forest land. These are strategic and long-term contractors with fixed and flexible contracts. The flexibility of these suppliers is higher as they continuously exchange information with the PPC and can adapt their production.

2. *Pulp log from the public forest (C_2):*

This category includes suppliers working on public forest lands. These areas are allocated by the government to mills using timber licenses (TL) on a yearly basis. Contracts are between the PPC and contractors working on PPC that own TL. In addition, the PPC can receive logs or chips from other companies operating on their own TL. More information on this subject may be found in (Direction de la gestion des stocks ligneux, 2016).

3. *Pulp log from forest association of wood producers (C_3):*

This category includes purchases from the forest association of wood producers in Quebec (Available from https://www.foretprivee.ca/a-propos/mission-et-mandats/). A forest association is an aggregation of private forest landowners, putting wood on the market in a region, and organizing the process of selling and buying wood supply.

4. *Pulp log from private suppliers – imports (C_4):*

This category is primarily associated with timber purchases from private suppliers by their location abroad in the USA and neighboring Canadian provinces such as Ontario.

5. *Wood chips from private suppliers (C_5):*

This group includes wood chip purchases from sawmills and chip producers.

The characteristics of contracts are different depending on the business context associated with each supplier group. For contractors in PPC's forest land, the contracts have more flexibility relative to other groups. In addition, for contracts with suppliers in short distances, there is more flexibility. This is the same for wood chip suppliers since there are sawmills in the vicinity that are able to provide high-quality chips in short lead-time. In Table 1.3 the contracts of our case study are described.

Table 1.3. Different types of contracts.

Contract types	**Definition**
Exclusive	These are with contractors working on PPC's forestland or with suppliers located near the PPC.
Regular long-term	This type of contract can be considered as the classic contract, a contract of at least 1 year, with a fixed volume and a fixed price.
Regular short-term	This type usually covers purchases outside of Quebec, e.g. Ontario or the US.
Option	Short/long term contracts, with the possibility to reserve supply capacity of supplier for later periods

Flexible	Short/long term contracts which have a certain level of flexibility in the order level to increase or decrease

In this study, all planning to be done at the beginning of the year is assumed. Regular short-term contracts are included in our set with relative expensive prices compared to long-term contracts. This is to observe whether it is beneficial for the PPC to engage in punctual agreements other than long-term commitments.

Demand is provided based on historic data for previous years. The monthly demand for chips by the production mill is presented in Figure 1.3. Lower values in periods 4 and 5 are mainly due to maintenance periods at the mill. The problem is solved for 12 monthly periods.

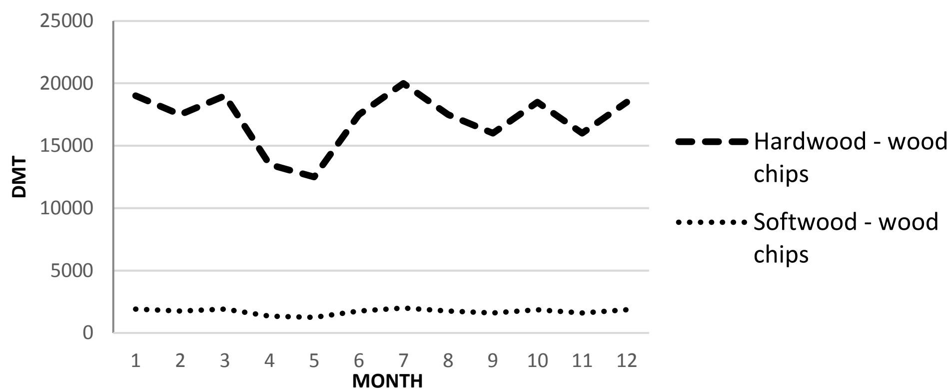


Figure 1.3. Monthly demand profile of wood chips at the mill.

Flexibility is determined based on the evaluation of each supplier. This depends on several factors such as the distance of the supplier and its business status (to which group it belongs). For flexible contracts of supplier group C1, parameter F_{gl}^{+} (as the upper level for modifying the order level) can reach (0.5), while it is less for other groups of suppliers. This is also the case for F_{gl}^{-}, being as low as (-0.3) for C1, while other groups have less downward flexibility. The least flexible contracts are assigned (0.001) in the upward direction and (-0.001) in the downward direction. These values are generated according to relations with suppliers and contract characteristics, while in our case study, PPC does not specifically mention this in the contract with suppliers. Thus, analytical insight about flexibility and its impact through its integration in the contracts may be provided.

Another important set of parameters are the thresholds for the total volume of supply from each group for all assortments. In Table 1.4 the values based on the PPC's previous years' data are provided. For example, supplier group C1 may be assigned from 8.6% to 25.6% of the total supply. In the results section, different insights are provided by varying these parameters.

Table 1.4. Supplier groups portfolio parameters.

Supplier group	**C1**	**C2**	**C3**	**C4**	**C5**
Minimum supply share	8.6%	14%	5%	5.5%	3.9%
Maximum supply share	25.6%	42%	15%	16.5%	18.9%

The maximum capacity of the woodyards and chipping process is shown in Table 1.5. These are data for each period expressed in DMT. For woodyards, this level is based on the minimum level of inventory (S_{rlt}). Chipping capacity is associated with permanent chipping lines at the mill and their capacity is expressed for pulp logs in volume before they are processed into chips.

Table 1.5. Capacity limits per period (DMT).

Parameter	P_{rl}^{R}				P_{rl}^{C}
Yard	R^{I}	R_1^{E}	R_2^{E}	R^{A}	**Chipping**
Hardwood	1.35* S_{rlt}			1.2* S_{rlt}	30 000
Softwood					3 000

The minimum level of wood chips in WCY is usually established by the procurement department to nearly half of the monthly consumption in order to have sufficient time for acting in an emergency. Figure 1.4 includes information about the target levels of inventory at woodyards. Similar to demand data, for softwood assortments, these levels are approximately one-tenth of the levels for hardwood assortments. It is important to note that the target levels are highly dependent on seasonality and since the planning year begins in January, inventory levels decrease after the third period (March). This is the impact of the spring thaw period on transportation with payload reduction and limited/closed access to forest and wood supply price rises. A similar decrease may be observed in November due to heavy rain periods.

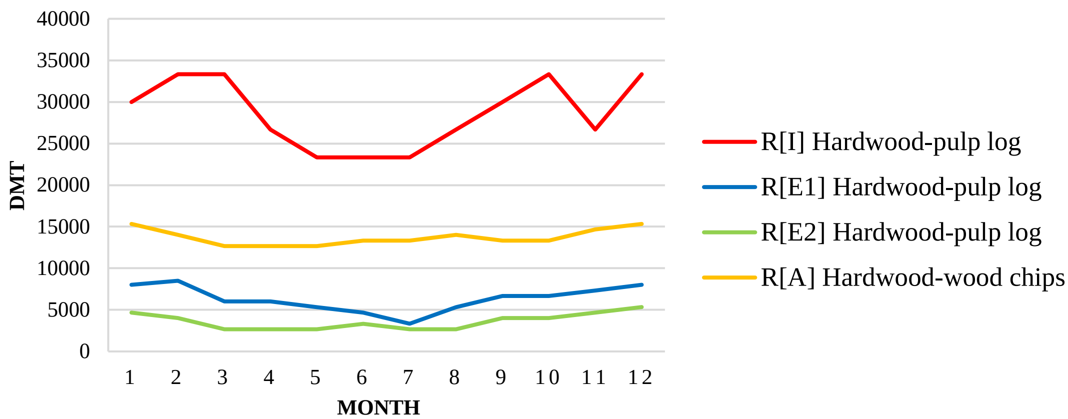


Figure 1.4. Target stock level at yards for wood chips and pulp log.

Penalty costs related to inventory levels and more or less than the permitted monthly levels are included. This is due to extra resources that have to be employed to manage extra supply or risks related to the shortage of supply and its consequences for purchasing expensive wood fiber. Penalty costs for pulp log inventory are 300 CAD$/DMT when below target level and 200 CAD$/DMT above the target level. For the wood chip yard, penalty costs are 500 CAD$/DMT when below the target level and 300 CAD$/DMT when above the target level. The assignment of values to penalty costs are tested multiple times to ensure that the approximation of such values does not have an impact on the current analysis.

Costs related to our case are extracted from interviews with PPC's experts and related studies for Quebec. With the exception of purchasing costs of different assortments, those which are not for the current year were then estimated for 2019 using the inflation rate calculator from the US inflation calculator (US inflation calculator, 2019). Costs in US$ are converted into CAD$ using the website of Banque du Canada in 2019. A summary of these data is provided in Table 1.6.

Table 1.6. Values of cost parameters in each period.

Parameter	Description	Costs (CAD$/ DMT)
$C^{C}_{rll'}$	Chipping process	Hardwood: **29.6** Softwood: **39.5**
$C^{L^A}_{gl}$	Wood chips	**142.5**
$C^{L^E}_{gl}$	Pulp log	From **87.7** up to **186.4** according to supplier
Y_l	The price for extra wood in the open market	**130.5**
C^{I}_{rl}	Inventory cost per time period	PLY: **4.19** WCY: **11.65**

The values in Table 1.6 are average and used for illustration purposes. For inventory costs, it is assumed that the higher holding costs are associated with WCY and for PLYs these costs are lower. The opening cost of external woodyards is 125,000 CAD$ for each, if decided at the beginning of the planning, and happens only once.

1.3 Results

The aim of this study is to evaluate the usage of contracts with no flexibility and low relative price compared to contracts with flexibility and high relative price. Each flexible contract is matched by an inflexible one, which differs only in the unit price from the latter.

The model was implemented in AMPL using CPLEX 12.6 solver. The computer is a 64 bit with a 2.30 GHz CPU and 15.7 GB RAM. The results for the base case are first presented. Only inflexible contracts are included (status quo). In this case, there are 750 contracts including different durations as well as short-term contracts. The problem, in this case, includes 181,808 variables and 1,620,370 constraints. The total procurement cost for the base case is 29.7 million CAD$. The problem is solved to optimality in 10 seconds. In the following, different variations from the base case and results are provided by regarding the flexibility in contracts and then in variating supply portfolio strategy.

1.3.1. Flexibility

For evaluating the impact of flexibility in contracts, three instances are included. The base case (case a1) described above is with only fixed contracts, the second case is with only flexible contracts (case a2) and third case is with both fixed and flexible contracts (case a3). In cases a1 and a2 there are 750 contracts, while case a3 is the integration of contracts in both cases, resulting in 1500 available contracts. The number of variables and constraints for case a2 is the same as base case a1. For case a3, these numbers are respectively 362,558 and 3,240,370. Case a2 was solved in 30 seconds and case a3 in 65 seconds. The results are shown in Table 1.7.

*Table 1.7. Results for three cases based on flexibility in contracts (inflexible a1, flexible a2 and mixed case a3) (*1000 CAD$).*

Case	Yard fixed cost	Inventory Penalty cost	Transportation	Purchasing	Chipping	Contract fixed costs	Inventory		Extra wood sales	Objective function
							Wood chips	Pulp log		
a1	250	207	3 338	14 719	6 246	131	2 112	3 654	962	29 697
a2	125	0	2 704	15 875	6 186	115	2 085	3 315	1 431	28 976
a3	125	0	2 653	14 427	6 190	105	2 036	3 212	1 789	26 961

Penalty costs for case a1 occurs for the hardwood and softwood pulp log. For the hardwood pulp log, the minimum target level is violated in period 1, as well as the maximum target level in period 5. For the softwood pulp log, the minimum target level is violated in period 1.

The results demonstrate the benefits of a mix of cheaper-inflexible and more expensive-flexible contracts. One benefit is through savings in purchasing costs. For case a2 the purchasing cost is higher than in other cases. They are more expensive because they provide flexibility in order levels and may be adjusted in the course of the planning period. However, flexibility in adjusting order levels decreases transportation costs. Contract fixed costs also decrease from case a1 to case a2 and are the lowest for case a3. A fewer number of contracts are required when both flexible and inflexible contracts are available.

Cases a2 and a3 also provide better extra wood sales by providing more freedom to manage the supply from external suppliers and drawing profit from PPC's forest land. The flexibility in contracts helps to adjust the order levels in considering the possibility of selling a portion of wood produced in PPC's forest land. Thus, ordering is optimized mostly by external suppliers, while taking maximum advantage of selling extra wood from PPC's forest land.

For case a1, both external woodyards are in operation, while in cases a2 and a3 only one external woodyard is opened. Inventory cost is, therefore, lower for cases a2 and a3, especially for pulp log storage. To compare the inventory levels for each case, Figure 1.5 illustrates hardwood assortments and Figure 1.6 softwood assortments.

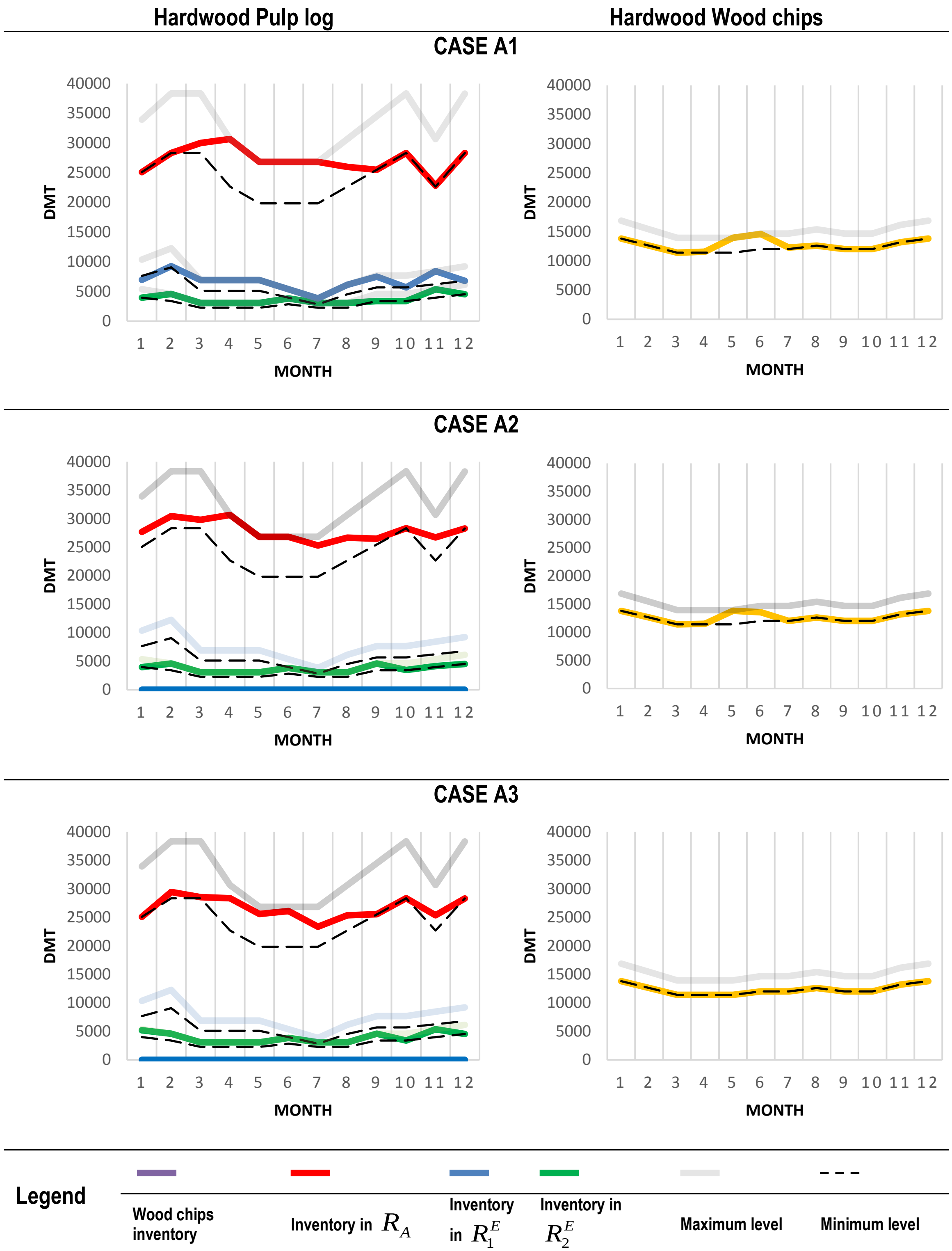


Figure 1.5. Inventory level at yards for hardwood assortments.

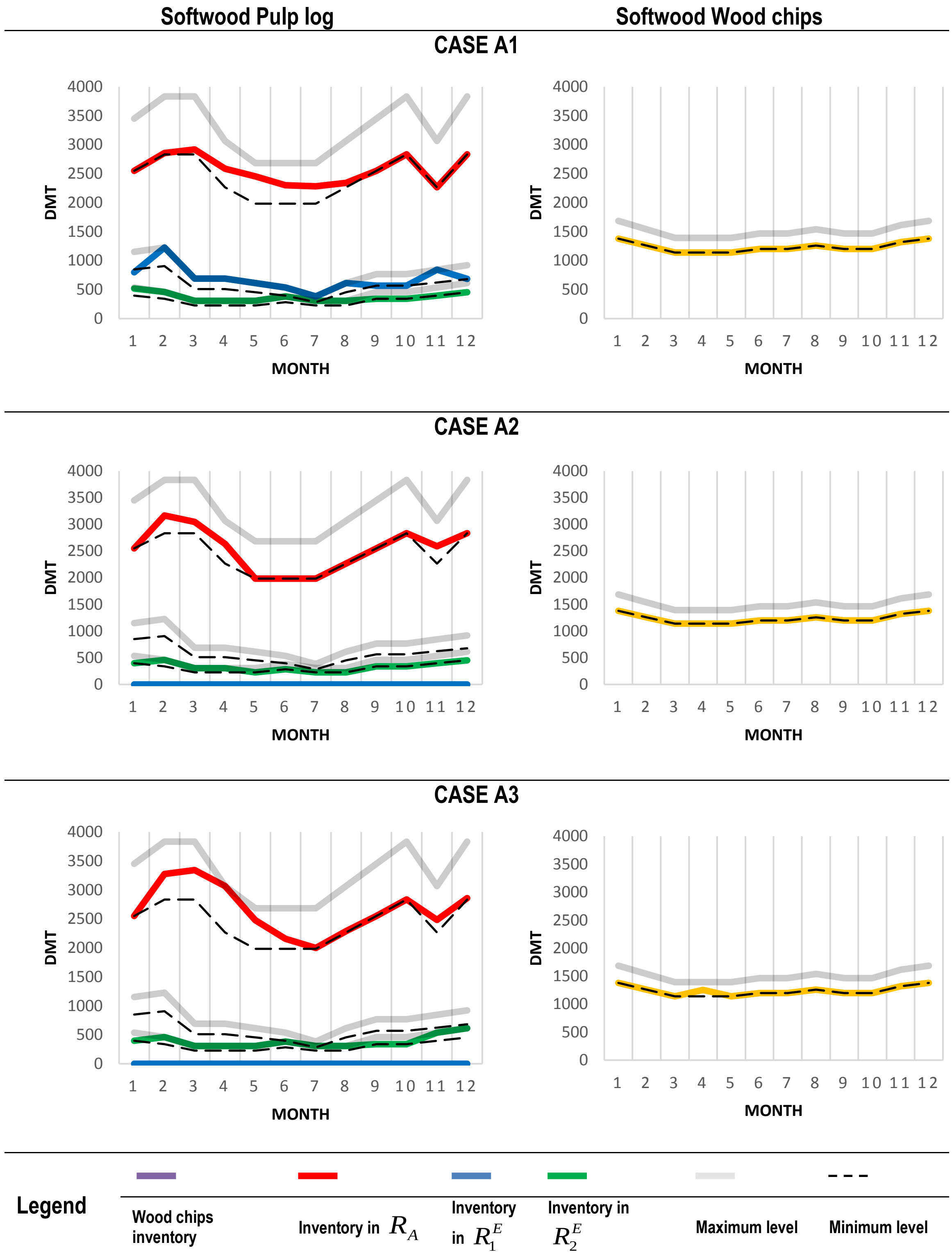


Figure 1.6. Inventory level at yards for softwood assortments.

