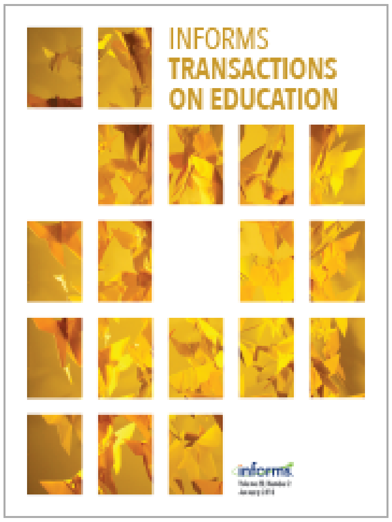


INFORMS Transactions on Education

Publication details, including instructions for authors and subscription information:
http://pubsonline.informs.org

Game—The Transportation Game

Foroogh Abasian, Mikael Rönnqvist, Philippe Marier, Dag Fjeld

informs
http://pubsonline.informs.org/journal/ited

INFORMS TRANSACTIONS ON EDUCATION
Vol. 21, No. 1, September 2020, pp. 1–12
ISSN 1532-0545 (online)

Game

The Transportation Game

Foroogh Abasian,[a] Mikael Rönnqvist,[a] Philippe Marier,[a] Dag Fjeld[b]

[a] Département de Génie Mécanique, Université Laval, Québec, Québec G1V 0A6, Canada; [b] Norwegian Institute of Bioeconomy Research, Oslo NO-1431, Norway

Contact: foroogh.abasian.1@ulaval.ca, https://orcid.org/0000-0002-2947-1354 (FA); mikael.ronnqvist@gmc.ulaval.ca (MR); philippe.marier@forac.ulaval.ca (PM); dag.fjeld@nibio.no (DF)

Received: September 28, 2017
Revised: December 10, 2018; March 3, 2019; June 24, 2019; July 28, 2019
Accepted: August 1, 2019
Published Online in Articles in Advance: April 13, 2020

https://doi.org/10.1287/ited.2019.0223

Abstract. This paper presents an online educational game focusing on hierarchical procurement planning in a simulated forest supply chain with multiple companies. The purpose is to provide an understanding of the importance of individual decisions and their medium- to long-term impacts on the entire supply chain. The transportation game comprises three phases, each simulating hierarchical decision making when three competing companies (i.e., the game players) are making simultaneous decisions on the available resources. Each game phase also requires concurrent collaboration and competition. The phases represent different planning levels from long-term to short-term planning, considering the collaboration concept within the supply chain. The simulated supply chain objective is to minimize resource purchasing and transportation costs. The purchasing cost will be fixed after the first phase. The chance of decreasing transportation costs, however, is available until the end of the game. We develop three optimization models for each game phase. Once the game is finished, it compares the players' results with optimal solutions prepared upfront. Finally, we present some comments about the game experience in various classrooms.

Keywords: serious game • transportation • supply chain planning • forestry • collaboration

1. Introduction

The planning decisions in the forest supply chain include procurement, production, distribution, and marketing over the planning horizon. In the long term, strategic planning should adjust to the harvesting, transportation, and production capacities with demand changes over several years. Tactical management deals with annual or monthly changes in transportation capacity or the allocation of new harvest areas. Operational planning manages routing, backhauling, and detailed scheduling for transportation, production, and distribution planning (Rönnqvist 2003). Planning may require cooperation among all the network entities to be more efficient. To explain the complex concept of hierarchical planning, supply chain processes, and logistics planning, especially in forestry, a transportation game has been developed, facilitating the education of coordination, information sharing, negotiation, and collaboration to students, managers, and planners.

Several supply chains require long-term and short-term decisions. One example includes the forest industry, where some strategic planning decisions cover several hundred years; some process control requires online decision making (D'Amours et al. 2008). Integrating strategic, tactical, and operational planning into hierarchical planning with the goal of proposing a decision-making framework is a suitable planning method for the forest industry. These three planning stages deal with the complexity of planning problems, especially when objectives and time zones are different. It is critical to achieve consistency in the planning to guarantee that higher-level decisions on lower-level planning and preserving costs and benefit values are feasibly implemented. This scenario was introduced by Rönnqvist et al. (2015) as an open problem in forestry. There are several coordination mechanisms in place to deal with this concern. One of these common mechanisms uses anticipation models to implicitly evaluate upper-level decisions considering lower-level behaviour. Beaudoin et al. (2008) proposed an anticipation model to integrate key operational-level decisions into the tactical phase. Another mechanism uses bilevel models, where the upper level provides policy decisions and the lower level provides the feedback from several potenial independent models. Paradis et al. (2018) utilize a bilevel formulation for distributed wood-supply planning. Their results verified the impact of this approach on risk mitigation.