Figures 1.5 and 1.6 show that by applying flexibility, the inventory tends to decrease. In cases a2 and a3 the external woodyard R[E1] remains closed, thus, avoiding the fixed cost of opening that woodyard. The inflexibility does not allow the inventory to follow the exact target levels in case a1. In cases a2 and a3, operating with only one external woodyard is the reason for high inventory levels at the beginning of planning. For wood chip inventory, except inflexible case a1, the model approximately follows the minimum level. However, in general, higher inventory costs for wood chips transfer the inventory fluctuations to pulp log woodyards. The information about the selected contracts is gathered in Table 1.8 to observe the portfolio of selected contracts.

Table 1.8. The number of selected contracts for each case per assortment.

Assortment	Case	Number of selected contracts	Short-term	Flexible	Inflexible
Hardwood pulp log	a1	62	2	-	62
	a2	51	0	51	-
	a3	48	0	31	17
Hardwood wood chips	a1	10	0	-	10
	a2	9	0	9	-
	a3	9	0	3	6
Softwood pulp log	a1	11	0	-	11
	a2	7	0	7	-
	a3	8	0	2	6
Softwood wood chips	a1	1	0	-	1
	a2	2	0	2	-
	a3	1	0	0	1

For case a1, more contracts are needed to satisfy the demand and inventory targets. In case a1, two short-term expensive contracts are also selected for the hardwood pulp log. As mentioned above, there are still penalty costs associated with this case. Therefore, it is challenging to achieve the optimal selection. It is shown that for cases a2 and a3, no short-term contracts are required. In case a3 the mix of both contracts is chosen. As shown in case a3, except for the hardwood pulp log, it is better to sign more inflexible contracts and a few flexible ones. In other words, a high level of flexibility is required for hardwood pulp log, while inflexible contracts can nearly satisfy the requirements of other assortments. Comparing the total number of selected contracts, the numbers confirm the results in Table 1.7, where the least contract fixed cost is for case a3. The supply portfolio is presented in Table 1.9.

Table 1.9. Supply portfolio for each case, comparing the relative percentage of total volume and relative percentage of selected contracts (%).

Case		PPC's forest land	Forest association	Public land	Private pulp logs	Private wood chips	Short-term
a1	Volume	24.8	29.9	12.6	15.1	17.4	0.2
	Contracts	16.7	29.7	15.5	22.6	13.1	2.4
a2	Volume	25.6	25.8	13.3	16.5	18.8	0
	Contracts	21.7	27.5	15.9	18.8	15.9	0
a3	Volume	25.6	25.3	13.9	16.5	18.7	0
	Contracts	22.7	28.8	16.7	16.7	15.5	0

In cases a1 and a2, forest association suppliers have the largest share of supply. The second biggest share is allocated to PPC's forest land. In all cases, public land has the lowest share. The supply share of different groups of suppliers does not show a significant difference between case a2 to case a3.

Comparing the relative percentage of selected contracts, most contracts are with forest associations. For PPC's forest land, the percentage increases noticeably by adding flexibility. In case a1, a relatively high percentage of contracts is needed for private pulp log suppliers to provide only 15% of total supply volume. Thus, the fixed cost of contracts as well as the complexity of managing the contracts rise.

1.3.2. Portfolio

The current model is also used to evaluate results for different portfolio strategies. This enables the search for which supplier group provides better opportunities for increasing or decreasing their supply share (A_c^+ and A_c^-). It allows the evaluation of each group of suppliers separately by conducting sensitivity analysis based on the proportions from different supplier groups and verifying whether there are better contracts available with that supplier group. Figure 1.7 illustrates the portfolio limits and the selected portfolio by the model on case a3 discussed in the above section.

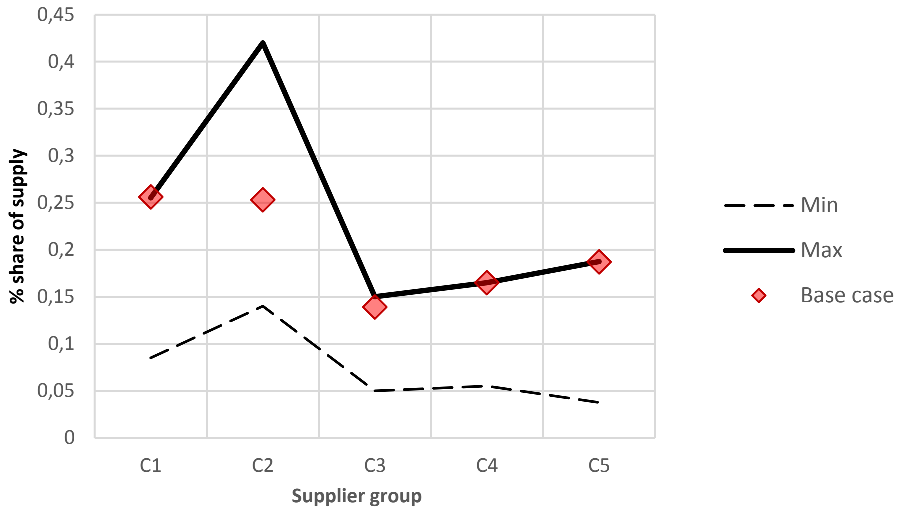


Figure 1.7. Portfolio values for case a3 as the base case.

Each group is evaluated by expanding its portfolio limits by 25%. Thus, the upper level is increased to ($1.25\,A_c^+$) and the lower level is decreased to ($0.75\,A_c^-$). The results are based on case a3 since it includes all of the contracts and thus enable to provide better insight. Therefore, the results are generated in a way that the model optimizes the reallocation of supply to decide whether or not it is beneficial to change the base case portfolio. In cases b1 to b5, five different variations are provided from the base case for each group of suppliers. For example, case b1 applies 25% on A_1^+ and A_1^- for only PPC's forest land suppliers, while others (A_c^+ and A_c^-) remain the same as the base case. The following results in Table 1.10 are obtained.

Table 1.10. Supply portfolio based on changing portfolio parameters for each group separately (%).

Case	PPC's forest land	Forest association	Public land	Private pulp logs	Private wood chips
a3	**25.6**	**25.3**	**13.9**	**16.5**	**18.7**
b1	**32.0**	20.4	12.4	16.5	18.7
b2	25.6	**25.3**	13.9	16.5	18.7
b3	25.6	25.3	**13.9**	16.5	18.7
b4	25.6	22.9	12.4	**20.4**	18.7
b5	25.6	21.9	12.7	16.5	**23.3**

Based on the variations in the portfolio parameter for each group of suppliers, and in the presence of all contracts (case a3), we can observe that there are potential savings in the supply share for all groups except forest association (case b2) and public landowners (case b3). This suggests that there are contracts that can decrease the costs of procurement, which have not been chosen due to portfolio constraints in case a3.

For PPC's forest land (case b1), this demonstrates that better contracts are available for selection. It may also be observed that there are opportunities to replace some contracts of forest association and public land suppliers with private pulp log and wood chip suppliers. The reason for some percentages not fluctuating in some cases is that they have already reached their maximum allowable share. Only forest associations and public land suppliers are those that do not provide better options, even though increasing their portfolio limits individually.

It is also noticeable that contracts with PPC's forest land are more advantageous. However, there are numerous implications in too low or too high volume harvesting operations in this land to respect the appropriate harvest rotations. Strategic supply and silvicultural considerations (annual allowable cut) apply in this matter to prevent deforestation in the long-term.

1.4 Discussion

In the present model, the objective was to evaluate the procurement strategy in the presence of flexibility in contracts. Different portfolio parameters were also tested to check for opportunities for each group of suppliers. In all evaluations, the optimal portfolio to minimize the total cost of procurement was provided. It was observed that the purchasing cost of flexible contracts, although relatively high, may provide better management of procurement operations and decrease overall costs. Thus, the best strategy financially is to include both sets of flexible and inflexible contracts. This analysis provides explicit insights with a large set of contracts compared to existing studies such as Blanco et al. (2018) with a small set.

These results suggest that although adding flexibility to contracts may increase the purchasing costs, it provides better inventory costs and ultimately lower overall procurement cost. While flexibility comes with the inventory savings, by comparing total costs of procurement, decision-makers are suggested to include cheap inflexible contracts in the portfolio. In other words, having solely flexible or inflexible contracts are more expensive than having a mix of flexible and inflexible contracts.

It may also be concluded that different groups of suppliers may provide opportunities for the PPC. This is shown by differing the portfolio settings from the status quo and provides the possibility to decide on the share of each group of suppliers or revise portfolio parameters. This aspect is rarely addressed in previous similar studies on procurement contracts such as Feng et al. (2013). We found out that public land and forest association suppliers do not include any better contract opportunities with allowing 25% more supply share. Allowance of 25% more supply share for PPC's forest land contractors, private pulp log and private wood chip suppliers, provides a better solution for the problem in terms of procurement costs. The best strategy may need further strategical and long-term silvicultural considerations.

1.5 Conclusion

A new mixed-integer programming model was developed in a multi-period environment as a tool for selecting contracts to satisfy the monthly demand of a pulp and paper company (PPC). The model finds the portfolio of contracts that minimizes the procurement costs. The current model is valuable in embedding rarely studied details in the procurement process such as contract characteristics and enables decision-makers to evaluate the selected portfolio in the presence of different settings and compares the alternatives. The analysis in this study was not possible previously in practice due to the large size of the problem including simultaneous considerations of different types of contracts, groups of suppliers, and flexibilities in order volume. Deciding on the correct trade-off between purchasing costs and flexibility improves accuracy and the time of calculations compared to traditional methods.

The current study does not consider uncertainty about future deliveries. Although the deterministic solution is optimal, the selected portfolio should be evaluated in the presence of real events. Future work should include uncertainty and sourcing risks in the planning of the procurement process. One approach is to conduct simulations in the presence of the risks on procurement operations and monitor the variations between deterministic solutions and actual solutions while another strategy may be to develop a stochastic optimization method to find the best portfolio for the contracts in the presence of the risks.

1.6 Acknowledgements

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Chapter 2 Evaluation of Sourcing Contracts in Wood Supply Procurement using Simulation

Résumé

Les opérations d'achat dans les entreprises forestières sont exposées à divers risques, qui peuvent augmenter les coûts d'approvisionnement. Des exemples de risques sont la non-fiabilité et la rupture du contrat. Les modèles de planification déterministes ne peuvent pas parfaitement refléter la complexité des applications du monde réel sujet a divers risques. Dans la pratique, les industries forestières utilisent des contrats pour garantir le volume du bois. Des prévisions mensuelles sont établies pour le volume de livraison et sont principalement basées sur l'expérience du personnel d'approvisionnement et le volume total des contrats. Les livraisons manquées dans les contrats conduisent à une inadéquation entre l'offre et la demande de fibre de bois et augmentent les coûts d'approvisionnement en raison des coûts d'inventaire élevés ou des achats coûteux sur le marché libre. Des études antérieures sur la simulation de l'impact des risques d'approvisionnement sur les opérations d'achat ont été menées; cependant, aucun n'a abordé la sélection des contrats. Dans l'industrie forestière, chaque contrat possède ses propres caractéristiques telles que la flexibilité, le volume, le calendrier et le prix de livraison. Une approche de simulation Monte Carlo est mise en œuvre pour analyser le comportement d'une approche de planification déterministe. Les événements aléatoires sont générés en formulant différents types de risques d'approvisionnement, ayant un impact à court ou à long terme. La simulation est intégrée à un modèle de planification déterministe pour chaque période. Les résultats ont montré que la gestion des risques d'approvisionnement est facilitée par des contrats flexibles par rapport aux contrats fixes, malgré leur coût d'achat plus élevé.

Mots-clés: Analyse des Risques, Simulation, Foresterie, Logistique, Modélisation de l'Incertitude, Évaluation des Performances

Abstract

Procurement operations in forest companies are exposed to various risks, which may increase procurement costs. Examples of risks are the contract's unreliability and contract breach. Deterministic planning models cannot perfectly reflect the complexities of real-world applications in the presence of sourcing risks. In practice, forest industries use contracts to guarantee the wood supply. Monthly forecasts are prepared for the delivery volume and are primarily based on the experience of procurement staff and the total volume of contracts. Missed deliveries in the contracts lead to a mismatch between the supply and demand for wood fiber and increase the costs of procurement as a result of high inventory costs or expensive purchases from the open market. Previous studies on simulating the impact of sourcing risks on procurement operations have been conducted; however, none have addressed the selection of procurement contracts. In the forest industry, each contract possesses its own characteristics such as flexibility, volume, schedule and price of delivery. A Monte Carlo simulation approach is implemented to analyze the behavior of a deterministic planning approach. Random events are generated by formulating different types of sourcing risks, having either short- or long-term impact. The simulation is embedded with a deterministic planning model in each period. Results showed that management of sourcing risks is easier by flexible contracts in comparison with fixed contracts, despite their higher purchasing cost.

Keywords: Risk Analysis, Simulation, Forestry, Logistics, Uncertainty Modelling, Performance Evaluation

2.1 Introduction

In a Pulp and Paper Company (PPC), an evaluation of costs for alternative procurement plans is generally performed manually. Due to a large number of alternatives, it is difficult to evaluate each one individually during the planning and implementation of the procurement plan. The selected portfolio of supply contracts provides the schedule of wood fiber deliveries for each period and is referred to as the "forecast plan". Since procurement operations account for a high portion of the company's expenses (Jain 2016), it is important to ensure that the forecast plan is implemented to avoid unexpected modifications. Various risks interrupt the conformity of the real deliveries with the forecast plan.

The absence of integrating sourcing risks in the forecast plan of real-world applications results in increasing costs. Additional expensive contracts may be required to compensate for the lack of deliveries. Moreover, a lot of time and energy from procurement decision-makers is required to compare the performance of different plans in order to decide on the best procurement strategy. Some contracts might be advantageous if the cost characteristics are only considered; however, during the implementation of actual operations, they may cause problematic changes in total costs of the plan due to the unreliability of their deliveries. The objective of the present study is to compare the performance of various strategies for selecting a supply portfolio.

Miller (1977) stated that "risk occurs where the future is not known, but the probability distribution of possible futures is known". In Kersten et al. (2006) it was denoted that "risk is the damage - assessed by its probability of occurrence - that is caused by an event within a company, its supply chain or its environment". These definitions suggest that the term "risk" can be adapted for an event in the future that is not known in advance, but where its occurrence can be estimated with a probability. However, as stated by Gadow (2000), "uncertainty" represents known expected damage from a risk. For example, for a buyer, there is a probability that its supplier delivers less supply than the order amount. In the case where the probability and variation from the order volume are known, the delivery volume becomes an uncertain parameter and there is a risk of a supply shortage.

Risk is important in procurement planning when it comes to the question of sole sourcing versus portfolio sourcing (Martel and Klibi, 2016). In Rauch (2010), the supply share of a supplier is defined by a percentage of the total demand for feedstock. This study showed that the supply share is dependent on the market situation and varies between short- or long-term contractors. Risks integrated into their planning were bark beetles and storms. A stochastic simulation approach using a Monte Carlo simulation approach was used to hedge sourcing risks.

The selection of sourcing contracts need to account for the external environment as well (Lee, 2009). Near the end of the winter season, the procurement becomes challenging in Nordic countries and wood fiber price is uncertain (Gallagher et al., 2003). This is due to the limitation of harvesting and transportation when the frozen ground begins to melt. This period is referred to as the thaw period. The challenge is to plan for this period, while its starting date is uncertain. This will either result in high inventory costs due to the high volume of deliveries before spring if delayed (i.e. long winter season) or cause risk of shortage if advanced (i.e. early spring).

Evaluations lead to a better analysis of selecting the best supply contract to improve delivery forecasts before the implementation of the plan (May et al., 2015). The performance of different strategies, such as flexible and fixed contracts, is compared based on the model proposed by Rahimi et al. (2019). The developed model helped to decide on the best selection of contracts to supply wood fiber for the PPC. Three sourcing risks are integrated: contract breach, the start of the thaw period, and contract's unreliability. For simulating the operational process, the Monte Carlo simulation approach is used as a tool to determine the possible distribution of outputs (Vose, 2008). Very few studies have quantified the impact of sourcing risks on the selected contracts (Hamdi 2017; Merzifonluoglu 2017); however, none have measured this in the presence of different groups of suppliers. There are similarities in contracts and their characteristics (e.g. reliability or flexibility level) among each group of suppliers. To our knowledge, no studies have addressed the complexity of contract selection for a PPC including a large set of contracts.

The remainder of this paper is structured as follows. Section 2 provides a review of the relevant literature. Section 3 provides a description of the problem while Section 4 presents the simulation approach. Section 5 describes the case study, including risk and uncertainty data, Section 6 provides the results of the evaluations and Section 7 includes the conclusion.

2.2 Literature review

A review of supply contracts may be found in Cachon (2003). In fixed contracts, the buyer and its suppliers agree on a price, the delivery volume and schedule of deliveries. Although the PPC mitigates the risk related to the variations in the price of raw materials, inventory risk emerges due to inflexible order levels (Martínez-de-Albéniz and Simchi-Levi, 2005). Option contracts were introduced to mitigate inventory risk. In this contract type, the buyer prepays a small portion of the order price upfront and reserves a certain level of capacity from the supplier. Inventory risk is transferred from the buyer to suppliers using option contracts. Flexible contracts share inventory risks between both PPC and its suppliers by fixing an order level in the beginning and then adding a possibility to change order level by an agreed percentage. For this purpose, PPCs require the best combination of price and flexibility for contracts. Despite the great benefits of using contracts, difficulties arise during their implementation. Some of these difficulties were addressed by Martel and Klibi (2016) as poorly stated expectations, no continuous improvement, lack of flexibility, and poor relationship management. Therefore, it is necessary to evaluate the performance of contracts (Wang et al., 2017).

In the study of Everett et al. (2000), a stochastic model was presented that covered ten years of capital planning. They presented three scenarios for the market: expected, optimistic and pessimistic. However, the model was too large to solve to optimality. Three different plans were generated for each scenario and each plan was simulated in the presence of other scenarios. The variance of results was significant, denoting a considerable risk involved with each plan.

The optimal selection of contracts is addressed by Talluri and Lee (2010) for the application of manufacturing firms. Authors presented insight to manufacturing managers on choosing the right contract (short-, long- or mid-term), in the presence of market price uncertainty, investment costs, and supplier capacity restrictions. Bansal et al. (2007) restated the problem of supplier selection to contract selection regarding their different types, prices, and durations. They classified contracts based on each criterion to achieve the optimal selection of contracts by developing a mathematical model to minimize procurement costs.

Merzifonluoglu (2015) considered option contracts in selecting an optimal supply portfolio in the presence of uncertain spot market, supply and demand. A portfolio selection was analyzed in order to maximize profit. Sensitivity analysis indicated the preference of a supplier with a high unit cost over a supplier with low unit cost due to its favorable yield factors. It was concluded that the reserved capacity in option contracts can mitigate risks. The decision variables for contracts were related to order volume and reserve capacity for option contracts, without the possibility to select contracts.

Snyder et al. (2010) have discussed mitigation strategies including sourcing flexibility, where suppliers have the possibility of adapting to modifications in the order level. Mitigation strategies are also mentioned in Sodhi and Tang (2012) by having flexibility and redundancies in the supply chain.

On the other hand, Demirel et al. (2012) denoted that under certain conditions the manufacturer may benefit from upfront commitments instead of flexible contracts.

Although in the literature, studies have evaluated procurement planning by considering sourcing contracts, there is a gap in the evaluation of the procurement plan based on the selection of contracts. In addition, portfolio constraints are not addressed by different groups of suppliers. Evaluation of the procurement plan by formulating different types of risks increases the originality of this study to mimic real-world applications. Flexible and option contracts are provided to test the efficiency of fixed, flexible and a mix of both contracts.

2.3 Problem description

The procurement of PPC requires finding an appropriate mix of contracts (fixed, flexible and options) to satisfy the wood fiber demand of production mills. The design of the contract and their characteristics are negotiated in advance followed by an evaluation of the available sourcing options and selection of the best contracts.

To introduce a description of how the replanning process works in reality, the flowchart of the procurement control process in each period is illustrated in Figures 2.1 and 2.2. The figures present the mitigation strategy in the presence of short- and long-term sourcing risks, respectively. Short-term risks have an instantaneous impact on the deliveries of the actual period. In contrast, long-term risks may not only impact the actual period but may also influence future periods. The impact of short-term risks, usually originating from a contract's unreliability, is recovered quickly by inventory or modifying the order volume of flexible contracts. Long-term risks are related to disruptive changes in procurement, whether supplier-related or originating from external sources such as the environment or government. Generally, the mitigation of short-term risks requires fewer modifications and is managed by the current portfolio and inventory. Long-term risks, however, might require adding new contracts to the procurement plan and accounting for hedging shortage risk in upcoming periods.

In the presence of sourcing risks, the delivery volume of supply can be variable and cause a mismatch between supply and demand. In case of shortage, spot market purchases are possible if no new contract is available. PPC procurement decision-makers struggle to comply with inventory target levels. The risks either influence deliveries of a single period or have a long-term impact. In both cases, it is difficult to modify the plan. Constraints of the problem enhance its complexity including portfolio strategy and capacity of the chipping. To decide on the modifications in the plan, the supply should respect the inventory target, with the objective of minimizing the total costs of procurement. Evaluations help achieve the range of variation of the objective function and inventory levels in the presence of different scenarios.

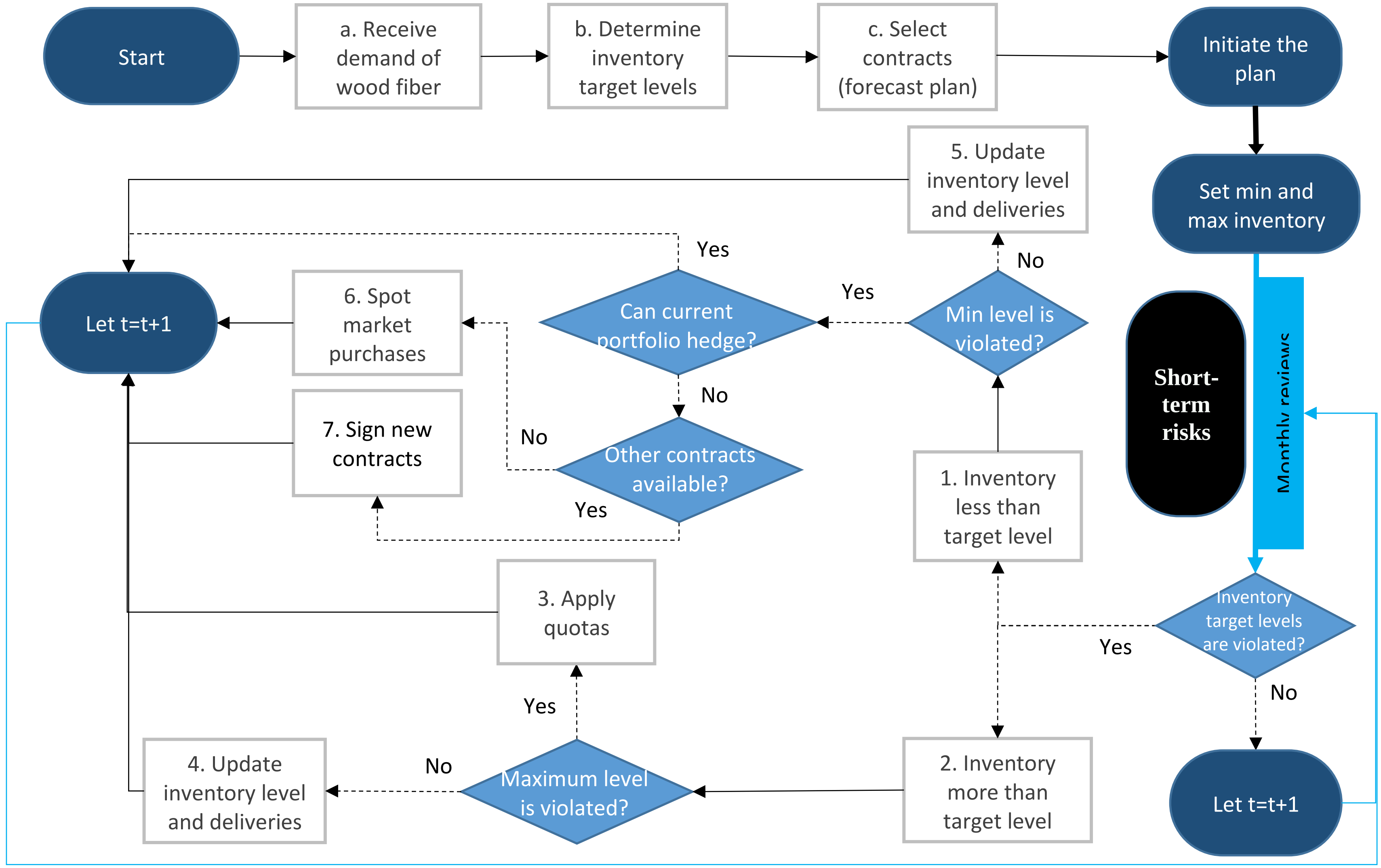


Figure 2.1. Flowchart of procurement planning in the presence of short-term risks.

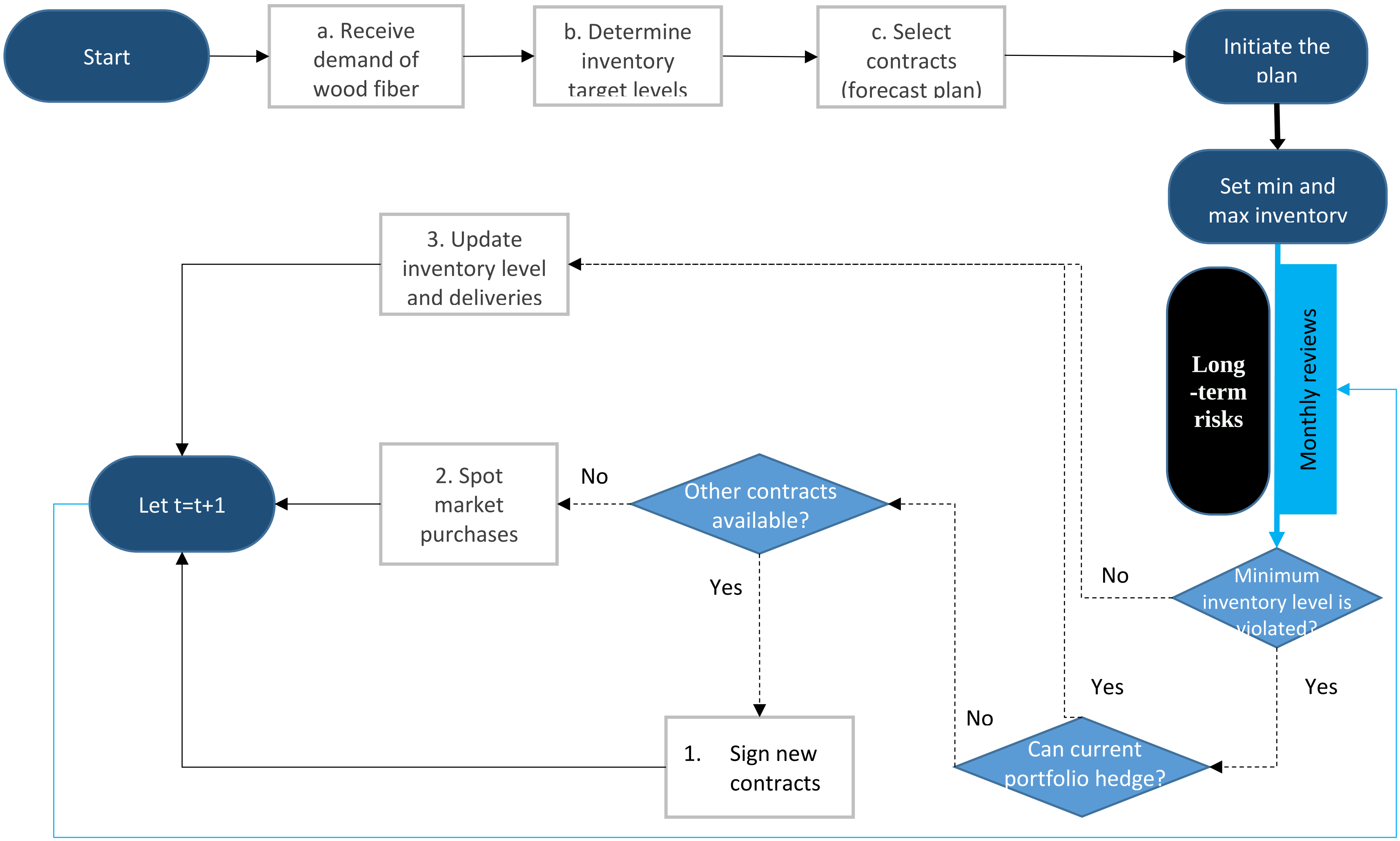


Figure 2.2. Flowchart of procurement planning in the presence of long-term risks.

During the procurement planning of the PPC, the focus is on target stock levels in woodyards as the control variable for modifying the plan in case it is necessary. Target levels for inventory management are calculated based on the mitigation strategy at the company to keep the required volume for a given number of production cycles (Eriksson et al., 2015). Target stock levels are determined based on the woodyard characteristics, such as capacity, historical data on the contract's reliability and demand for wood fiber.

Since this study focuses on the procurement department of the PPC, the starting point is at the beginning of the financial year, when the procurement department receives the demand for wood fiber from the production department. This is followed by an annual procurement plan that is carried out with monthly revisions (Bredström et al., 2010). Demand is for wood chips from different wood species belonging to either softwood or hardwood assortments. The wood supply comes in the form of wood chips or pulp logs. Chipping machines at the mills are used to transform pulp logs into wood chips. This is added to the deliveries from wood chip suppliers in order to satisfy the demand of raw material by mills. The mix of assortments depends on the production recipes of the mills.

The procurement staff has a set of available contracts that have already been negotiated. Each group of suppliers is allotted by a share of total supply, depending on the portfolio strategy of the PPC. After the contracts are selected, the PPC determines the forecast for deliveries for each month. These steps are denoted as *a*, *b* and *c* in the flowcharts in Figures 2.1 and 2.2. After determining the forecast plan, the implementation phase is initiated and monthly reviews are performed to check the conformity of the forecast plan and actual operations. A mitigation strategy is decided by monitoring the impact of risks in the short- or long-term. The PPC monitors the real deliveries of suppliers in each period and records variations from the forecast plan.

2.4.1 Short-term risks

2.3.1.1 Start of the thaw period

In countries with long winters such as Canada, the thawing occurs towards the end of winter. During that time, which may last several weeks, weight limits are established for transportation to protect roads from degradation. The price of the wood supply may rise since access to forest roads is reduced. Hence, companies tend to accumulate high inventory prior to the thaw period to mitigate the risk of expensive purchases if deliveries are decreased. In case the thaw period begins earlier or with more delay than what was considered in the forecast plan, there is a risk of extra inventory holding costs or shortage of wood supply.

2.3.1.2 Contract's unreliability

One common source of variation in the plan is the unreliability of contracts. This is based on the difference between the delivery volume in the forecast plan and actual operations. Although the variations for an individual contract may be relatively small, the accumulation of these variations may have a noticeable impact on the costs of procurement and level of inventory. Different causes associated with this risk include, but are not limited to, failure in transportation or harvesting equipment and market variations. It is important to consider the unreliability of some contracts in the presence of market variations since suppliers may find a more beneficial market elsewhere and violate their commitment to PPC based on their contracts.

2.3.1.3 Dealing with short-term risks

As illustrated in Figure 2.1, if no considerable difference from target inventory levels is noticed, variations are updated, the same portfolio is maintained and the plan is continued to the next period. If, however, deliveries violate target stock levels, the process falls into one of the two directions (boxes 1 or 2).

box 1. By verifying the minimum level, if inventory levels are less than the target, the PPC decides if they need to find other contracts or the inventory can hedge. If the variation is not considerable, the inventory and plan are updated (box 5). Otherwise, the current portfolio is verified with option and flexible contracts and if not fulfilled, other contracts are checked. If available, the PPC signs a new contract (box 6), otherwise, a spot market purchase is done (box 7).

box 2. If inventory levels are more than the schedule, the maximum stock level is verified and if the capacity of the woodyards allows, an oversupply is accepted (box 3). Otherwise, quotas are applied (box 4) and the plan is updated. Quotas were used by LeBel and Carruth (1997) and its application was based on an inventory upper limit.

2.4.2 Long-term risks

2.3.2.1 Contract breach

In the forest industry, some suppliers may not be able to continue delivering the orders. This is a problematic issue where suppliers may either find a better market to sell their products or simply terminate their operations due to other reasons such as fire or infestation of their harvesting zones. Although with low probability, the impact can be large. Thus, it is important to recognize what the outcome and best mitigation strategy would be after losing contracts in that case.

2.3.2.2 Dealing with long-term risks

Figure 2.2 illustrates that these risks are not only affecting the current period delivery, but also the future deliveries, and the lost volume might be considerable. If inventory cannot hedge, the company verifies the current portfolio to determine if the option and flexible contracts can compensate. Otherwise, new contracts are sought and signed if available. In the case there are not enough contracts available with the current portfolio to cover the lost volume for the upcoming periods, spot market purchases are required. The main difference with short-term risks is the consideration of mitigation strategies for the total planning horizon, while the current period deliveries might occur according to the forecast plan.

Sourcing risks prevent the exactitude of the real delivery and order volumes. In addition, the market price of wood fiber is changing continuously, and thus, the price of new contracts may be variable as well. As shown in Rahimi et al. (2019), neither sole fixed nor flexible contracts result in optimal procurement costs; however, the optimal strategy is a mix of both types of contracts. To further develop the performance of each procurement strategy, the framework in this study is developed to complete the gaps of a contract portfolio evaluation for the PPC.

2.4 Methodology

The proposed plan that is evaluated is a deterministic model developed by Rahimi et al. (2019). It is also embedded with a simulation approach for re-planning in each month. The objective of the model is the minimization of total procurement costs by selecting a portfolio of sourcing contracts. In order to evaluate the proposed procurement plan, the simulation approach should be developed to enable the integration of sourcing risks into forecast deliveries. In each period, the real volume and price of deliveries are determined based on random events. The procurement plan is then updated based on the impact of events on the deliveries from suppliers. A sequence of random events in one planning horizon creates a scenario. Numerous scenarios are generated by a Monte Carlo approach and the plan is re-optimized after realization of random events in each period and decisions are modified. In the end, by updating the procurement plan with real deliveries in each scenario, multiple values of the objective function and other variables are used in the statistical analyses of the procurement plan's performance.

2.4.1 Mathematical model

The model is adapted from Rahimi et al. (2019) with a brief description presented below. Notations and their definitions are presented below.

Sets :

R	Set of woodyards
T	Set of time periods
L	Set of assortments
C	Set of supplier groups
G_c	Set of contracts for supplier group c

Supporting set :

R^E	Set of pulp log yards (PLY)
R^A	Set of wood chip yards at mills (WCY)
L^E	Set of pulp log assortments
L^A	Set of wood chip assortments

Parameters:

D_{lit}	The demand for wood chip assortment l for mill i at time period t
S_{rlt}	Target stock level in woodyard r for assortment l at time period t
C^I_{rl}	Inventory unit cost in woodyard r for assortment l
X^I_{rl}	Initial inventory in woodyard r for assortment l
$C^T_{r'rlt}$	Unit transportation cost from woodyard r' to woodyard r for assortment l at time period t
C^G_{grlt}	Unit transportation cost for contract g to deliver to woodyard r the assortment l at time period t
$K_{rll'}$	The conversion rate of debarking (before chipping) in woodyard r to convert pulp log assortment l to wood chip assortment l'
$C^C_{rll'}$	The unit cost of the chipping process in woodyard r to convert pulp log assortment I to wood chip assortment l'
C^R_r	Fixed cost of opening external woodyard r (no construction activity)
P^R_{rl}	The capacity of woodyard r allocated to store assortment l
P^C_{rl}	The capacity of the chipping process in woodyard r for transforming pulp log assortment l
C^L_{glt}	Cost in contract g per unit assortment l at time period t
C^F_g	Initiation fixed cost when contract g is selected
Q_{glrt}	The nominal volume in contract g for assortment l to be delivered to woodyard r at time period t
Y_l	The unit price of extra assortment l to be sold in the market
F^+_{gl}	The maximum level of flexibility for the nominal volume of contract g for assortment l (%)
F^-_{gl}	The minimum level of flexibility for the nominal volume of contract g for assortment l (%) (negative value)

A_c^+	Maximum share of supply for supplier group c (%)
A_c^-	Minimum share of supply for supplier group c (%)
W_{cl}	The maximum level to be sold in the market from supplier group c (%) for extra assortment l
M	A large numerical value
C_{lt}^{SP}	The unit price of assortment l at time period t purchased from the spot market
P^s	Penalty cost per unit of inventory more than the target level
P^l	Penalty cost per unit of inventory below the target level

Decision variables:

u_{rlt}	Inventory of assortment l in woodyard r at the end of period t
$x_{r'rlt}^R$	Volume of assortment l transferred from woodyard r' to woodyard r at period t
x_{grlt}^G	Order volume ordered by PPC for assortment l by contract g to be delivered to woodyard r at period t
x_{glt}^E	Extra volume of assortment l sold in open market, from contract g at period t
x_{lt}^{SP}	Spot market purchases for assortment l at period t
u_{rlt}^s	Volume of assortment l exceeding the maximum level in woodyard r at period t
u_{rlt}^l	Volume of assortment l below the minimum level in woodyard r at period t
z_g	Binary variable, 1 if contract g is selected, and 0 otherwise
v_r	Binary variable, 1 if external woodyard r is decided to be opened, and 0 otherwise

Decision variables of the model are operational (i.e. decided for each monthly period), or strategic (i.e. decided once at the beginning). Strategic variables are the selection of contracts and opening an external woodyard. Operational decisions are related to the decisions for order volume or flow between different nodes in the procurement network, as well as inventory-related decision variables. The objective function is the minimization of the total procurement costs as shown below:

Total procurement costs = **Strategic costs** + $\sum_{t\in T}$ **Operational costs** (1)

Strategic costs = one-time costs of selected contracts + opening costs of woodyards (2)

Operational costs = purchasing + transportation + chipping + inventory holding – revenue from extra wood sales + penalty $\forall t \in T$ (3)

Fixed cost= $\sum_{c\in C}\sum_{g\in G_c} C_g^F z_g + \sum_{r\in R^E} C_r^R v_r$ (4)

Purchasing and transportation cost=

$$\sum_{l\in L} C_{lt}^{SP} x_{lt}^{SP} + \sum_{r\in R}\sum_{c\in C}\sum_{g\in G_c}\sum_{l\in L}(C_{grlt}^G + C_{glt}^L)x_{grlt}^G \quad \forall t \in T \qquad (5)$$