Several educational games have been adapted for the forest industry. The online Wood Supply Game (D'Amours et al. 2017) is an adaptation of the popular beer-distribution game developed to educate the effect on coordination and information sharing among all stakeholders in a divergent wood supply chain (Sterman 1989). It focuses on an operational planning environment. Another online educational tool is the Collaboration Game (D'Amours and Rönnqvist 2013). Unlike the Wood Supply Game, the Collaboration Game focuses on collaboration and negotiation between a set of companies working in the same region. Moreover, the game is based on a real case study involving eight Swedish companies (Frisk et al. 2010). The game's purpose is to understand basic theoretical principles of collaboration and understand how they are used to find an efficient partnership with a potential of high cost savings and stability.

The transportation game was an earlier version of a hierarchical educational game (Fjeld and Hedlinger 2005). This paper-based game minimized loading and unloading of transportation freight. Although this developed game had a well-defined structure to teach transportation planning, some weaknesses needed to be addressed. First, the game's general goal was restricted to transportation planning in a cut-to-length contest. Our goal in the current transportation game, however, is to provide an introduction into hierarchical procurement planning of a supply chain in an educational setting. Second, the paper-based game had a fixed game setup. But our online platform lets teachers select their desired level of difficulty, number of runs, and time limits. Third, the paper-based game provided the collaboration concept at an operational level of transportation planning—that is, backhaul planning. Instead, we provide the opportunity of collaboration in tactical levels in the online game. Above all, online accessibility facilitates fast computation, negotiations, and information sharing—all updated in real time. The availability of optimization models in such educational settings is another contribution to our developed game. Player performances at each phase are fixed as the input for the optimization model during the next game phase; they are compared with optimal performance at all stages.

Section 2 provides a game description and its three phases. Section 3 presents the optimization models for each phase. Sections 4 and 5, respectively, present experiences from some illustrative examples and conclusions.

2. Game Description

2.1. Game Basics and Map

The game was designed for three players in simultaneous competition and collaboration within three different phases in a hierarchical planning environment. The game may be repeated in a chosen number of periods, often set at two periods—2 weeks—in our case. The overall aim is to minimize the cost of a

Figure 1. Illustration of the Game's Map

Notes. Supply points are demonstrated by circles. The sawmill and pulp and paper mill icons determine the mill locations for each team. The numbers display the demand of each mill. The teams are differentiated by different colors.

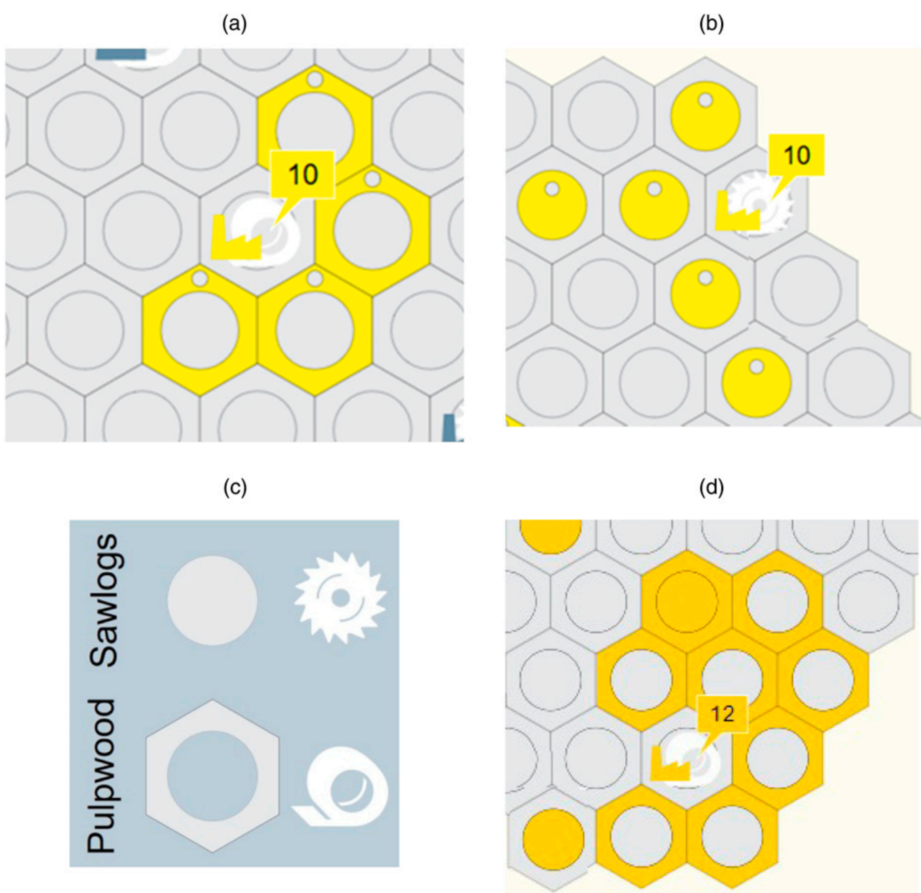
series of coupled decision-planning processes. The cost relates to the wood-product purchases and their hauling costs. The initial setting is a hexagonal map with 61 (or 91, depending on game size selected) potential supply areas and a set of existing mills with demand. Each mill is either a paper mill or a sawmill differentiated by logos; the mills have been given a demand for pulp logs or sawlogs within each period (Figure 1(a)). Each circle in the figure is a supplier of exactly one full truckload of sawlog and one full truckload of pulpwood (Figure 1(b)). The distances between a supply point and a demand point are expressed as the number of links one needs to move between them. The three phases of the game are as follows:

- Phase 1 (strategic): Select supply areas and product combination (all companies involved);
- Phase 2 (tactical): Decide on collaboration through wood exchanging (all companies involved);
- Phase 3 (tactical): Decide transportation—that is, allocation between supply and demand points (individual companies).

2.2. Phase 1: Acquiring Supply Areas

The objective at the first phase is to purchase supply areas and products close to the mills. Hence, the transportation cost can be controlled from the start. Figure 2, (a) and (b), displays a player selection from pulpwood and sawlog supply nodes. Each supply point is presented as a hexagon with interior and exterior parts, each demonstrating supply of sawlog and pulpwood (Figure 2(c)). Figure 2(d) demonstrates the player selection in a single map. If both products are bundled at the supply point, there is a rebate, such that it is cheaper to purchase them together than separately. Here's one disadvantage: The demand may be spread out; the supply of one product is closer than the other product. During the game, each player selects supply areas and products. One company may select supply points and products at every round, followed by the second and third companies. This process is repeated until all demands are satisfied. Lastly, the available time per turn is set. For example, for 10 units of supply area selection per turn, two minutes are enough for the players.

Figure 2. Demonstration of Pulpwood and Sawlog in the Map



Notes. (a) A player selection among pulpwood supply nodes. (b) A player selection among sawlog supply nodes. (c) For each node, the hexagonal interior or exterior determines the area's composition as the sawlog supplier (pulpwood). (d) The selected resources in a single map for one player.

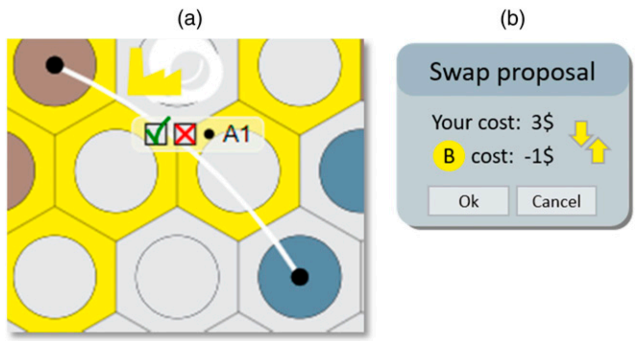
Competition among players for a supply point depends on the mill configuration. Two main strategies can be used. The first strategy selects bundled (cheaper) supply areas in or close to the middle of mills with the caveat that collaboration is sufficient to improve the situation later. The second selects supply areas with single products (more expensive) close to mills to minimize transportation costs. For example, the resource price is set in a way that purchasing one area costs five for each area and each product. If both products are purchased as a bundle, the cost is eight—that is, a rebate of two. The transportation cost is one for each unit length illustrated by each line on the map. The purchasing cost will be fixed for the rest of the game, although opportunities to reduce transportation cost remains open. Each player tries to balance the purchasing cost with the distances from its different mills. However, the competition between players does not let them select whatever they desire to have. Depending on players' insights, this phase could be done in a collaborative environment where players negotiate the area they desire to have or purchase the area without negotiation.

Many companies can select areas they own themselves, whereas other companies need to purchase from independent forest owners or through members in forest associations (Bredström et al. 2010). To select supply areas, it is highly important to consider the scheduling of the harvesting operations (Frisk et al. 2016). The costs are often approximated depending on the estimated composition of assortments and volumes and the distance to mills. Some general cases where the costs are nonlinear were described by Kong et al. (2015). The competition between different companies is hard to describe, and there is little research published on this specific aspect. The subsequent potential collaboration is, however, described in phase 2.