Transportation cost between woodyards= $\sum_{r'\in R^E}\sum_{r\in R}\sum_{l\in L^E} C_{r'rlt}^T x_{r'rlt}^R \quad \forall t \in T$ (6)

Chipping cost= $\sum_{r\in R^A}\sum_{l'\in L^A}\sum_{l\in L^E}(C^C_{rll'}\sum_{r'\in R^E}x^R_{r'rlt})$ $\forall t\in T$ (7)

Inventory holding cost= $\sum_{r\in R^A}\sum_{l\in L}C^I_{rl}u_{rlt}$ $\forall t\in T$ (8)

Revenue from extra wood sale= $\sum_{c\in C}\sum_{g\in G_c}\sum_{l\in L}Y_l x^E_{glt}$ $\forall t\in T$ (9)

Penalty cost= $\sum_{r\in R}\sum_{l\in L}(P^s u^s_{rlt}+P^l u^l_{rlt})$ $\forall t\in T$ (10)

Constraints in the problem are summarized below.

$$u_{rlt}\le P^R_{rl}v_r+u^s_{rlt} \quad \forall r\in R, l\in L \quad (11)$$

$$\sum_{r\in R^E}\sum_{l'\in L^E}\sum_{t\in T}(K_{rl'l}\sum_{g\in G_c}x^G_{grl't})\ge A^-_c\sum_{r\in R^A}\sum_{t\in T}D_{rlt} \quad \forall c\in C, l\in L^A \quad (12)$$

$$\sum_{r\in R^E}\sum_{l'\in L^E}\sum_{t\in T}(K_{rl'l}\sum_{g\in G_c}x^G_{grl't})\le A^+_c\sum_{r\in R^A}\sum_{t\in T}D_{rlt} \quad \forall c\in C, l\in L^A \quad (13)$$

$$\sum_{r\in R^A}\sum_{g\in G_c}\sum_{t\in T}x^G_{grlt}\ge A^-_c\sum_{r\in R^A}\sum_{t\in T}D_{rlt} \quad \forall c\in C, l\in L^A \quad (14)$$

$$\sum_{r\in R^A}\sum_{g\in G_c}\sum_{t\in T}x^G_{grlt}\le A^+_c\sum_{r\in R^A}\sum_{t\in T}D_{rlt} \quad \forall c\in C, l\in L^A \quad (15)$$

$$\sum_{r'\in R}\sum_{l\in L}\sum_{t\in T}x^R_{r'rlt}+\sum_{c\in C}\sum_{g\in G_c}\sum_{l\in L}\sum_{t\in T}x^G_{grlt}\le v_r M \quad \forall r\in R^E \quad (16)$$

$$X^I_{rl}+\sum_{c\in C}\sum_{g\in G_c}x^G_{grlt}=u_{rlt}+\sum_{r'\in R}x^R_{rr'lt}-\sum_{r'\in R^E}x^R_{r'rlt} \quad \forall r\in R^E, l\in L^E, t\in\{1\} \quad (17)$$

$$u_{rl,t-1}+\sum_{c\in C}\sum_{g\in G_c}x^G_{grlt}=u_{rlt}+\sum_{r'\in R}x^R_{rr'lt}-\sum_{r'\in R^E}x^R_{r'rlt} \quad \forall r\in R^E, l\in L^E, t\in T\setminus\{1\} \quad (18)$$

$$X^I_{rl}+\sum_{c\in C}\sum_{g\in G_c}x^G_{grlt}+\sum_{l'\in L^E}(K_{rl'l}\sum_{c\in C}\sum_{g\in G_c}x^G_{grl't}) +x^{SP}_{lt}=u_{rlt}+D_{rlt} \quad \forall r\in R^A, l\in L^A, t\in\{1\} \quad (19)$$

$$u_{rl,t-1}+\sum_{c\in C}\sum_{g\in G_c}x^G_{grlt}+\sum_{l'\in L^E}(K_{rl'l}\sum_{c\in C}\sum_{g\in G_c}x^G_{grl't}) +x^{SP}_{lt}=u_{rlt}+D_{rlt} \quad \forall r\in R^A, l\in L^A, t\in T\setminus\{1\} \quad (20)$$

$$\sum_{r'\in R^A}x^R_{rr'lt}\le P^C_{rl} \quad \forall r\in R^E, l\in L^E, t\in T \quad (21)$$

$$u_{rlt}+u^l_{rlt}\ge S_{rlt}v_r \quad \forall r\in R, l\in L, t\in T \quad (22)$$

$$(F^+_{gl}+1)Q_{grlt}z_g\ge x^G_{grlt}+x^E_{glt} \quad \forall c\in C, g\in G_c, r\in R, l\in L, t\in T \quad (23)$$

$$(F^-_{gl}+1)Q_{grlt}z_g\le x^G_{grlt}+x^E_{glt} \quad \forall c\in C, g\in G_c, r\in R, l\in L, t\in T \quad (24)$$

$$W_{cl}\sum_{r\in R}x^G_{grlt}\ge x^E_{glt} \quad \forall c\in C, g\in G_c, l\in L, t\in T \quad (25)$$

$$x^G_{grlt}, x^R_{rr'lt}, x^E_{glt}, u_{rlt}, u^s_{rlt}, u^l_{rlt}\ge 0 \quad \forall r'\in R, l\in L, t\in T \quad (26)$$

$$v_r, z_g\in\{0,1\} \quad \forall c\in C, g\in G_c, r\in R \quad (27)$$

Constraint set (11) represents the inventory level of woodyards for each assortment if the woodyard is opened. Constraint (12) and (13) denote that each supplier group for pulp logs should respect the supply portfolio limits, while constraint (14) and (15) are for the wood chip supply. The woodyards opening constraint is shown by (16). Pulp log flow balance constraints in PLYs are shown in (17) and (18). Flow balance for wood chips in WCYs is shown in (19) and (20). The maximum capacity of the chipping process is shown in constraint (21). In (22) target stock level in woodyards is denoted. Constraint sets (23) and (24) show the flexibilities in the contracts. For extra wood sales, there is a maximum level on the extra volume of sold material, shown by (25). Non-negativity and integer variables are defined in constraints (26) and (27).

2.4.2 Monte Carlo simulation

The simulation approach is first developed followed by different scenarios that are generated based on identified risks. Monte Carlo simulation is performed by generating numerous random events based on sourcing risks. It provides information on how the procurement plan changes over the planning horizon in the presence of random events. The simulation is embedded with a deterministic planning model in each period to modify the procurement plan after the realization of random events.

The first category of risks is the breach in contracts and their corresponding lost delivery volume from the moment of the breach to the end of the contract. The second category includes random variations related to the start of the thaw period. The third is based on the reliability of a specific contract where random variations from the forecast plan in each period are considered. After integrating these risks into the simulation approach, deliveries are updated in each period and the gap between the forecast plan and actual operations is considered in order to modify the procurement plan accordingly. For this purpose, the procurement plan is re-optimized for the remaining of the planning horizon in each period. The simulation is repeated a fixed number of times to achieve a confidence interval for the results. The formulation of sourcing risks is explained below in addition to an illustrative example of the simulation approach for generating random events.

2.4.2.1 Short-term risks

Thaw period

Aside from the probabilistic beginning of the thawing, different suppliers may not be able to comply with the contract during the thaw period, as wood harvesting and in-wood operations become very limited. To mimic the start of the thaw period, historic data from the Société de l’assurance automobile du Québec (2018) regarding the dates in which thawing begins and ends were extracted and analyzed. The three climate zones of Quebec were considered and suppliers were categorized according to their locations in these zones. A zone is a geographical area that is separated from other zones by the duration of its winter season. Figure 2.3 is adapted from the Société de l'assurance automobile du Québec (2018) and illustrates three zones in Quebec.

Figure 2.3. Three climate zones in Quebec.

For suppliers in zones where the winter season lasts longer in duration, the thawing ends at least at the same time as the zones with shorter winters, if not later. Table 2.1 demonstrates the logical sequence for the possibilities of the beginning and end of the thawing while considering that zone 3 has the longest winter and zone 1 as having the shortest winter. Considering a random binary variable that denotes the thawing in each period by h_{wt} $(where;\ t \in \{March, April, May\}\ and\ w \in \{1,2,3\})$, it is suggested that thawing may start in March or April and last two months. If the thawing forecast was different from the real thawing start date, for those suppliers who are sensitive to the thaw period in each zone, probability distributions were assigned to simulate delivery variation.

Table 2.1. Four scenarios of the thawing characterized by month and three transportation zones.

		March			April			May		
	Scenario	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 1**	**Zone 2**	**Zone 3**
h_{wt}	1	0	0	0	1	1	1	1	1	1
	2	1	0	0	1	1	1	0	1	1
	3	1	1	0	1	1	1	0	0	1
	4	1	1	1	1	1	1	0	0	0

As shown in Table 2.1, if h_{wt} equals one, the thaw period begins during the current month and in the associated zone. Some assumptions are provided to help in formulating this risk as shown below:

- Each contract is associated with only one climate zone;

- The probability of the thawing scenarios is more for scenarios 2 and 3, based on the frequency of occurrence in previous years;
- After the realization of the thaw period, the nominal volume in the contract may be revised by the procurement decision-maker. The order is adapted by considering the schedule of deliveries based on the thawing forecast and is shifted one period forward or backward according to the real thawing.

Therefore, the variations in the volume of deliveries are presented as follows:

γ : Risk factor for the maximum percentage of variation in price if thawing starts on period t'

$$\tilde{Q}_{grl,t+1} = Uniform[1-\gamma,1]*\bar{Q}_{gl,t+1}$$

$$\tilde{Q}_{grl,t+2} = Uniform[1-\gamma,1]*\bar{Q}_{gl,t+2}$$

Volume variations are applicable for first and second periods after thawing. Considering four probable scenarios for the thawing based on Table 2.1, PPC may encounter less wood supply than the forecast plan if the real delivery volume is less than the order volume. As a result, the company may need to sign short-term contracts to avoid the risk of shortage. The price of wood supply for available contracts is likely to be higher during these periods. We denote the price uncertainty in those periods by $\tilde{C}^L_{glt}$ for the period where the thawing is announced and by $\tilde{C}^L_{gl,t+1}$ for the period immediately after the start of the thaw period.

$\bar{C}^L_{glt'}$: Price of the order volume (from the forecast plan)

η : Maximum increase in the price of the contracts during the first period of the thaw period

θ : Maximum increase in the price of the contracts during the second period of the thaw period

$$\bar{C}^L_{glt} = Uniform[\bar{C}^L_{glt}, \eta + \bar{C}^L_{glt}]$$

$$\tilde{C}^L_{gl,t+1} = Uniform[\bar{C}^L_{gl,t+1}, \theta + \bar{C}^L_{gl,t+1}]$$

Contract's unreliability

The randomness associated with deliveries is integrated during the planning horizon due to several reasons, notably, machinery failure, uncertain harvesting and transportation capacity, market variations, and the tendency of suppliers to maximize their profit by not delivering wood supply based on a contract and selling the supply to another client instead. To formulate the unreliability of contracts, two parameters are assigned to each contract and are referred to as “risk factors”. These risk factors are the maximum possible variation for that contract from the order volume, representing upward variations (i.e. more than order volume) and downward variations (i.e. less than order volume). They are based on the historical data of similar contracts from previous years. Therefore, real delivery is randomly calculated by multiplying the order volume by a random value generated between upper and lower risk factors. The formulas are presented below.

Considering that the order volume in period t is $\bar{x}^{G}_{grlt}$ for each contract and each scenario, the following definitions are required:

α : Risk factor for the maximum percentage of variation (%)

β : Risk factor for the minimum percentage of variation (%)

$\bar{C}^{L}_{glt'}$: Price of the order volume (from forecast plan)

$\bar{x}^{G}_{grlt}$: order volume (from forecast plan)

$\tilde{x}^{G}_{grlt}$: Real volume (in presence of random events)

$$\tilde{x}^{G}_{grlts} = Uniform[\bar{x}^{G}_{grlt}(1-\beta), \bar{x}^{G}_{grlt}(1+\alpha)]$$

$$\tilde{C}^{L}_{glt'} = Uniform[\,\Omega t', Wt'] * \bar{C}^{L}_{glt'}$$

To create random events in simulation for this sourcing risk, values are generated so that the real volume will vary between $1+\alpha\%$ and $1-\beta\%$ of the order volume.

2.4.2.2 Long-term risks

Contract breach

This risk is added to the simulation approach by a probability associated with each contract. It is an estimation based on the business environment surrounding that contract and the information of the procurement decision-maker about that contract. Therefore, each contract may be canceled with a probability. In summary, considering the risks defined above, risk formulations are demonstrated in Table 2.2.

Table 2.2. Formulation of risks and uncertain parameters.

Uncertainty parameter	parameter	Probability distributions
Order volume	$\tilde{x}^{G}_{grlt}$	$Uniform[(1-\beta),(1+\alpha)] * \bar{x}^{G}_{grlt}$
Price during the thaw period	$\tilde{C}^{L}_{glt}$	$Uniform[\bar{C}^{L}_{glt}, \eta+\bar{C}^{L}_{glt}]$
	$\tilde{C}^{L}_{gl,t+1}$	$Uniform[\bar{C}^{L}_{gl,t+1}, \theta+\bar{C}^{L}_{gl,t+1}]$
Nominal volume during the thaw period	$\tilde{Q}_{grl,t+1}$	$Uniform[1-\gamma,1] * \bar{Q}_{gl,t+1}$
	$\tilde{Q}_{grl,t+2}$	$Uniform[1-\gamma,1] * \bar{Q}_{gl,t+2}$

2.4.2.3 Mitigation strategies

New contract selection

One option for mitigating the risk of shortage is to select other contracts, if available. With this approach, it is possible to quickly evaluate new contracts in the portfolio. In each period, new contracts are decided on by the model to be selected.

Adjusting the volume of option contracts

Using flexible and option contracts in this study, the risk of high inventory costs is transferred from PPC to suppliers. Option contracts can be activated in periods where PPC requires more supply from the forecast plan or vice versa. Therefore, it combines flexibility with long-term contracts. While it is beneficial to possess them, reserving the capacity from suppliers in advance is more expensive.

Spot market

In the presence of extreme random events, where other mitigation strategies are not efficient enough, the company must purchase wood fiber from the spot market. It is assumed that the price is known in advance. According to decision-makers, procuring wood from the spot market is more expensive. This option is usually an expensive strategy for replenishing the supply in case of delayed or lost deliveries.

Quotas

Quotas are used to manage oversupply. Due to the thaw period, the PPC may contract with numerous suppliers in advance. If the thaw period is delayed, oversupply is likely. Deliveries above the maximum level of woodyards will be refused.

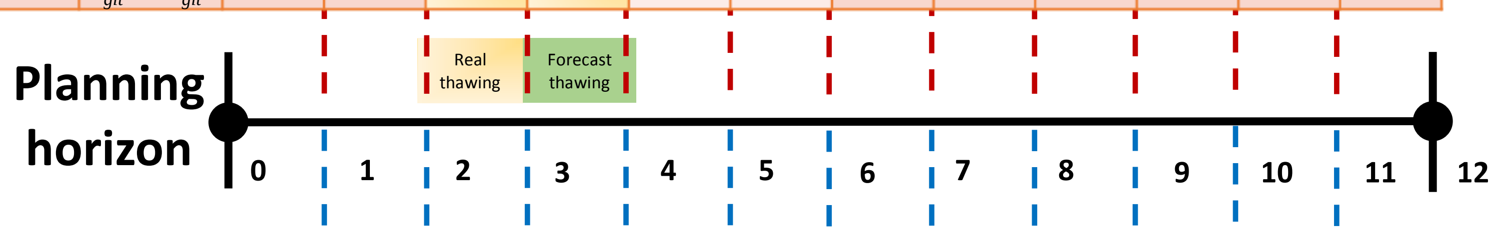
2.4.2.4 Illustration of one event of the simulation approach

Figure 4.2 illustrates one event in the simulation approach. It is a representation of the sourcing risks in each planning period and shows the mitigation strategies used to cope with the impact of risk on order volume and price of deliveries.

The horizontal axis represents the planning horizon of one year divided into 12 months. Sourcing risks occur, shown above this axis, and mitigation strategies are chosen as shown below the axis. Thus, in period 3the thaw period began one period earlier than the thawing forecast and delivery volume decreased by 1200 DMT, while the price increased by $15 for affected contracts. The respected volume from the contract breach is the volume that is no longer delivered due to the cancellation of the associated contract. For variations related to the unreliability of contracts, the difference of the real volume compared to the order volume is shown in each period. To mitigate the impact of the aforementioned variations in the volume and price of deliveries, a decision was not necessary for the first period; however, following this first period options were used from flexible contracts. Short-term contracts available from periods 2 to 4 were selected. In periods 3 and 4, it was also necessary to purchase from the spot market to compensate for the impact of the early thaw period. Close to the end of planning there were more deliveries which required applying quotas and decreasing the order volume from flexible contracts.

Risks

		1	2	3	4	5	6	7	8	9	10	11	12
Breach	$\bar{Q}_{grlt} - \tilde{Q}_{grlt}$	-150	-800	-1100	-912	-	-	-190	-434	-93	-311	-	-75
Deviation	$\bar{x}_{grlt} - \tilde{x}_{grlt}$	140	90	250	-300	-450	350	100	-	65	150	-	44
Thaw	$\bar{Q}_{grlt} - \tilde{Q}_{grlt}$	-	-	-1200	-	200	200	300	100	-	200	200	-
	$\bar{C}^{L}_{glt'} - \tilde{C}^{L}_{glt'}$	-	-	+15	+5	-5	-	-	-	-	-	-	-



Mitigation

		1	2	3	4	5	6	7	8	9	10	11	12
New contracts	**Volume**	-	300	900	300	-	-	-	-	-	-	-	-
Option contracts	**volume**	-	400	500	500	250	-	-	250	-	-	-100	-30
Spot market	**Volume**	-	-	300	100	-	-	-	-	-	-	-	-
Quotas	**Volume**	-	-	-	-	-	-	-70	-	-50	-50	-	-

Figure 2.4. Example of the simulation approach with the impact of respective risks and mitigation actions for one scenario

2.5 Case study

The present case study is adapted from that presented in Rahimi et al. (2019) with the addition of risk properties. Risks are integrated into the planning process to generate the optimal deterministic plan in each step of the simulation. Figure 2.5 illustrates a network of groups of suppliers in relation to the PPC. Five main groups are mentioned which refer to this case in Quebec and where each group provides an average of 300 contracts. Exclusive contracts exist between PPC and contractors on PPC's own forestland. In addition to this, every group provides all types of contracts such as fixed, flexible and option contracts. In contrast to the deterministic planning, there is the possibility of providing the wood fiber from the spot market.

The cost of contracts is negotiated and agreed upon in advance. Therefore, PPC procurement decision-makers are required to select among those contracts. The price of the fixed contract is less than the option and flexible contracts. The price of flexible and option contracts are up to 50% more than similar fixed contracts. The price of wood fiber in all contracts varies between 87.7 and 186.4.

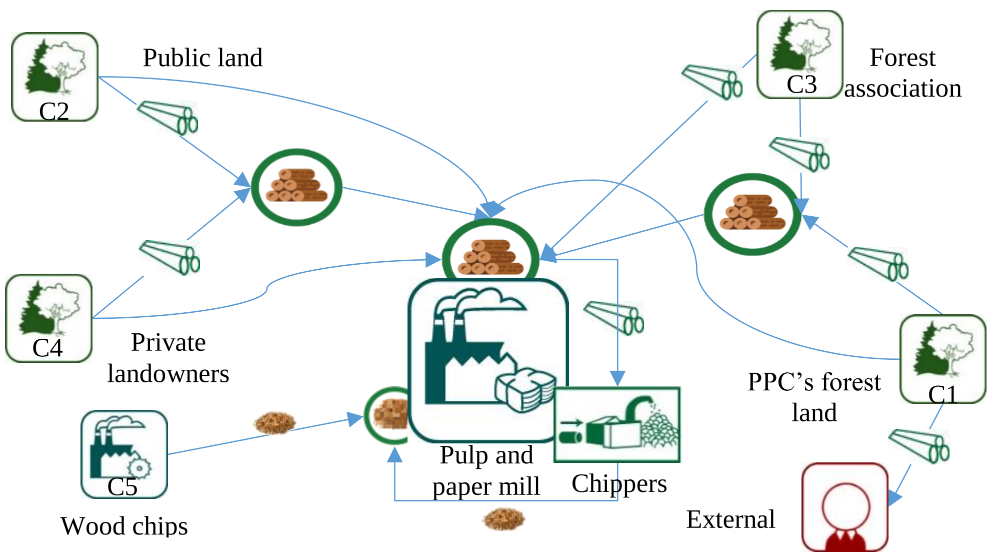


Figure 2.5. The flow of wood fiber for the case study

The size and key characteristics of the case are summarized in Table 2.3. The planning is done for 12 months. Detailed information is available in Rahimi et al. (2019).

Table 2.3.Case size and key characteristics.

Abbreviation	Set	Size
Woodyard for pulp logs	R^E	3
Woodyard for wood chips	R^A	1
Assortments	L^A	2

	L^E	2
Supplier groups	C	5
Contracts	G	1500

In addition to the fixed and known data, it is necessary to account for the stochastic nature of the problem. The necessary data are provided for three types of risks in procurement in Tables 2.4 and 2.5 below.

Table 2.4. The probability distribution for uncertain parameters.

Uncertainty parameter	Parameter	Probability distributions
Price of available contracts	$\tilde{C}^{L}_{glt'}$	$Uniform[-3,3]*\bar{C}^{L}_{glt} \quad \forall t \in T$
Delivery volume	$\tilde{x}^{G}_{grlt}$	$Uniform[(1-\beta),(1+\alpha)]*\bar{x}^{G}_{grlt}$
Price during the thaw period	$\tilde{C}^{L}_{gl,t+1}$ $\tilde{C}^{L}_{gl,t+2}$	$Uniform[\bar{C}^{L}_{gl,t+1}, 5+\bar{C}^{L}_{gl,t+1}]$ $Uniform[\bar{C}^{L}_{gl,t+2}, 5+\bar{C}^{L}_{gl,t+2}]$
Volume during the thaw period	$\tilde{Q}_{grl,t+1}$ $\tilde{Q}_{grl,t+2}$	$Uniform[0.8,1]*\bar{Q}_{gl,t+1}$ $Uniform[0.8,1]*\bar{Q}_{gl,t+2}$

Table 2.5. Probability of different scenarios for the thaw and breach risks.

Scenarios	Scenario number	Probability of occurrence
The start of the thaw period	Scenario 1	12.5%
	Scenario 2	37.5%
	Scenario 3	37.5%
	Scenario 4	12.5%
Contract breach	Scenario per each contract	2%

The values of the risk factors for the contract's unreliability depend on the characteristics of the contracts, such as flexibility, order price, and delivery volume. With respect to the volume, private owners are more sensitive to the selling price. Therefore their deliveries may be relatively riskier if a more reasonable price is found by another client. On public land, PPC pays fixed stumpage directly to the government but is guaranteed to a certain allotment. They must only secure harvesting capacity by contract. Wood chip producers are relatively more reliable, as wood chips are secondary products of sawmills. Wood chip deliveries are, therefore, assumed to vary less than pulp log deliveries. These assumptions are included in generating α and β for respective contracts per group. To provide a scale of the risk factors for contracts, it has been observed that for risky ones it can reach up to 30% (more or less than order volume), while for reliable contracts these risk factors are closer to zero. Finally, it is assumed that spot market purchases are quite costly which encourages the continuation of the available portfolio and evaluation of its efficiency.

2.6 Results

A computer with a 2.30 GHz CPU and 15.7 GB RAM was used to run the simulation (and optimization) model. 10 simulations was done for each of the cases of using inflexible (a1), flexible (a2) and the mix of both sets (a3). Table 6.1 gives the results from both the forecasted plan (F-xx) and the simulated operations (A-xx). For the inflexible set of contracts, (A-a1 and F-a1), a significant difference was found due to the large purchases from the spot market and from violating inventory target levels. Even though many contracts are signed during the actual operations (purchasing cost increases by about $3,000,000 CAD), more supply is needed to avoid the shortage. When adding flexibility to contracts, the performance is improved and the total costs of the actual operations are less than the inflexible portfolio. Although, in contrast to the forecast plan that suggests the mixing of flexible and inflexible contracts, the simulation shows that case a2 with sole flexible contracts perform better with less total costs.

Standard deviations of the results help in identifying the reliability of the forecast plan. As shown in Table 2.7, the standard deviation (from the simulations) of cost segments in case a1, is generally more than in other cases, confirming that the plan is relatively sensitive to different scenarios. By considering the possible lower and upper bound of each case, for some scenarios, case a2 demonstrates more promising results and for other scenarios case a3 is the best strategy.

To highlight the minimum and maximum range that procurement costs can reach in the actual operations, the distribution of results is illustrated in Figure 2.6. Results are shown for three cases: a1, a2 and a3 in the same chart.

Table 2.6. Cost comparison of the forecast plan (inflexible F-a1, flexible F-a2 and a mix of the two previous cases F-a3) and actual operations (inflexible A-a1, flexible A-a2 and a mix of the two previous cases A-a3) (in $1000 CAD)

Case	WF	P + S	TR	PU	CH	CF	Inventory		EW	OF-P	OF
							WC	PL			
F-a1	250	207 + 0	3 338	14 719	6 246	131	2 112	3 654	962	29 490	29 697
F-a2	125	0	2 704	15 875	6 186	115	2 085	3 315	1 431	28 976	28 976
F-a3	125	0	2 653	14 427	6 190	105	2 036	3 212	1 789	26 961	26 961
A-a1	250	4 170 + 3 349	3 184	17 816	5 748	205	2 062	3 391	891	35 162	39 333
A-a2	250	694 + 3	2 656	17 590	5 668	137	2 033	3 531	1 605	30 258	30 952
A-a3	125	2 022 + 117	2 708	17 720	5 639	186	2 032	3 078	1 682	29 930	31 953

Table 2.7. The standard deviation of costs for actual operations ($1000 CAD)

Case	WF	P + S	TR	PU	CH	CF	Inventory		EW	OF-P	OF
							WC	PL			
A-a1	0	567 + 1 085	27	394	15	6	19	23	35	1 156	1 288
A-a2	0	250 + 5	37	567	5	10	7	25	38	570	622
A-a3	0	358 + 68	37	355	9	7	8	32	56	369	514

OF: objective function, OF-P: objective function-penalty, EW: extra wood sales, PL: pulp log, WC: wood chips, CF: contract fixed costs, CH: chipping, PU: purchasing, TR: transportation, P+S: penalty + spot market purchases, WF: woodyard fixed cost

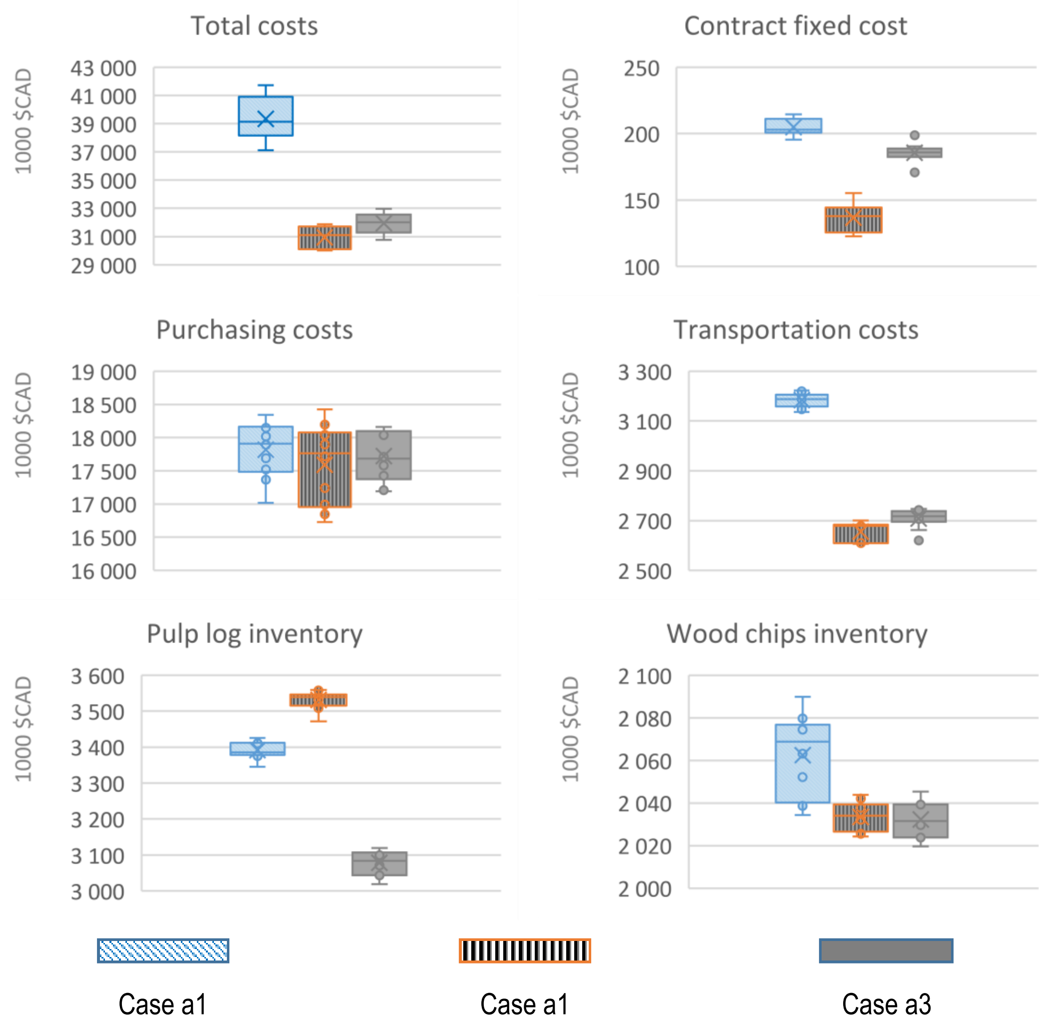


Figure 2.6. Box and whisker plot for different cost segments comparing case a1, a2 and a3.

Results in Figure 2.6 emphasize that the pure flexible contract set will have lower costs compared to other cases. Although purchasing costs might vary more, it helps to control the costs of transportation. In addition, the ability to modify the order volume of a flexible strategy according to the nominal volume can be used to accumulate inventory in advance instead of selecting new contracts in the presence of sourcing risks affecting deliveries of future periods. Therefore, relatively higher inventory costs occur. In the fixed contract set, the absence of flexibility results in selecting new contracts such that their nominal volume may be additional to the needs of PPC. In order to manage the total volume of supply in the procurement network, the transportation is too occupied to allow a balance in woodyard oversupply and inventory costs. Thus, this results in having more transportation costs in inflexible strategy. To understand the impact of each sourcing risk separately, more details are provided in Table 2.8 below. In Table 2.9 the standard deviation of each case is provided.

Table 2.8. Cost comparison of actual operations with the flexible set (A-a2) for different combinations of sourcing risks ($1000 CAD).

Case	WF	P + S	TR	PU	CH	CF	Inventory		EW	OF-P	OF
							WC	PL			
A-a2	250	694 + 3	2 656	17 590	5 668	137	2 033	3 531	1 605	30 258	30 952
1*	250	326 + 5	2 589	15 593	5 669	104	2 057	3 649	1 534	28 374	28 701
2+	250	0	2 604	16 095	5 670	114	2 038	3 508	1 656	28 622	28 622
3x	250	451 + 6	2 632	17 568	5 669	132	2 038	3 590	1 605	30 295	30 747
1,2	250	355 + 12	2 589	16 118	5 669	113	2 048	3 594	1 604	28 783	29 139
1,3	250	760 + 11	2 635	17 270	5 667	128	2 047	3 621	1 498	30 126	30 886
2,3	250	631 + 11	2 635	17 757	5 669	138	2 026	3 489	1 625	30 354	30 986

Table 2.9. The standard deviation of costs for actual operations for different combinations of sourcing risks (1000 CAD$)

Case	WF	P + S	TR	PU	CH	CF	Inventory		EW	OF-P	OF
							WC	PL			
A-a2	0	250 + 5	37	567	5	10	7	25	38	570	622
1*	0	25 + 9	1	6	0	1	1	9	34	36	45
2+	0	0	4	13	0	1	0	9	4	17	17
3x	0	214 + 17	28	912	6	10	9	16	55	914	939
1,2	0	56 + 13	4	19	0	2	3	9	19	29	65
1,3	0	234 + 10	48	503	7	8	11	11	31	507	559
2,3	0	311 + 32	39	411	5	7	8	30	37	416	520

*The scenario with the risk of only contract's unreliability

+The scenario with the risk of only the start of the thaw period

xThe scenario with the risk of only contract breach

Comparing the total costs of each scenario by combining a breach in contracts with any other risks results in the worst impact. It is shown that the combination of the contract's unreliability with the thaw period imposes higher costs on the actual operations compared to the forecast plan. However, comparing the objective functions of the cases, where only the contract's unreliability or the thaw period occurs, shows an improvement in total costs. This is due to the fact that, on average, a greater volume of wood supply may be delivered compared to the forecast plan, thus, providing a chance of having a higher volume at lower prices. The contracts that provide a better price and volume are allocated with more share of supply during re-planning, while expensive contracts are allocated less share of supply.

From Table 2.8, it may be observed that some risks may reduce the negative effects of others. For example, when volume variations increase in some periods, they can compensate a part of the volume loss due to contract breach (comparing case A-a2 in the presence and absence of a contract's unreliability). Therefore, there are not only threats related to sourcing risks, but managing the risks properly may provide some opportunities to reduce the aggregated impact on procurement costs. The re-optimization of the plan in each period finds the best mitigation strategy to cope with the overall impact of sourcing risks rather than each risk separately.

Comparing standard deviations in Table 2.9 demonstrates that the contract breach has the highest variation in cost segments, while the thaw period contains the least. Most variations are observed in purchasing costs and inventory violations from target levels, especially in the presence of a contract breach. To compare inventory levels between the forecast plan and actual operations, different sourcing strategies are used as mentioned above, in the presence of all sourcing risks. The inventory results are shown in Figure 2.7 for the hardwood assortment for the flexible set, fixed set, and mix of contracts.

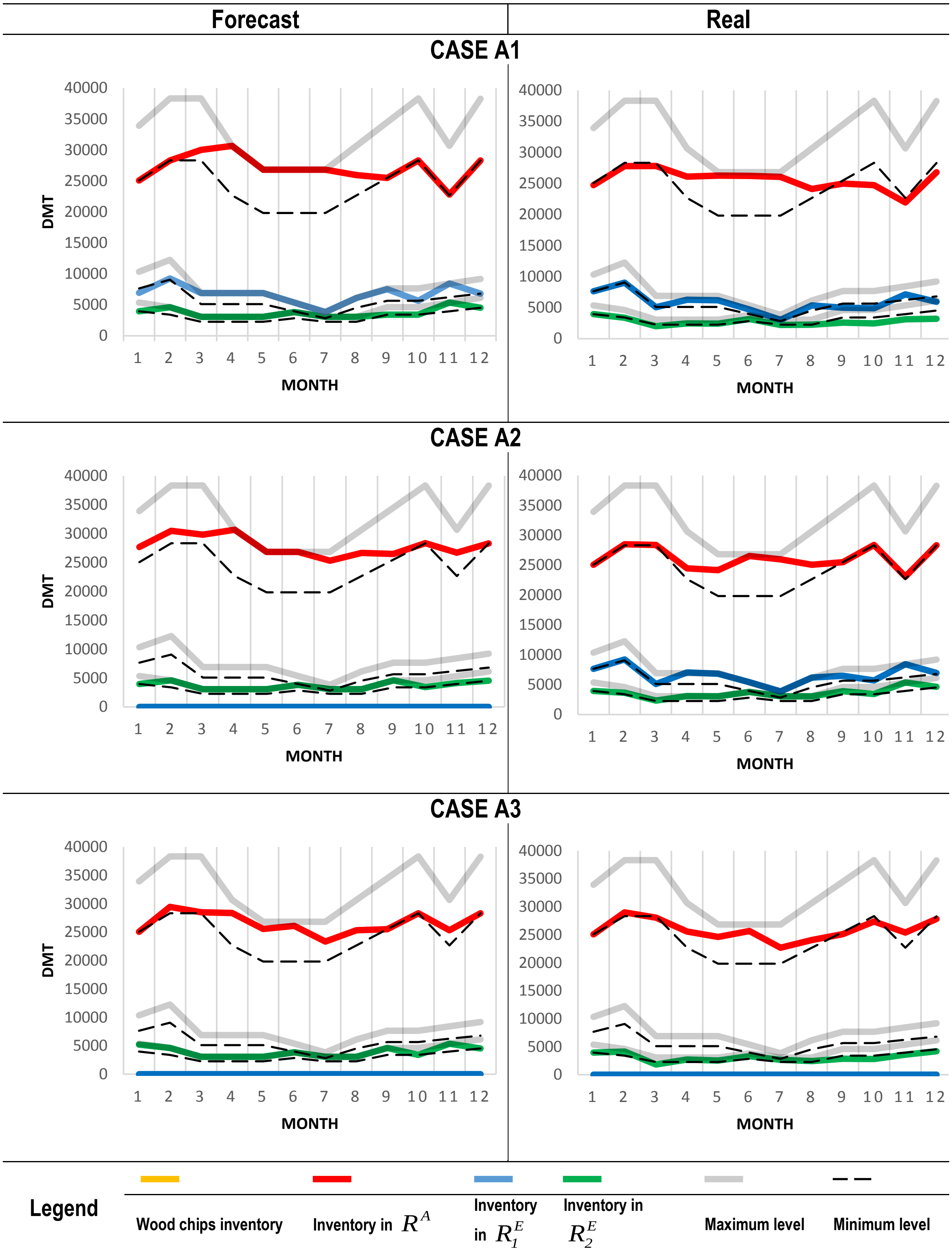


Figure 2.7. Inventory level of yards for hardwood pulp log (forecast plan VS. real plan).

In all cases, the inventory tends to decrease during the actual operations. For case a3, the mix set of inflexible and flexible contracts is advantageous by selecting only one woodyard in the forecast plan. During the simulation, with real deliveries, it is established that one woodyard is still sufficient. However, at the beginning of the actual operations for case a2, it is beneficial to open a second woodyard, in contrast to its forecast plan to be able to use it for wood supply transfer between woodyards. This decision stands for all scenarios during the simulation for case a2. In the second case, the inventory is also less violated than case a1 and a3, since flexible contracts are able to better manage the inventory. As demonstrated with the cost comparison in case a1, the inventory target level is violated near the end of planning. Fixed contract sets do not allow for rapid modifications in case of major risks.

2.7 Conclusion

In this article, sourcing risks are integrated into the procurement plan and the plan is simulated to realize their respective impact on total volume and price of deliveries. The variations in cost and inventory levels were determined and analyzed. Random events were generated by a Monte Carlo simulation approach. Our evaluations provided a more realistic view of the performance of the selected procurement strategy compared with deterministic planning. The performance of using different contract sets was analyzed with this approach. In the presence of all sourcing risks, the pure flexible portfolio provided better total costs than the other two cases (with fixed or with a mix of both fixed and flexible contracts). The importance of flexibility in the procurement was shown by providing lower costs and more stable inventory levels. Although some risks caused higher unexpected costs, there were opportunities that may help to reduce the negative effects of other risks, such as reduced costs from delayed deliveries which decrease inventory costs in some scenarios.