2.3. Phase 2: Decide on Collaboration Through Wood Exchanging

Following the harvest-area selection, a modification tool that includes wood exchanging among companies can progress the decisions made (Forsberg et al. 2005). In this regard, the game provides the possibility of exchanges between players' areas, marking the first practice of collaboration and negotiation for the players. They should wisely find the areas in a win–win strategy to create advantages for everyone. Exchanging harvest areas does not change the players' purchasing cost during the first phase, although transportation cost may be reduced. One exception: The exchanging companies agree to pay or receive a payment for the exchange—an interesting option if a company would get a worse or better logistic configuration.

Figure 3. Illustration of an Area Exchange



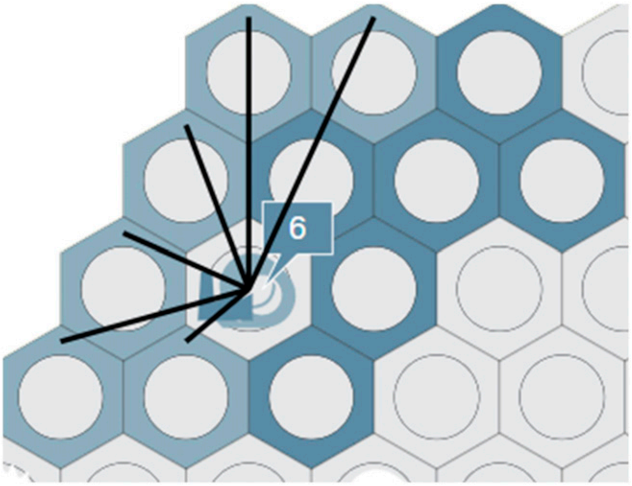
Notes. (a) The exchange proposal. (b) The swap proposal with offering a price.

Figure 3(a) depicts an example of an exchange proposal between players. The exchange must take place in the same product; the improvements may not be the same for the two players. This condition requires communication that may span over multiple exchanges. The player could offer or ask for a price in each exchange (Figure 3(b)). This is the point when players practise their negotiation skills to convince other competitors in the supply chain to collaborate, even if they save less than others or vice versa. At this time, the swap is proposed and made once the offer is accepted by involved players. We also note that there may be multiple proposals for the same area. These proposals are removed once the main proposal is accepted.

2.4. Phase 3: Assigning Areas to Mills

In the third phase, it is crucial to allocate areas to mills as best as possible to guarantee that the demand is satisfied with the least possible transportation cost. In previous phases, the transportation cost was estimated by the game; however, in this phase, it is fixed based on player

Figure 4. Illustrating the Assignment Phase



Note. The lines show the possible assignment options for the selected mill.

assignment. In practice, this problem is a standard transportation problem with flows between supply areas and mills as decision variables and supply-and-demand constraints. The assignment phase serves as an internal planning tool for each company to reduce its direct transportation cost and is available only if more than one mill per resource assortment is at the player's disposal. Players choose their mills and then allocate their areas. Figure 4 depicts a view of this phase.

2.5. Result Presentation

Once the game has finished, players will notice an interactive result window. Figure 5 displays the result of a game run in a class with seven groups. Several options are available to the players. First, the overall performance of each group is compared with the optimal solution. The group with the least average cost is declared the winner. The winner is illustrated by the red circle in the result table. Second, a player-performance summary in each phase is provided under the plus sign beside each phase. For example, at the phase acquisition, the overall cost for group 1 is 992—a result from the purchasing cost, excluding the rebate (Figure 5(b)). Following the acquisition, group 1 did nine swaps with 18 unit costs, gaining 12 units (Figure 5(c)). Player performance at the third phase could show players how far they are from optimality (Figure 5(d)). These figures display the effect of each phase in cost reduction and the relationship between planning levels. It clearly shows appropriate swaps; assignments will reduce costs and create win moves for all players. This proves the importance of integration and collaboration in supply chain planning.

The bar-chart icon in Figure 5(a) appears as a pop-up bar chart to compare all group costs with optimal solutions (Figure 6). The chart could draw for each week or for each individual player in different groups.