By using the evaluations that were presented in this paper, companies may be able to reduce delays associated with making proper mitigation decisions. Our simulation not only provides estimations on the impact of sourcing risks in a short time but also uses real information to re-optimize the plan in each period. Re-optimization of the entire model ensures a balance between penalty costs for violations from inventory target levels and spot market purchases, to determine the best mitigation strategy.

As an improvement effort to reduce the gap between the forecast plan and actual operations, the procurement plan needs to take into consideration sourcing risks, while performing the forecast plan. As a future study, the goal is to provide a stochastic programming model of the problem in order to have an average optimized plan in the presence of sourcing risks to better anticipate the underlying uncertainty.

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Chapter 3 Selecting Wood Supply Contracts under Uncertainty using Stochastic Programming

Résumé

Une grande partie des dépenses dans les industries forestières est associée à l'approvisionnement en bois. De nombreux fournisseurs sont impliqués et obtenir des contrats d'approvisionnement en bois à des prix compétitifs est un défi constant pour les responsables des achats. Une difficulté majeure est l'exposition de l'approvisionnement à divers risques, notamment le début du dégel du printemps, la rupture de contrat ou le manque de fiabilité des fournisseurs. Un plan d'approvisionnement doit prévoir des événements aléatoires et inclure des mesures pour contrer leur impact négatif. Les actions de recours doivent être planifiées en tenant compte de l'incertitude des volumes et des fluctuations des prix du bois. S'appuyer sur des outils manuels est à peine capable de considérer tous les aspects de ce problème. Une approche de programmation stochastique est proposée pour soutenir l'élaboration d'un plan d'approvisionnement. Dans ce modèle, plusieurs types de contrats, y compris les contrats fixes, flexibles et d'options avec des durées différentes, sont inclus. La sélection de contrats proposée à partir d'un modèle de programmation stochastique donne une optimalité moyenne en présence de scénarios plausibles. Le modèle de programmation stochastique en deux étapes développé décide de la sélection du portefeuille optimal de contrats pour minimiser les coûts d'approvisionnement totaux. À partir d'une étude de cas développée à partir des caractéristiques d'une entreprise forestière au Québec, le coût moyen d'approvisionnement de 30 millions de dollars résulte de l'approche de programmation stochastique. Les résultats ont montré une économie moyenne de 4% en utilisant la programmation stochastique par rapport à l'approche déterministe.

Mots-clés: Programmation Stochastique, Approvisionnement en Bois, Sélection de Contrats, Stratégie de Portefeuille

Abstract

A large portion of expenses in the forest industries is associated with wood supply procurement. Numerous suppliers are involved and securing wood supply contracts with competitive prices is a constant challenge for procurement managers. A major difficulty is the procurement exposure to various sourcing risks including the start of the spring thaw, contract breach, or unreliability of suppliers. A procurement plan should anticipate random events and include measures that counter their negative impact. Recourse actions must be planned by considering volume uncertainty and wood price fluctuations. Relying on manual tools is hardly capable of considering all aspects of this problem. A stochastic programming approach is proposed to support the development of a procurement plan. In this model, several types of contracts including fixed, flexible and option contracts with different durations are included. The proposed selection of contracts from a stochastic programming model yields average optimality in the presence of plausible scenarios. The developed two-stage stochastic programming model decides on the selection of the optimal portfolio of contracts to minimize total procurement costs. Based on a case study developed from the characteristics of a forest company in Quebec, the average procurement cost of $30 million resulted from the stochastic programming approach. Findings showed an average saving of 4% by using stochastic programming compared to the deterministic approach.

Keywords: Stochastic Programming, Wood Supply Procurement, Contract Selection, Portfolio Strategy

3.1. Introduction

In a Pulp and Paper Company (PPC) procurement department is responsible for developing an annual plan, which includes the selection of suppliers and their contracts. The plan provides a periodic expected delivery volumes. Tang (2006) stressed that while acquiring a wide range of suppliers is advantageous to share risks, the management of numerous suppliers becomes challenging. The complexity increases in the presence of different types of suppliers in the forest sector. In Quebec-Canada, the location of our case study, a large proportion of forest lands is under public ownership (approximately 82%) while the remaining is owned by many small private woodlot owners and a few large industrial owners (Gouvernement du Québec, 2016). The suppliers in each group have different business status which affect the characterisitics of their contracts.

For suppliers working on mixed forest, with different tree species, overlapping procurement operations occur and collaboration with their clients is required to reduce costs of obtaining wood allotment (Beaudoin et al., 2010). In this environment, the production volume of different assortments for forest companies is interdependent. Therefore, a supplier working on these lands may prioritize its profitability based on the market condition. This decision can impact deliveries of companies who has contracts with that supplier If numerous suppliers in mixed forest deliver more volume than expected at the same time, it may result in extra inventory costs. Otherwise, if less volume is delivered, risk of supply shortage increases. As a result, reliability of suppliers are important to be considered for the PPC, In the procurement operations based on the fixed contracts, variations are more likely to increase procurement costs, since theydo not permit modification of the order volume.

One other major risk for our study is the spring thaw which affects transport activities in Nordic countries such as Canada, for instance. Specifically, during the thaw period, snow and ice in the road structure begin to melt and wet soft ground reduces the allowed road capacity and thus the payload of trucks. The forest road network, which is not paved, might be completely closed to wood transport to avoid road structure damages. Such difficulty in procuring wood results in seasonal price fluctuations (i.e. often an increase) (Gallagher et al., 2003) while the start of the thaw period remains uncertain.

Another main issue is related to complete stoppage of contracts' deliveries. Although contracts create a commitment between suppliers and the PPC, suppliers may not be able to fulfill their contracts due to reasons such as fire or infestation in their harvesting zones. Although with low probability, the impact of such events can be large. In addition, the conditions in the market have forced many suppliers to shut down their operations, consequently breaching the contract with the PPC. For example, several closures occurred around 2008 when international market changes forced companies to lay off shifts or close their operations (Pinkerton and Benner 2013).

Since, in the current study, we focus on the sourcing risks and their impact on the volume of deliveries from suppliers, the three abovementioned categories of risks can resemble other risks. Sourcing risks influence procurement operations at different magnitudes and the impact may persist from the short- to the long-term. The main impact is on the volume of deliveries, causing a partial or complete stoppage of a typical contract. Therefore, a mismatch between wood supply and demand is probable. As a result, procurement costs after implementation of a deterministic plan can be relatively high. It was demonstrated by Rahimi et al. (2020) that 35% deviation might occur in the procurment budget in the absence of integrating abovementiond sourcing risks. This study was a simulation of real world events with an embedded optimization model of the procurement plan. Martel and Klibi (2016) stated that selecting the suppliers wisely could decrease the risk of having variations in the characteristics of deliveries. To mitigate the impact of variations, they suggested that flexibility with partnership among suppliers could be elaborated. Traditionally, the procurement operations are managed through contracts. In this regard, regular contracts are the most common and they are modeled by fixed price, discount, and fixed duration contracts. Integration of flexibility in the operations can be considered by using flexible contracts. Flexible contracts allow the buyer to change the order level with a usually higher unit cost than fixed contracts (Blanco et al. 2018).(

The Stochastic Programming (SP) approach is an efficient method when the future realizations of uncertainty can be estimated by a probability distribution or by a set of scenarios. By applying sourcing risks and their associated probability distributions, possible scenarios of random events are determined (Ben-Tal et al., 2000). The SP considers all generated scenarios for generating the optimal solution (Birge & Louveaux, 1997). Thus, the optimal solution from this approach provides an average optimal value.

Having sufficient historical data for the deliveries of contracts and spring thaw, as well as the probabilistic nature of contract breaches, plausible scenarios based on random events, may be generated. In addition, the objective of this study is to provide a procurement plan for the PPC that has an optimal expected total procurement cost. In the presence of the inventory in the woodyards, conservative solutions may result in costly strategies. Therefore, a two-stage SP approach is developed based on the Deterministic Model (DM) presented in Rahimi et al. (2020). Solving multistage SP is often challenging. Therfore an approximations is usually obtained by reducing the number of stages

(Giovanni and Boomsma, 2016). When considering a two-stage approach, the first stage variables are determined by viewing all scenarios. In the literature, optimal first-stage decisions are referred to as control variables or “here and now” variables. Second stage decisions are only made once the uncertainty is realized. For each scenario, new values for the second stage variables are determined (i.e. a set of recourse decisions, also called state variables or “wait-and-see” variables).

In the current study a two-stage SP model will be developed for the procurement operations of a PPC. We will show the benefits of this approach versus DM, while comparing three cases with fixed, flexible, and a mix of fixed and flexible contracts. The objective is to propose the best procurement strategy that result in minimum total costs, while we compare the reliability of the proposed plans from each solution method as well. The comparison of solution methods will be against Oracle, as the best theoretical solution.

The remaining of the paper is organized as follows. Section 2 summarizes the literature on SP models and their application. It also highlights the gap between existing SP applications in the literature and the application of the SP in this study in order to address the integration of risks into different sets of contracts. Section 3 presents the extension of the deterministic modelDM to the SP model. Section 4 describes the case study. Computational results for the SP model are presented in Section 5 followed by a conclusion in Section 6.

3.2. Literature review

In the study by Chopra and Sodhi (2004) benefits of multiple sourcing strategies and controlling supply risks were mentioned. Risks in procurement were introduced by causing fluctuations in the price of deliveries from suppliers or transportation costs. Drivers of these risks were the exchange rate and duration of contracts. In Dulmin and Mininno (2003) and Sarkis et al. (2007), it is addressed that selecting suppliers is the most important task, as it has a high impact on quantity, quality, time and price of purchased material.

Everett et al. (2000) formulated the optimal allocation of suppliers to mill by a mixed-integer programming model. Their proposed model has determined decisions in tactical and strategic levels. The sourcing options consist of pine and eucalyptus logs from several suppliers, chips from sawmills, and recycled papers. Philpott and Everett (2001) presented a stochastic programming model for a PPC for a planning period of ten years. Their stochastic model presented three scenarios for the market forecast, as expected, optimistic, and pessimistic forecasts. However, the size of the problem was too large to achieve optimal results. Nevertheless, the results of the model for the three scenarios showed considerable variability.

In a study by Bansal et al. (2007) the problem is defined as selecting both contracts and suppliers for a multinational company. In order to do that, contracts are classified based on characteristics such as their types, prices, durations, and suppliers. Their deterministic model suggested the optimal sourcing strategy by minimizing the costs. In the study by Talluri and Lee (2010), the authors investigated the optimal selection of contracts in manufacturing firms by mixed-integer programming approach. They presented insights to manufacturing managers on choosing the right contracts (short, long or mid-term), in the presence of market price uncertainty, supplier discounts, investment costs, and supplier capacity restrictions. An important conclusion of their study was that the long-term contract strategy might not be superior to short-term strategy. This was also concluded that no strategy systematically dominated others.

In this literature, many studies have adapted SP approach in the forest sector. Recently, Ouhimmou et al. (2019) investigated the design of a distribution network under demand uncertainty. The problem was tested in the context of the pulp and paper industry to determine the selection of warehouses and their required rental space. The authors used a robust optimization approach to minimize the total distribution cost. The decision was made on the trade-off between investing in PPC's own warehouses and leasing warehouses from the other third-party logistics companies. The proposed robust solution enabled the PPC to hedge against demand uncertainty and minimized its distribution costs. There was, however, no consideration of supply uncertainty in this study. In addition, no contracts were used and the operations were focused on the customers of the PPC products. The uncertainty in supply was included in the supply chain of a forest biomass power plant by Shabani et al. (2014). A two-stage linear SP model was used with the first-stage decision as the amount of biomass to be purchased, stored and consumed from each supplier in the first three periods. For the remaining nine months of planning, these variables were considered as second-stage. They showed that the SP model was able to generate more profit than that of the DM. Only long-term fixed contracts were included with suppliers and customers, while some transactions were possible without a contract.

In Cunico and Vecchietti (2015), authors described the benefits of selecting suppliers and contract types to propose an optimal set of suppliers and considered uncertainty in the characteristics of deliveries from suppliers. The configuration of contracts was addressed by three different types of contracts. However, all contract types were considered as fixed, if selected. In addition, only difference among contract types were in price and volume. The problem was considered for a simple network that did not include warehouses or terminals. There was no distinction between different sourcing risks causing short- or long-term variations in the supply.

More types of contracts such as flexible and option contracts were considered by Blanco et al. (2018), however tested by a case with only thirteen contracts. The authors proposed a solution approach for biomass supply planning. They used the two-stage SP model for two phases of their solution approach and historical data to create scenarios with a combination of past data and time-series forecasts. The problem was considered from the perspective of the company that receives raw materials from suppliers. First-stage decisions were the delivery times and amounts in the first week while the remaining weeks included second-stage decisions. The uncertainty was included in the electricity price, demand for heat, and fuel price. Large number of contracts is not tested with their approach, while the consideration of fixed and flexible contracts and the generation of scenrios through sourcing risks formulation is similar to the our study. The expansion of the study to include different groups of suppliers is another difference between two studies, which adds another contribution on managing the supply portfolio.

Investigation of the previous studies showed that no work had propose an SP contract selection model for large-sized procurement operations of a PPC. Most of the previous studies have generated scenarios with direct consideration of probability distributions for uncertainty or by using time-series analysis, such as in Blanco et al. (2018). Furthermore, the difference of our study with Cunico and Vecchietti (2015) is the consideration of long and short-term sourcing risks for generating scenarios, i.e. simultaneous consideration of the contracts' unreliability, contract breach, and the start of the thaw period.

The consideration of different types of contracts has been studied by Blanco et al. (2018), but only with a limited number of contracts. Furthermore, the uncertainty was not considered in the delivery volume from suppliers. In our study, we consider a large portfolio of contracts with volume uncertainty in addition to a delivery price uncertainty for alternative contracts. The consideration of different groups of suppliers has not been investigated in the contract selection area. Each supplier may have different contracts due to the different locations and status of its operations. Nevertheless, by assuming a single location for a supplier, contracts may still differ in duration or volume flexibility levels. The main contributions of this study are:

1. To develop a two-stage SP model that combines optimal contract selection with different sourcing risks, groups of suppliers, types of contract, and their related uncertainties in delivery volume and price.
2. To develop a scenario generator based on sourcing risks (i.e. the contracts' unreliability, contract breach, and the start of the thaw period)
3. To apply the proposed SP model on a large-sized case study and compare it with DM and Oracle. Three cases are evaluated with our proposed SP approach to compare the portfolio with fixed contracts, flexible contracts and a mix of both sets.

3.3. Stochastic programming model

In the present study, the solution approach is to develop an SP model of the procurement planning. To integrate risks, scenarios have to be generated. The method to generate scenarios is based on the Monte Carlo approach. First, the SP model is developed in this section based on the DM by Rahimi et al. (2020). Then, the generation of scenraios will be explained. The performance of the SP model is compared by two other approaches, Oracle and the plan from DM. For each method, three cases are compared by consideration of different contract sets and the results will be discussed to underline the best procurement strategy.

SP development

In SP, uncertainty is represented through scenarios. In this context the data occur with a given probability, while the objective is to optimize the expected cost. The SP model for this study is developed based on the mixed-integer DM presented in Rahimi et al. (2020). The DM optimizes the procurement process assuming complete information regarding contracts and the procurement network. It is used to select the sourcing contracts, external woodyards available to store wood (merchandizing yard), order volume from each contract, the flow of material and inventory level in woodyards. Decisions are made to minimize the procurement costs in the presence of constraints such as the capacity of woodyards, chipping process capacity and inventory target levels. A portfolio constraint is also included to account for the preferences of the PPC in dividing the supply among different supplier groups. Fixed and flexible types of contracts in relation to various types of suppliers are considered. Each contract possesses characteristics such as volume, start and end, schedule of deliveries, and volume flexibility (if not a fixed contract). Suppliers are categorized based on forestland ownership, which affects the characteristics of contracts. Multi-period procurement planning is considered with multiple woodyards and multi-assortments. Assortments are different tree segments and differ in species, dimensions, and quality. For a PPC, in the present case, softwood wood chips, hardwood wood chips, softwood pulp logs, and hardwood pulp logs are used for the production process at the mill. Woodyards are divided into the wood chips yard (WCY) and pulp logs yard (PLY). Only one WCY is located at the mill. One PLY is also located at the mill, while there are two external PLYs (merchandizing yard) available to be opened.

The extension of the DM model is done by formulating a two-stage SP. In a two-stage SP, the decisions that are made before the realization of uncertainty are "first stage" decisions (in our case contracts selected at the beginning during the period one). The "second stage" decisions are made after occurrence of the uncertain events (in our case volume of flow in the network, inventory levels, and the contracts selected after the first period). There is one set of first-stage decision variables and constraints. Non-anticipatively constraints are used to ensure this. However, the number of sets of two-stage decisions equals to the count of scenarios. First-stage decisions are made in the face of uncertainty to satisfy all scenarios. Second-stage decisions that are actually implemented depends on the realized uncertain events. The objective is to maximize the expected value of total costs of procurement splited in two parts; the term(s) with the first stage variables and the terms with the second stage variables. Second part is multiplied by the probability of each scenario (in our case equally distributed probabilities for all scenarios). The definition of sets, parameters, and variables are provided below to present the SP model.

Sets :

S	Set of scenarios
R	Set of woodyards
T	Set of time periods
L	Set of assortments
C	Set of supplier groups
G_c	Set of contracts for supplier group c
G_c^1	Set of contracts with supplier group c starting from the first period
G_c^2	Set of contracts with supplier group c starting after the first period

Supporting set :

R^E	Set of pulp log yards (PLY)

R^A	Set of wood chip yards at mills (WCY)
L^E	Set of pulp log assortments
L^A	Set of wood chip assortments

Parameters :

Q_{glrts}	The nominal volume of assortment l to be delivered to woodyard r at t in contract g for scenario s
ρ_s	Probability of each scenario
D_{rlt}	Demand for wood chips for mill r for assortment l at t
S_{rlt}	Inventory target level for assortment l in woodyard r at t
C^I_{rl}	Inventory unit cost for assortment l in woodyard r
X^I_{rl}	Initial inventory for assortment l in woodyard r
$C^T_{r'rlt}$	Unit transportation cost for assortment l from woodyard r' to woodyard r at t
C^G_{grlt}	Unit transportation cost for assortment l for contract g to deliver to woodyard r at t
$K_{rll'}$	Conversion rate in woodyard r to convert pulp log assortment l to wood chips assortment l'
$C^C_{rll'}$	Unit cost of chipping operations in woodyard r to convert pulp log assortment l to wood chips assortment l'
C^R_r	Fixed cost of opening external woodyard r
P^R_{rl}	Capacity of woodyard r allocated to store assortment l
P^C_{rl}	Capacity of chipping operations for transforming pulp log assortment l in woodyard r
C^L_{glts}	Cost per unit assortment l in contract g at t for scenarios s
C^F_g	Initiation fixed cost when contract g is selected
Y_l	Unit price of selling extra assortment l from harvesting operations in open market
F^+_{gl}	Maximum level of flexibility for the nominal volume of contract g for assortment l (%)
F^-_{gl}	Minimum level of flexibility for the nominal volume of contract g for assortment l (%) (negative value)

A_c^+	Maximum share of supply for supplier group c (%)
A_c^-	Minimum share of supply for supplier group c (%)
W_{cl}	Maximum level for extra assortment l to be sold in the open market from supplier group c (%)
C_{lt}^{SP}	Unit price of assortment l at t purchased from spot market
P^s	Penalty cost when inventory increases above the target level
P^l	Penalty cost when inventory decreases below the target level
M	A large number equals the total volume of available deliveries

Variables :

u_{rlts}	Inventory of assortment l in woodyard r at the end of period t in scenario s
$x_{r'rlts}^R$	Flow of assortment l from woodyard r' to woodyard r at t in scenario s
x_{grlts}^G	Flow of assortment l by contract g to woodyard r at t in scenario s
x_{glts}^E	Extra volume of assortment l sold in open market, from contract g at t in scenario s
u_{rlts}^s	Volume of assortment l exceeding the maximum level in woodyard r at t in scenario s
u_{rlts}^l	Volume of assortment l below the minimum level in woodyard r at t in scenario s
x_{lts}^{SP}	Volume of spot market purchases for assortment l at t in scenario s
z_{gs}	Binary variable equals 1 if contract g is selected, and equals 0 otherwise (first stage variable if $g \in G_c^1$, and second-stage variable if $g \in G_c^2$)
v_r	Binary variable equals 1 if external woodyard r is decided to be opened, or otherwise equals 0 (during one year)

The SP model is formulated to closely reflect how the PPC acquires the information throughout the procurement planning. In the first period, full information regarding deliveries and their characteristics is assumed. However, in the following periods, the volume and price of deliveries may change due to sourcing risks.