To track performance in each group, players need to click on the group name. A new window will appear (Figure 7(a)). All features in Figure 5 are available

Figure 5. The Interactive Result Table

(a)

companies: All | A | B | C — weeks: All | 1 | 2

	Phase 1 Acquisition	Phase 2 Swap (1$)	Phase 3 Transport (1$)	Total	Demand	Avg	Opt %
Group #1	992	18 [9]	1828	2838	288	9.85	108.9%
Group #2	1016	4 [2]	1858	2878	288	9.99	110.4%
Group #3	958	12 [6]	1912	2882	288	10.01	110.6%
Group #4	992	28 [14]	1844	2864	288	9.94	109.9%
Group #5	1000	2 [1]	1946	2948	288	10.24	113.1%
Group #6	1012	12 [6]	1844	2868	288	9.96	110.1%
Group #7	998	36 [18]	1908	2942	288	10.22	112.9%
Optimal (collab)	894	64 [32]	1648	2606	288	9.05	

(b)

	Phase 1 Purchase (4$)	Discount (2$)	Optimal Trsp
Group #1	1152	-160	1804
Group #2	1152	-136	1844
Group #3	1152	-194	1904
Group #4	1152	-160	1884
Group #5	1152	-152	1904
Group #6	1152	-140	1862
Group #7	1152	-154	1806
Optimal (collab)	1152	-258	1868

(c)

Phase 2 Swap (1$)	Swap Gain
18 [9]	12
4 [2]	-12
12 [6]	-28
28 [14]	-54
2 [1]	0
12 [6]	-34
36 [18]	-46
64 [32]	-220

(d)

Phase 3 Transport (1$)	Optimal Trsp	Difference
1828	1816	12
1858	1832	26
1912	1876	36
1844	1830	14
1946	1904	42
1844	1828	16
1908	1760	148
1648	1648	0

Notes. (a) An overall view of group performances. (b) The optimal transportation cost considering the selected territories. (c) The group costs and potential gain in phase 2. (d) Comparisons between player and optimal solution transportation cost in phase 3. Avg, average; collab, collaborative; opt, optimal; trsp, transportation.

Figure 6. Selection Phase Results Demonstrating the Planning Cost for the Current Phase During the First Week

Note. Collab, collaborative.

in this result table. Figure 7, panels (b) and (c) compare the average and acquisition costs, respectively. The visual comparison between player selection and the optimal solution is provided by clicking on the map icons (Figure 7, (d) and (e)).

Once all result tables have been compiled, the players showing the best improvement, best purchasing cost, and best transportation cost will receive awards. Ultimately, all game players with minimum total cost will receive awards because they have a productive supply chain.

2.6. Game Setup and Control

The game is accessible online at http://forac-old.fsg.ulaval.ca/TransportGame/. The game's web interface is built using HTML, CSS, JavaScript, and SVG. Each user interaction is communicated to the game server using URL requests. Any player's web interface communicates with the game server every three seconds to inquire about new events or status changes that may have occurred since the last action. The vb.net web server stores each player's status during the game into an SQL database. This same server monitors player actions and changes the game status as needed—for example, to change phases or to trigger an event that should be reflected in the interface, such as displaying the end game results. All detailed information on decisions and cost of three players per game is available through the platform.

On the first page, the game link directs the players to play or create a game or do administration setup (Figure 8). Players may view all initial settings for a new game by clicking the **Create a game** option. The option includes the number of mills for each player, the mills' location, the demand, the costs, the number of periods, and timing for each phase. Moreover, this option provides some predefined games to accelerate game setup. Select **Game administrator** to multiply or delete a created game. Depending on the number of students per class, teachers can create the number of games desired. Preferably, each player is represented by one student. If the number of students is insufficient to form groups of three, however, two students may participate as one player. Players are seated next to each other to communicate and negotiate. In general, it should take 15 minutes to describe the game and an hour to run the game.

Teachers should start the game by providing a short introduction. This serves to clarify the game's general objectives and explain how to play the game in its three phases. This information is in the appendix. Following the introduction, players select **Play game** and select their game name (Figure 9). Then, the players will define their name and log in to the predefined game.

3. Optimization Models

To evaluate the player performance and provide education about the hierarchical planning concept, we make use of three optimization models, each representing one game phase. To compare optimal scenarios with player performance, the open-source solver GLPK, stored on the server, is called by the server, passing on the model and data in the form of flat text files. The input data for each optimization model is collected from the latest player changes in the game. The server reads back the optimal results. These are stored within the SQL database for subsequent web user interface upon request. The optimization models not only evaluate performance in each phase, but also find theoretical optimal solutions that may be used in discussions before or after the game. Additionally, the models may be used in more advanced project assignments for the students before or after the game. We define indices, sets, parameters, and decision variables below.

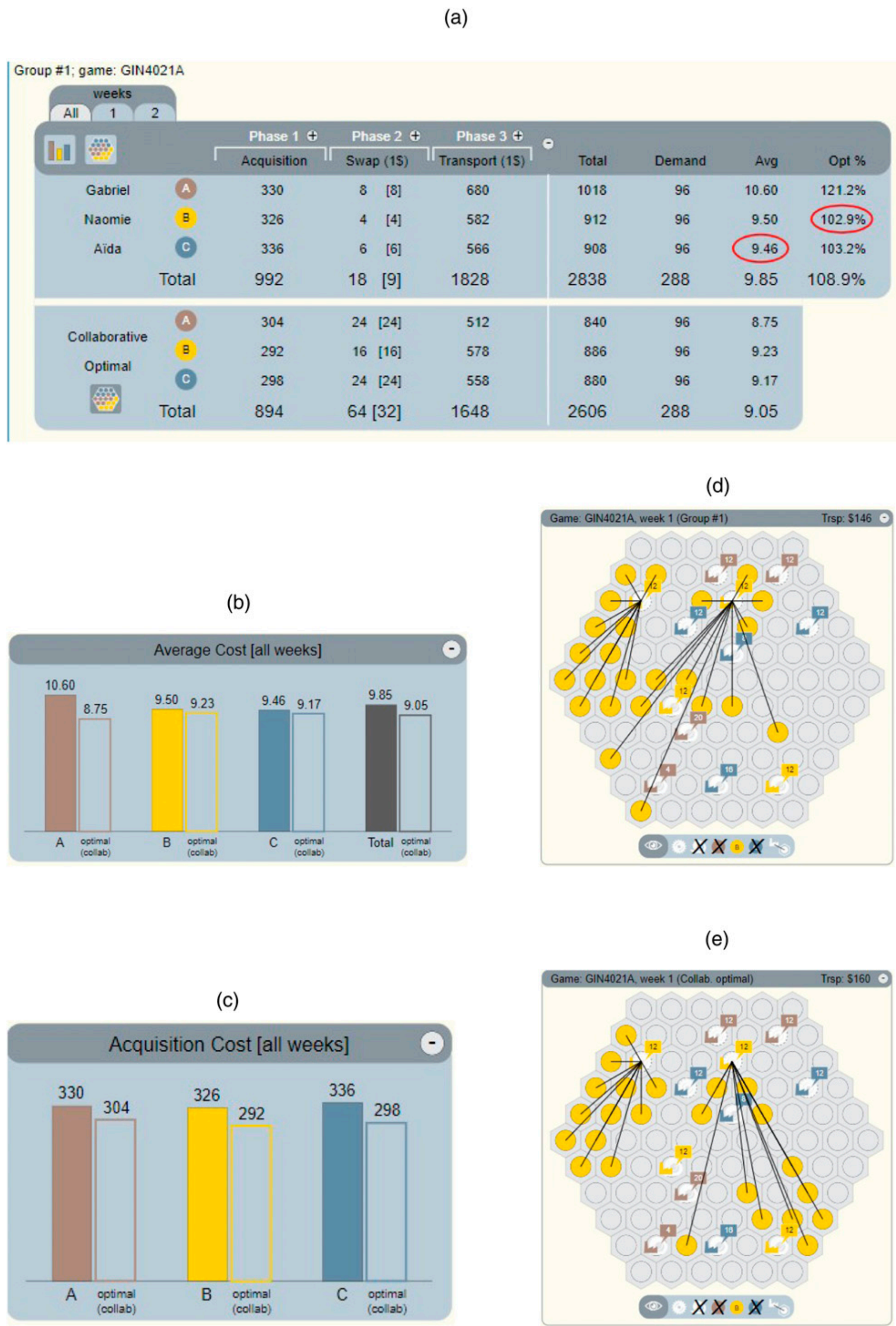
Indices and sets are as follows:

w: set of weeks
T: set of teams
L: set of map node location
P: set of products
M_p^t: set of mills type p of team t
M^t: set of all mills of team t
M_p: set of mills type p
M: set of all mills

Parameters:

d_{wm}: demand of mill m at week w

Figure 7. Interactive Result Presentation for Each Group



(a)