To develop a SP model, a new set is added for designated scenarios, shown by index $s \in S$. The probability of occurrence for each scenario is denoted by ρ_s. Parameters that will change for the SP model are related to the nominal volume of contracts (Q_{glrts}). The price of available contracts (C_{glts}^L) is also dependent on each scenario so that they are able to mimic the market variations.

Decisions regarding the opening of woodyards as well as the selection of contracts starting in the first period are first-stage variables. These decision variables remain the same for all scenarios. Therefore, no variations will occur during the first period. However, decisions related to the contracts starting after the first period are considered as second-stage variables, since their potential selection is dependent on each scenario. Other second-stage decision variables include inventory levels, order volumes, chipping volumes, spot market purchases, and penalties for violating inventory target levels in woodyards.

In order to separate the first-stage decision variables for contracts beginning in the first period, and other contracts (starting from the second period or later), a new set is defined by G_c^1. Based on the schedule of deliveries, every contract with deliveries in the first period is assigned to this new set. The selection of contacts in this set is considered a first-stage decision variable. The decision of selecting other contracts from the set G_c^2 is a second-stage decision variable and is unique for each scenario. Variables related to the procurement network are illustrated in Figure 3.1. Triangles represent woodyards while circles denote suppliers and production mills.

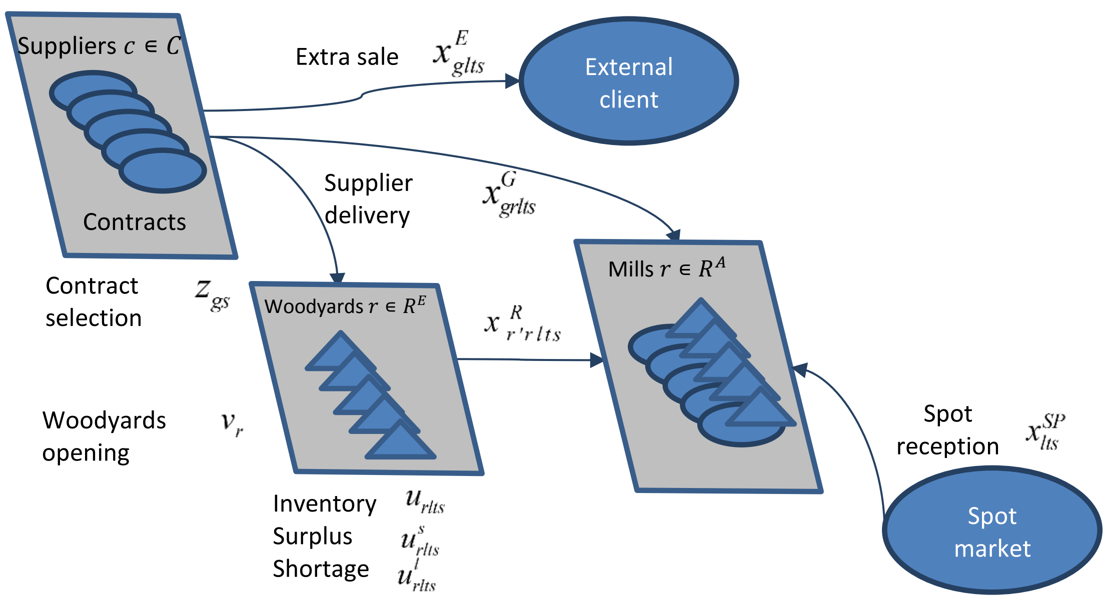

Figure 3.1. Illustration of the decision variables in the procurement network.

The objective function is to minimize the total cost of the procurement plan for all scenarios. It is calculated by multiplying the probability of each scenario (ρ_s) by its corresponding procurement cost.

The summation of probabilities for all scenarios equals one ($\sum_{s\in S}\rho_s = 1$). The objective function and constraints of the SP model are presented below:

$$Min\ Z: \sum_{s\in S}\rho_s \times Operational\ cost_s^z + \sum_{r\in R^E} C_r^R v_r \tag{1}$$

Where $Operational\ cost_s^z$ is a function of second-stage variables as shown below, except for contracts, which are divided into first-stage and second-stage decision variables:

$$\sum_{t\in T}(\sum_{r'\in R^E}\sum_{r\in R}\sum_{l\in L^E} C_{r'rlt}^T x_{r'rlts}^R \tag{1a}$$

$$+\sum_{r\in R}\sum_{c\in C}\sum_{g\in G_c}\sum_{l\in L}(C_{grlt}^G + C_{glt}^L)x_{grlts}^G \tag{1b}$$

$$+\sum_{r\in R^A}\sum_{l'\in L^A}\sum_{l\in L^E} C_{rll'}^C(\sum_{r'\in R^E} x_{r'rlts}^R) \tag{1c}$$

$$+\sum_{r\in R^A}\sum_{l\in L} C_{rl}^I u_{rlts} \tag{1d}$$

$$-\sum_{c\in C}\sum_{g\in G_c}\sum_{l\in L} Y_l x_{glts}^E \tag{1e}$$

$$+\sum_{r\in R}\sum_{l\in L}(P^s u_{rlts}^s + P^l u_{rlts}^l)) \tag{1f}$$

$$+\sum_{c\in C}\sum_{g\in G_c^1} C_g^F z_{gs} + \sum_{c\in C}\sum_{g\in G_c^2} C_g^F z_{gs} \tag{1g}$$

S.t:

$$u_{rlts} \le P_{rl}^R v_r + u_{rlts}^s \qquad \forall r\in R, l\in L, t\in T, s\in S \tag{2}$$

$$\sum_{r\in R^E}\sum_{l'\in L^E}\sum_{t\in T}(K_{rl'l}\sum_{g\in G_c} x_{grl'ts}^G) \ge A_c^- \sum_{r\in R^A}\sum_{t\in T} D_{rlt} \qquad \forall c\in C, l\in L^A, s\in S \tag{3}$$

$$\sum_{r\in R^E}\sum_{l'\in L^E}\sum_{t\in T}(K_{rl'l}\sum_{g\in G_c} x_{grl'ts}^G) \le A_c^+ \sum_{r\in R^A}\sum_{t\in T} D_{rlt} \qquad \forall c\in C, l\in L^A, s\in S \tag{4}$$

$$\sum_{r\in R^A}\sum_{g\in G_c}\sum_{t\in T} x_{grlts}^G \ge A_c^- \sum_{r\in R^A}\sum_{t\in T} D_{rlt} \qquad \forall c\in C, l\in L^A, s\in S \tag{5}$$

$$\sum_{r\in R^A}\sum_{g\in G_c}\sum_{t\in T} x_{grlts}^G \le A_c^+ \sum_{r\in R^A}\sum_{t\in T} D_{rlt} \qquad \forall c\in C, l\in L^A, s\in S \tag{6}$$

$$\sum_{r'\in R}\sum_{l\in L}\sum_{t\in T} x_{r'rlts}^R + \sum_{c\in C}\sum_{g\in G_c}\sum_{l\in L}\sum_{t\in T} x_{grlts}^G \le M v_r \qquad \forall r\in R^E, s\in S \tag{7}$$

$$X_{rl}^{I} + \sum_{c \in C} \sum_{g \in G_c} x_{grlts}^{G} = u_{rlts} + \sum_{r' \in R} x_{rr'lts}^{R} - \sum_{r' \in R^E} x_{r'rlts}^{R} \quad \forall r \in R^E, l \in L^E, t \in \{1\}, s \in S \tag{8}$$

$$u_{rl,t-1,s} + \sum_{c \in C} \sum_{g \in G_c} x_{grlts}^{G} = u_{rlts} + \sum_{r' \in R} x_{rr'lts}^{R} - \sum_{r' \in R^E} x_{r'rlts}^{R} \quad \forall r \in R^E, l \in L^E, t \in T \setminus \{1\}, s \in S \tag{9}$$

$$X_{rl}^{I} + \sum_{c \in C} \sum_{g \in G_c} x_{grlts}^{G} + \sum_{l' \in L^E} (K_{rl'l} \sum_{c \in C} \sum_{g \in G_c} x_{grl'ts}^{G}) = u_{rlts} + D_{rlt} \quad \forall r \in R^A, l \in L^A, t \in \{1\}, s \in S \tag{10}$$

$$u_{rl,t-1,s} + \sum_{c \in C} \sum_{g \in G_c} x_{grlts}^{G} + \sum_{l' \in L^E} (K_{rl'l} \sum_{c \in C} \sum_{g \in G_c} x_{grl'ts}^{G}) = u_{rlts} + D_{rlt} \quad \forall r \in R^A, l \in L^A, t \in T \setminus \{1\}, s \in S \tag{11}$$

$$\sum_{r' \in R^A} x_{rr'lts}^{R} \leq P_{rl}^{C} \quad \forall r \in R^E, l \in L^E, t \in T, s \in S \tag{12}$$

$$u_{rlts} + u_{rlts}^{l} \geq S_{rlt} v_r \quad \forall r \in R, l \in L, t \in T, s \in S \tag{13}$$

$$(F_{gl}^{+} + 1) Q_{grlts} z_{gs} \geq x_{grlts}^{G} + x_{glts}^{E} \quad \forall c \in C, g \in G_c, r \in R, l \in L, t \in T, s \in S \tag{14}$$

$$(F_{gl}^{-} + 1) Q_{grlts} z_{gs} \leq x_{grlts}^{G} + x_{glts}^{E} \quad \forall c \in C, g \in G_c, r \in R, l \in L, t \in T, s \in S \tag{15}$$

$$W_{cl} \sum_{r \in R} x_{grlts}^{G} \geq x_{glts}^{E} \quad \forall c \in C, g \in G_c, l \in L, t \in T, s \in S \tag{16}$$

$$z_{gs} = z_{gs'} \quad \forall c \in C, g \in G_c^{1}, s = 1, s' \in S \setminus \{1\} \tag{17}$$

$$x_{grlts}^{G}, x_{rr'lts}^{R}, x_{glts}^{E}, u_{rlts}, u_{rlts}^{s}, u_{rlts}^{l} \geq 0 \quad \forall r' \in R, l \in L, t \in T, s \in S \tag{18}$$

$$v_r, z_{gs} \in \{0,1\} \quad \forall c \in C, g \in G_c, r \in R, s \in S \tag{19}$$

Minimization of the total cost is calculated as a summation of woodyards opening costs (1) and operational costs (1a-1g), as a function of uncertain parameters. The inventory maximum level is defined by (2). Portfolio limits per group of suppliers are denoted by constraint sets (3-6). Constraint sets (7) ensure that the flow exists only for an opened woodyard. Inventory balance constraints are shown by constraint sets (8-11).). Spot market purchases are considered in the constraint set (10) and (11) to replenish in case of shortage. Constraint sets (12) denote the capacity of the chipping operations. Inventory target levels are satisfied by constraint sets (13). Constraint sets (14) and (15) are related to the ability to modify the order volume of flexible and option contracts upward or downward. The maximum allowable level to sell extra wood is denoted by constraint sets (16). Constraint sets (17) imply the non-anticipatively constraints for the selected contracts in the first month. By these non-anticipatively constraints, first-stage decisions for selecting contracts are ensured to have the same values for each scenario. Finally, non-negativity constraints are provided by (18) and (19).

3.3.1 Scenario generation

The scenario generator integrates all sourcing risks and mimics different situations. Each scenario is a combination of the impact of three sourcing risks: contract breach, the start of the thaw period, and unreliability of contracts. The variations are applied to the values that are initially associated with the volume and price of contracts. The distribution of random events was consulted by decision-maker, since no evidence of their distribution was available at the time of this study. It was concluded that they can be approximated by uniform distribution.

The monthly nominal volume of contracts is different for each scenario. A price uncertainty was included for contracts during the thaw period. Therefore, each scenario will contain different variations in the volume of the contract and if not selected in the first period, will have different variations of price during the thawing. Varying the volume and price is performed by using probability distributions. The following sequence of actions was used to generate each scenario:

- By considering a continuous uniform distribution between zero and one, a contract is breached in a specific period, if the generated value is less than $Þ_{gt}$ $(0 \leq Þ_{gt} \leq 1, g \in G_c, c \in C, t \in T)$. The value of $Þ_{gt}$ is determined by a procurement decision-maker estimating the likelihood of each contract to be terminated. Therefore, assuming the generated value is $\Phi \in Uniform[0,1]$, the contract will stop the deliveries from that period in order to the end of the planning horizon, if $\Phi \leq Þ_{gt}$. The characteristics of deliveries for each breached contract are updated. Then, the volume of each breached contract in each scenario ($\sum_{r \in R, l \in L} Q_{grlts}$) is set to zero for all *t*, immediately after the period they are breached.
    - For the beginning of the thaw period, four scenarios are possible depending on three climate zones in the province of Quebec, where zone 1 is the southern region, zone 3 is the northern region, and zone 2 is in the middle of those two regions. Logically no thawing can happen in a zone located in north sooner than a zone located in south (e.g. zone 3 may not experience sooner thawing than zone 2 and 1). However, the beginning of thawing is possible in the same month for all zones. These are provided in Table 3.1 based on Rahimi

et al. (2020). The thaw period starts either on period 3 (March) or 4 (April) and lasts two months.

Scenario	March			April			May		
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
1	0	0	0	1	1	1	1	1	1
2	1	0	0	1	1	1	0	1	1
3	1	1	0	1	1	1	0	0	1
4	1	1	1	1	1	1	0	0	0

Table 3.1. Four scenarios of the thawing characterized by month and three transportation zones.

Contracts that are affected by the spring thaw will have a variation in the delivery volume if it happens earlier or later than expected. A higher price is expected for second-stage contracts as well. Variations are generated by uniform distribution, between the nominal volume in the contract and a fraction of that nominal volume.

- Two factors are added to introduce unreliability in contracts and induce variations in the volume delivered in each period. One factor represents upper variations and the other, lower variations. Factors are shown as a percentage of the contract volume. Thus, the delivery volume varies depending on the contract nominal volume, upper and lower factors. The uniform distribution is used for generating the variations.

Different scenarios are generated by repeating these steps. Each scenario differs with respect to the volume and price of deliveries. The number of scenarios is decided by considering a trade-off between computation time and having a diverse set of random events. In our case, the number of scenarios had direct impact on the computation time of the SP model to achieve an optimal solution. While it is better to generate scenarios as much as possible to achieve a more reliable solution, we needed to make a balance between the quality of the scenario set and the computation time. Therefore, after testing multiple times, the final set was decided to include 10 scenarios. We made sure that the scenarios cover most of plausible realization of uncertain events with consulting the decision-makers. By this means, the computation time to achieve an optimal procurement plan was in the acceptable range, predetermined by the decision-maker.

3.4. Case study

The case presented in this study is an adaptation of the one described by Rahimi et al. (2020). The wood fiber is delivered from suppliers to woodyards or the production mill (PPC) in the form of pulp logs and wood chips, in both softwood and hardwood species. The PPC has chipping capacity in the internal woodyard at the production mill to transform pulp logs to wood chips.

The PPC negotiates contracts with suppliers in five main groups, designated as C1 to C5 in Figure 3.2. There is a possibility of selling extra wood assortments from PPC's forestland (C1). Supplier groups C1 to C4 provide pulp logs to internal or external woodyards, while supplier group C5 delivers wood chips directly to the mills.

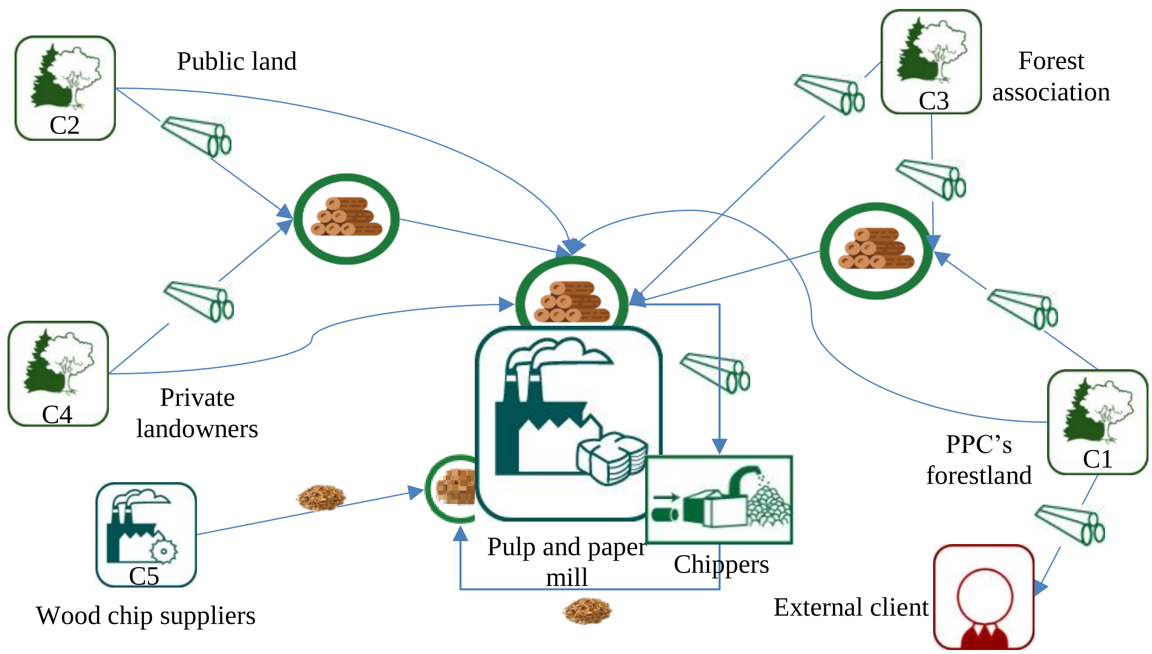

Figure 3.2. The flow of wood fiber from five groups of suppliers.

The first group of suppliers delivers pulp logs from PPC's forestland (C_1). It represents the contractors working on the PPC's private forestland. Typically, long-term contracts are in use with this group. The second group encompasses the pulp log suppliers from the public forest (C_2). This category relates to the contracts between the PPC and public land timber license holders. In addition, the PPC may receive logs or chips from other companies operating on their own public land. More information on this subject may be found in (Direction de la gestion des stocks ligneux, 2016). The third group are producers of pulp logs that are regulated by the forest association of wood producers (C_3). The purchases from these suppliers must go through the forest association of wood producers (Foretprivee.ca, 2019). A forest association is an aggregate of private forest landowners, placing wood on the market in a region. The association oversees the process of selling wood for its members. The fourth group are private suppliers providing pulp logs, mostly from outside of Quebec (C_4) [i.e. the

United States and Ontario]. The final group are wood chip suppliers (C_5) including purchases from sawmills and chip producers.

In addition to providing wood supply based on fixed contracts (i.e. the current approach for the PPC), flexible and option contracts for each group are included as well. The total number of available contracts is 1500 for all groups of suppliers in order to be close to the real case in the company. The limit on selecting the total volume to be supplied from each group by portfolio parameters is also considered as shown in Table 3.2. This is established by the procurement manager to maintain the diversity of suppliers in order to allow risk-sharing and avoid exclusive relations with few suppliers.

Supplier group	C1	C2	C3	C4	C5
Minimum supply share	8.6%	14%	5%	5.5%	3.9%
Maximum supply share	25.6%	42%	15%	16.5%	18.9%

Table 3.2. Supplier groups portfolio parameters.

The values of cost parameters are shown in Table 3.3. The costs are provided as an average value for different parameters. They are stated in Canadian dollars ($CAD) per unit of Dry Metric Tonne (DMT) of wood supply. The price of the fixed contract is less than the option and flexible contracts. Fixed and variable costs of flexible and option contracts are up to 50% more expensive than similar fixed contracts.

Parameter	Description	Costs (CAD$/ DMT)
$C_{gl}^{L^A}$	Wood chips price	**142.5**
$C_{gl}^{L^E}$	Pulp logs price	From **87.7** up to **186.4** according to the supplier
$C_{r'rlt}^{T}$	Transportation costs between woodyards	From external yard R[E1] to internal yard R[A]:**9** From external yard R[E2] to internal yard R[A]:**11**
C_{grlt}^{G}	Transportation costs from suppliers to woodyards	From **18.7** up to **106.3** according to the supplier
Y_l	The price for extra wood in the spot market	**130.5**
C_{rl}^{I}	Inventory cost per time period	PLY**: 4.2** WCY**: 11.7**

Table 3.3. Values of cost parameters in each period.

Figure 3.3 shows the demand profile of the PPC for each assortment. The drop in periods 4 and 5 is due to seasonality, where the deliveries decrease during thaw period and therefore the production is aligned to balance the supply and demand.

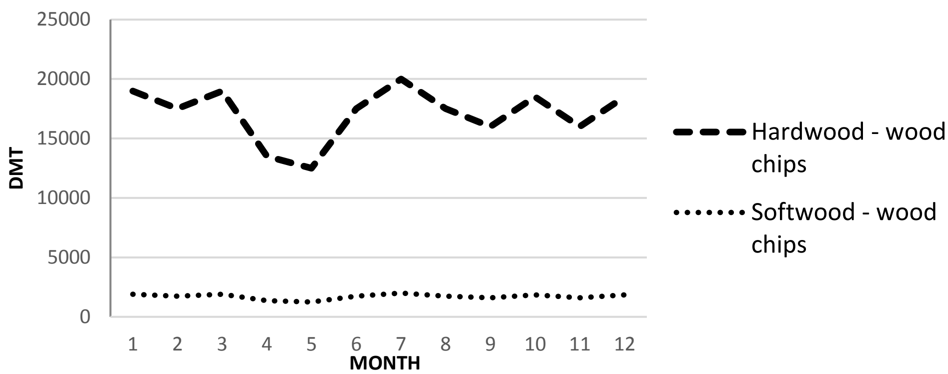

Figure 3.3. Monthly demand profile of wood chips at the mill.

Inventory and chipping costs are summarized in Table 3.4. All costs are stated in \$CAD/ DMT.

External woodyard	P_{rl}^{R}	Maximum capacity	**1.35*** S_{rlt}
	P^{s}	Penalty cost for extra inventory	Pulp log**: 200**
	P^{l}	Penalty cost for shortage	Pulp log**: 300**
	C_{r}^{R}	Fixed cost of opening	**125 000**
	C_{rl}^{I}	Inventory cost	**4.2**
Internal woodyard	P_{rl}^{R}	Maximum capacity	**1.2*** S_{rlt}
	P^{s}	Penalty cost for extra inventory	Pulp log**: 200** Wood chips: **300**
	P^{l}	Penalty cost for shortage	Pulp log**: 300** Wood chips: **500**
	C_{rl}^{I}	Inventory cost	**11.7**
	$C_{rll'}^{C}$	Chipping cost	Hardwood**: 29.6** Softwood: **39.5**
	P_{rl}^{C}	Capacity of chipping	Hardwood**: 30 000** Softwood: **3 000**
	$K_{rll'}$	Chipping conversion rate	**89%**

Table 3.4. The values of woodyard parameters in each period.

Assuming that the thaw period is expected to begin in April (period 4), the inventory level is established lower in periods 4 and 5 (April and May). The inventory target level for hardwood is illustrated in Figure 3.4. R[I] denotes the pulp log woodyard at the mill, R[A] represents the wood chips woodyard at the mill, and R[E1] and R[E2] are for external pulp log woodyards. The target level for softwood is one-tenth of the inventory target level for hardwood. The lower inventory target level in some periods, such as for period 11, is determined due to rain and the lower deliveries during these periods.

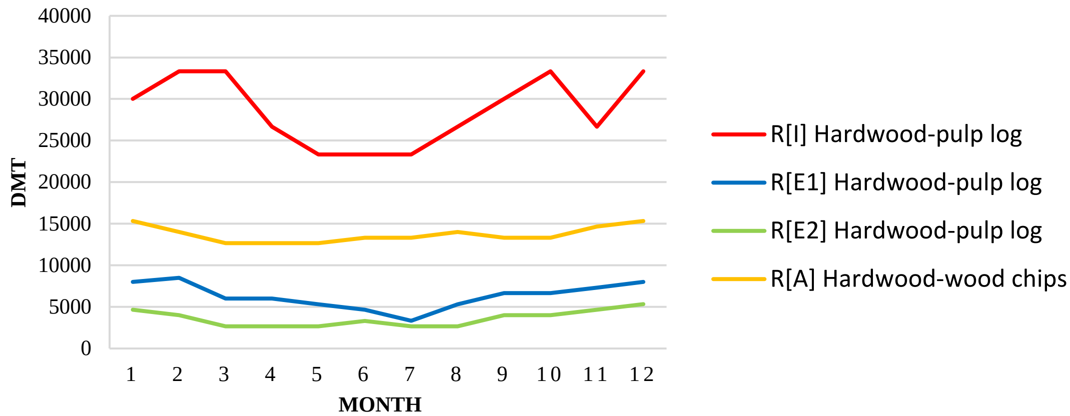

Figure 3.4. Inventory target levels in yards for wood chips and pulp logs.

Generating 10 different scenarios provide the ability to achieve the optimal solution in less than 20 hours. A breach in the contract and variations due to unreliability of contracts are randomly generated for 10 scenarios. The contracts in each group of suppliers are likely to breach by assigning different Þ_{gt} from 1% to 20%. According to the unreliability of contracts, the upper and lower factors for variation in the nominal volume of contracts are between 0% and 30%. For contract breach and related unreliability, lower probabilities are associated with supplier group C1 as the PPC has direct control over this group. The start of thawing considers the four possibilities showed in Table 3.1 based on historical data. Thus, in the 10 scenarios developed for the SP model, two of them have the same start of thawing as the forecast (scenario 1 in Table 3.1), two of them have the start of thawing on March for all zones (scenario 4 in Table 3.1), and three of them have the remaining possibilities (scenario 2 and 3 in Table 3.1).

3.5. Results

In the results, we are going to present three cases to evaluate the usage of contracts with no flexibility and low relative price (case a1), contracts with flexibility and high relative price (case a2), and a contract set with a mix of both types (case a3). Each flexible contract is matched by an inflexible one, which differs only in the unit price from the latter. The SP model is solved using a standard PC with a 16GB of RAM and 2.3 GHz processor. The model is programmed with AMPL software and solved by CPLEX 12.0. The size and solution time to complete optimality for different cases of the SP model is presented in Table 3.5. The problem was solved with the MIP gap of 1% in approximately one hour. The gap is calculated as the proportional difference between the solution from the best bound and the solution of the mixed-integer programming model. This is referred to as the relative gap of the optimal solution. The optimal solution is found considering the default gap setting of CPLEX, which is 0.00001%.

Case	Number of variables	Number of constraints	Solution time	
			Optimal solution	Within 1% MIP gap
a1	1,812,754	2,833,900	12.5 hours	1.5 hours
a2	1,812,754	2,833,900	14.0 hours	2.0 hours
a3	3,620,950	6,140,670	19.5 hours	3.7 hours

Table 3.5. Size and solution time for three cases (a1: fixed contracts, a2: flexible contracts, a3: mixed).

The efficiency of the SP solution is compared with the results obtained by two alternative approaches described below:

I. **Oracle Solution (Oracle)**: In this method, each deterministic problem is solved to optimality with all information available from the beginning. Then, the average objective value for all scenarios is calculated. The quality of the solution from an SP or deterministic model (DM) can be measured with this approach. The result of the oracle solution is theoretically optimal. However, it allows determination of the Expected Value of Perfect Information (EVPI) that decision-makers are willing to pay to know the exact realization of random events.

II. **Deterministic Model (DM)**: In practice, decision-makers implement a procurement plan typically by considering an expected scenario. In this approach, the results from solving a deterministic model with an expected scenario are used to fix the first-stage decision variables. Then, the deterministic model for each scenario is solved and the expected value of objective values is calculated. The comparison of this approach with the stochastic solution provides a Value of Stochastic Solution (VSS). This value denotes the savings that PPC may have by including uncertainty in the decision-making process.

The results for the expected value of procurement costs and their standard variation are shown for three cases in Table 3.6.

	Case	Oracle	SP	DM
Expected value	a1	31 092	33 009	34 562
	a2	29 358	29 806	31 008
	a3	27 514	28 287	29 311
Standard deviation	a1	685	981	2 243
	a2	181	215	750
	a3	152	187	976

Table 3.6. The expected value of costs for Oracle, SP, and DM (1000CAD$).

Considering the result for the SP model for case a1 as the fixed set of contracts, costs are higher by approximately$2 million compared to Oracle. For cases a2 and a3, the differences are $0.5 million and \$0.8 million, respectively. These differences are the EPVI, which denote the costs associated with uncertainty and incomplete information regarding the volume and price of deliveries. Case a2 has the lowest value among EPVIs. After that, case a3 shows a better EPVI, and the highest EPVI is for case a1.

A comparison of the DM and SP models is done by solving each model in the presence of 10 scenarios and calculating the expected objective values. The comparison provides the VSS of each case. The expected objective of the SP model for case a1 is \$1.5 million less than the DM model. For cases a2 and a3, they are \$1.2 million and \$1.0 million, respectively. Therefore, including uncertainty in the procurement planning with fixed contracts yields the highest savings. The volume flexibility in cases a2 and a3 can help manage uncertainty; However, fewer savings result from including uncertainty in planning with cases a2 and a3.

The variation in the results is shown by the standard deviation for 10 scenarios in Table 3.6. For all approaches, the variability of case a1 is more than all other cases. Case a3 has the least amount of variability, except in using DM, where case a2 has the least variability. In addition, the variability of the SP is less than DM. Therefore, the most reliable strategy is to implement the plan suggested by the SP approach with a mixed set of contracts. The suggested strategy is to favor flexible contracts, which allow managing uncertainty, in combination with cheaper fixed contracts to reduce total cost. To extend the comparison of the aforementioned approaches, their results are presented in the presence of individual scenarios in Figure 3.5.

Figure 3.5. The comparison of the total cost of procurement planning by Oracle, SP, and DM for 10 scenarios in the presence of fixed contracts (a1), flexible contracts (a2), and mixed contracts (a3).

Figure 3.5 shows that the deviation of the SP solution for each scenario is lower than the DM. In case a1, however, for some scenarios, DM demonstrates better results compared to SP. This may occur if the expected scenario in DM is close to a specific scenario. However, in other scenarios, there is a large loss compared to the SP solution. In cases a2 and a3, the SP solution always leads to better results. As observed in Figure 3.5, the SP and DM have provided similar objective values in case a3. These results indicate that using SP in the presence of fixed contracts is highly recommended.

An evaluation of different target levels is provided using the SP, to investigate their impact on the total cost in the presence of uncertainty. For this purpose, 15% upward and downward variations for both minimum and maximum target levels are considered for all woodyards. Those levels are based on the maximum variations of inventory for previous years. The results are shown in Table 3.7.

	Case	85%*target level	Target level	115%*target level
Expected value of SP	a1	31 736	33 009	35 263
	a2	28 402	29 806	31 544
	a3	27 070	28 287	29 778

Table 3.7. The SP expected value of costs for different inventory target levels ($1000 CAD).

Increasing inventory target levels will result in an increase of approximately $2 million in all cases while reducing the inventory target levels can save at least $1.1 million for PPC. Therefore, there is an opportunity to decrease inventory target levels, while risks are mitigated without imposing further costs due to shortage or high inventory. Although decreasing inventory target levels may improve results, this decision would require closer analysis based on the real contract data. This is to confirm if the new target levels provide opportunities or increase costs to mitigate shortage risks.

3.6. Conclusion

The integration of sourcing risk in the procurement of a PPC is a complicated subject, in the presence of large size operations. The objective of our study was to develop Aan SP model was developed for optimizing procurement operations of a large wood consuming mill in the presence of sourcing risksby including different types of sourcing contracts and groups of suppliers. The SP model supports the procurement manager on selecting contracts with respect to inventory target levels, seasonal variations, and contract-related risks. Decisions also take into account volume and price variations of potential selected contracts during the thaw period. Developed SP model was tested on a real case study and the resulted plan proved to perform better than the plan from DM approach. When a mix of fixed and flexible contracts is permitted, the plan obtained plan using the SP model is estimated to minimize save costs of up to a million dollars (3%) compared to deterministic DMpractices. In the presence of pure flexible contracts, this difference is close to $1.2 million (4% savings). Considering a portfolio with only fixed contracts, the difference reaches $1.5 million (5% savings). The current study contributed to the literature by proposing a new SP model which takes into account the real assumptions of procurement operations in a PPC.

Although the SP model requires rigorous model development and computational efforts, it provides an efficient solution with low variability for different scenarios. Using SP is highly recommended for cases with flexible contracts. It is due to its advantage over the deterministic model in all scenarios. The SP approach may benefit from the option and flexible contracts to mitigate the impact of sourcing risks. In addition, the variability of the SP results is much less than that of the deterministic model, providing high reliability of the procurement plan. Therefore, Ddecision-makers are, therefore, less likely to experience higher costs due to sourcing risks and related uncertainty.

For future research perspectives, more realistic data and information regarding sourcing risks and uncertainty can improve the applicability of the solution and scale of results. More evaluations may be conducted to compare the SP and deterministic models by using simulation. The expansion of the objective function to include environmental aspects is suggested as well. Transportation modes with different characteristics can be included to account for CO_2 emission and select a more sustainable procurement plan with minimum emissions.

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Conclusion

Three main projects were developed in this thesis to investigate the impact of various sourcing risks on the procurement plan of the PPC. The projects considered a multi-echelons in the value chain for the PPC such as suppliers, wood yards, and production mills. In the presence of risks, mitigation strategies were managed to hedge against their impact by preventing the supply shortage or high inventory costs. In this regard, spot market purchases, alternative contracts, and flexibility in some contracts were included. The developed projects included deterministic modeling, Monte Carlo simulation, and stochastic programming (SP) approaches. They were applied in a case study inspired by a PPC in Quebec, Canada.

To address the first question of the thesis "What is the optimal procurement plan for the PPC by considering a portfolio of sourcing contracts and supplier groups?", a mathematical model with the consideration of the procurement operation details was developed. The model proposed the best sourcing strategy with minimum total procurement costs by selecting a set of sourcing contracts. Contracts were detailed by having several characteristics such as price, volume, and volume flexibility. The suppliers were categorized by five main groups, which had a direct impact on the characteristics of contracts. The best allocation of the overall supply volume among the five groups of suppliers was discussed depending on the available contracts, i.e. fixed contracts or flexible contracts or both.

The second research question was, "What is the impact of sourcing risks on the procurement plan and the selected sourcing portfolio?" For this question, three types of risks, causing a partial or complete stoppage of deliveries were integrated. For the first risk, unreliability factors per contract to account for lower and upper variations in deliveries per period were identified. For the second risk, each contract was assigned by a breach probability. For the third risk, the probabilistic start of the thaw period was included. To evaluate the impact of these risks, a Monte Carlo simulation approach was developed and embedded with the deterministic model from the first project. The performance of the proposed plan was evaluated according to different scenarios by the average cost and its variations. Simulations provided insight into the potential performance of each procurement strategy. Approximately a saving of 14% was expected in the total cost of procurement by integrating flexibility into the sourcing portfolio. This is due to the possibility to change order volumes in relatively cheap contracts instead of selecting new contracts. In practice, by employing the developed simulation tool relatively high savings in decision-maker working time and energy is expected in comparison to performing manual evaluations.

In the third part of this thesis, the main issue was to control the difference between the expected volume and actual volume of deliveries and by developing a reliable forecast plan. It was aimed at answering the question “What is the optimal procurement plan that is expected to have minimum costs in the presence of sourcing risks?” The development of a stochastic programming model for PPC to consider sourcing risks and uncertainty was the objective of this project. The stochastic model helped to achieve a procurement plan which remains feasible during execution and is responsive to the variations in deliveries. A scenario generator based on a Monte Carlo approach was used to provide future realizations of uncertainty. Therefore, the model was able to take into account different realizations to generate the plan with an average optimal solution. The comparison of the stochastic and deterministic models revealed the potential savings that may occur by the integration of risks into the planning. The value of the stochastic solution was estimated by approximately half a million dollars, in case of having the mix of fixed and flexible (2% savings). In the presence of pure flexible contracts, this difference was about 1.2 million dollars (4% savings). Considering a portfolio with only fixed contracts the difference was 1.5 million dollars (5% savings).

Through these projects, it was concluded that the evaluation of the procurement strategy by different types of contracts is necessary to suggest an optimal portfolio. Fixed cheap contracts in combination with flexible ones and relatively more expensive ones suggest that there are opportunities in the mix of both types of contracts. Thus, precise analyses should be conducted on selecting contracts, which are economically cheaper but do not impose high risks, whereas expensive contracts should be considered for increasing the reliability of the operations.

To conduct this thesis we required to make a trade-off between academic contributions as well as consideration of practical assumptions. To satisfy both domains some limitaitons occurred. In order to define reliability data, flexibility parameters for contracts, and other missing data the authors had to rely on the information from the company as well as subjective analysis of contracts data. This assumption can be questioned later if more investigation can be done on the contracts data, such as reliability analysis, time-series analysis of variations in deliveries, etc.

Recommendations for future work

Four future research directions are suggested. The first one is to add the uncertainty of the price of wood in the spot market. This way, the spot market, as a mitigation strategy, will impose a risk of expensive purchases while it can also provide opportunities of lower prices in some periods. Therefore, the analysis of contracts can be extended by using the right of first refusal clause or stochastic revenue from selling extra wood in the spot market.

The second future direction is to include wood supply quality characteristics for each contract and the uncertainty related to them. The quality of wood assortments has a direct impact on the quality of final products, such as the size of wood chips. Therefore, the selection of sourcing contracts can be extended to consider this characteristic. In doing so, more details on types of assortments are necessary to include such as the species of the wood fiber, size of chips, and moisture level. It is also important to include the demand uncertainty for this step since the fluctuations in the recipe and the exact mix of assortments provide aspects that are more realistic.

In the third perspective, a more profound evaluation of the stochastic optimization model versus the deterministic model may be performed by simulation. Considering the developed Monte Carlo approach for the second study, a similar approach can be adapted to evaluate the efficiency of the proposed plan in mimicking the real situations.

Finally, risks management metrics could be integrated to provide a plan based on the risk attitude of the decision-maker. The variability index and downside risk are examples of popular metrics. The first one manages variations from the expected value and the latter controls the extreme variations of the cost spread. These are applicable for the risk-averse decision-makers who require optimization of the costs and risks simultaneously.

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