Group #1; game: GIN4021A

		Phase 1 Acquisition	Phase 2 Swap (1$)	Phase 3 Transport (1$)	Total	Demand	Avg	Opt %
Gabriel	A	330	8 [8]	680	1018	96	10.60	121.2%
Naomie	B	326	4 [4]	582	912	96	9.50	102.9%
Aïda	C	336	6 [6]	566	908	96	9.46	103.2%
	Total	992	18 [9]	1828	2838	288	9.85	108.9%
Collaborative Optimal	A	304	24 [24]	512	840	96	8.75	
	B	292	16 [16]	578	886	96	9.23	
	C	298	24 [24]	558	880	96	9.17	
	Total	894	64 [32]	1648	2606	288	9.05	

Notes. (a) The overall table. (b) Comparison of players' average cost. (c) Comparison of players' acquisition cost. (d) Final game map. (e) Optimal game map. Avg, average; collab, collaborative; opt, optimal.

c^d_{ml}: cost to deliver one-unit resource between mill m and node l

c^p_{ml}: cost of purchase one-unit resource

r: rebate if both sawlogs and pulpwoods are purchased for the same player

h_s: maximum number of swap for each player

Decision variables are as follows:

y_{wlt}: 1 if both pulpwood and sawlogs in harvest area l assigned to team t in week w; 0 otherwise

x_{wlm}: 1 if harvest area l assigned to mill m in week w; 0 otherwise

z_{wltp}: 1 if product p of harvest area l is owned by team t in week w (owning after swap)

i_{wltp}: 1 if product p of harvest area l is owned by

Figure 8. The First Page to Access the Game

Notes. Players should select **Play game**. Settings may be modified by selecting **Create a game** or **Game administrator**.

Figure 9. The Login Page

Notes. Players choose the game, define their name, and click **GO**. The numbers under **Groups** display the order in which the game will start.

team t in week w (initial selection; owning before swap)

s_{wltpt_2}: 1 if product p of harvest area l of team t swap to team t_2 in week w (after swapping)

AB_{wp}: the number of unpairwise swaps for product p in week w

3.1. Optimization Model for Selection Phase

The mathematical formulation for the selection phase is

$$\min \sum_{w\in W}\sum_{m\in M}\sum_{l\in L} c^d_{ml} x_{wlm} + \sum_{w\in W}\sum_{m\in M}\sum_{l\in L} c^p_{ml} x_{wlm} + \sum_{w\in W}\sum_{m\in M}\sum_{l\in L} r\, y_{wlt}, \tag{1}$$

s.t.

$$\sum_{m\in M_p} x_{wlm} \le 1, \qquad \forall w\in W, l\in L, \tag{2}$$

$$\sum_{l\in L} x_{wlm} \ge d_{wm} \qquad \forall w\in W, t\in T, m\in M^t, \tag{3}$$

$$2y_{wlt} \le \sum_{p\in P} i_{wltp} \qquad \forall w\in W, t\in T, l\in L, \tag{4}$$

$$1 + y_{wlt} \ge \sum_{p\in P} i_{wltp} \qquad \forall w\in W, t\in T, l\in L, \tag{5}$$

$$z_{wltp} \ge \sum_{m\in M_p^t} x_{wlm} \qquad \forall w\in W, l\in L, t\in T, p\in P, \tag{6}$$

$$\sum_{t\in T, p\in P: m\in M_p^t} z_{wltp} \le x_{wlm} \qquad \forall w\in W, l\in L, m\in M_p^t, \tag{7}$$

$$x_{wlm} \ge 0;\ y_{wlt}, i_{wltp}, z_{wltp} \in \{0,1\} \qquad \forall w\in W, l\in L, t\in T, p\in P, m\in M_p^t. \tag{8}$$

The model is designed to minimize the transportation and purchasing costs. Constraint set (2) assures that each harvest area is assigned to one sawmill and one paper mill at the most. Mill demands are satisfied in constraint sets (3). Constraint sets (4) and (5) determine whether players are eligible for the rebate or not. Constraint set (6) defines each territory owned by a company; this company must be assigned to a mill. Lastly, constraint set (7) determines a location assignment to a mill only if the mill company owns the location for that product type. The model is an integer programming model with binary variables.

Because the purchasing cost of players is constant after their selection, our objective functions for the remaining phases consider only transportation cost, given that this fixed purchasing cost will be added as a parameter to the other objective functions. This cost is not the optimal objective value; rather, it is the calculated cost after player selection in the game's first phase. It is shown by F_c, defined as follows:

F_c: purchasing cost of players in first phase of the game.

3.2. Optimization Model for Swap Phase

In phase 2, the selected areas for each player is determined and fixed as the input of model. Swap decision variables determine this phase's optimal solution.

The mathematical formulation for this phase is

$$\min \sum_{t\in T} F_t + \sum_{w\in W}\sum_{t\in T}\sum_{l\in L}\sum_{p\in P} c^d_{ml} z_{wltp} + \sum_{w\in W}\sum_{t\in T}\sum_{l\in L}\sum_{t2\in T} c^s_{ml} s_{wtlpt2} + \sum_{w\in W}\sum_{p\in P} c^s AB_{wp}, \tag{9}$$

s.t.

$$\sum_{t\in T} z_{wltp} = \sum_{t\in T} i_{wltp} \quad \forall w\in W, l\in L, p\in P, \tag{10}$$

$$\sum_{l\in T} z_{wltp} = \sum_{l\in T} i_{wltp} \quad \forall w\in W, t\in T, p\in P, \tag{11}$$

$$\sum_{t2\in T\setminus\{t\}} s_{wltpt2} \le 1 - z_{wltp} \quad \forall w\in W, l\in L, t\in T, p\in P, \tag{12}$$

$$\sum_{t2\in T\setminus\{t\}} s_{wltpt2} \le 1 - i_{wltp} \quad \forall w\in W, l\in L, t\in T, p\in P, \tag{13}$$

$$z_{wltp} = i_{wltp} - \sum_{t2\in T\setminus\{t\}} s_{wltpt2} + \sum_{t3\in T\setminus\{t\}} s_{wltpt3} \quad \forall w\in W, l\in L, t\in T, p\in P, \tag{14}$$

$$\sum_{t,t2\in T} s_{wltpt2} \le 1 \quad \forall w\in W, l\in L, p\in P, \tag{15}$$

$$\sum_{t2\in T}\sum_{l\in L}\sum_{p\in P} s_{wtlpt2} \le h_s \quad \forall w\in W, t\in T, \tag{16}$$

$$AB_{wp} \ge \sum_{l\in L} s_{wltpt2} + \sum_{l\in L} s_{wlt2pt} \quad \forall w\in W, p\in P, \tag{17}$$

$$y_{wlt}, i_{wltp}, z_{wltp}, s_{wltpt2}, AB_{wp} \in \{0,1\} \quad \forall w\in W, l\in L, t\in T, p\in P. \tag{18}$$

The objective function minimizes transportation and swap cost, considering the fixed purchasing costs in phase 1. Constraint set (10) assigns a selected harvest area either to its owner or another player as a swap. The number of ownerships for each player remains the same before and after swap in constraint set (11). Constraint sets (12) avoid swapping a territory if the player ends up owning it. Likewise, constraint set (13) prevents other players from receiving a territory that one owns at the beginning. The swap takes place during constraint set (14), prohibiting possession of a territory during swapping. Symmetry in swaps are considered in constraint set (15). Constraint set (16) restricts the number of swaps for each player. The number of unpairwise swaps are calculated in constraint set (17). Constraint set (18) defines binary restriction of all decision variables. The model is an integer programming model with binary variables. After solving this model, the selected harvest areas for each team are updated following the swap phase and are fixed as the input of third phase model—like the first phase model.

3.3. Overall Model

It is also possible to solve an overall problem where all phases are integrated. The model is an integer programming model with binary variables. Further, the overall model integrates the first phase and second phase models with similar constraints.

$$\min \sum_{w\in W}\sum_{t\in T}\sum_{m\in M^t}\sum_{l\in L} c^d_{ml} x_{wlm} + \sum_{w\in W}\sum_{t\in T}\sum_{m\in M^t}\sum_{l\in L} c^p_{ml} x_{wlm} + \sum_{w\in W}\sum_{t\in T}\sum_{m\in M^t}\sum_{l\in L} r\, y_{wlt} + \sum_{w\in W}\sum_{t\in T}\sum_{l\in L}\sum_{t2\in T} c^s s_{wtlpt2} + \sum_{w\in W}\sum_{p\in P} c^s AB_{wp}, \tag{19}$$

s.t.

$$\sum_{m\in M_p} x_{wlm} \le 1 \quad \forall w\in W, l\in L, \tag{20}$$

$$\sum_{l\in L} x_{wlm} \ge d_{wm} \quad \forall w\in W, t\in T, m\in M^t, \tag{21}$$

$$2y_{wlt} \le \sum_{p\in P} i_{wltp} \quad \forall w\in W, t\in T, l\in L, \tag{22}$$

$$1 + y_{wlt} \ge \sum_{p\in P} i_{wltp} \quad \forall w\in W, t\in T, l\in L, \tag{23}$$

$$z_{wltp} \ge \sum_{m\in M^t_p} x_{wlm} \quad \forall w\in W, l\in L, t\in T, p\in P, \tag{24}$$

$$\sum_{t\in T, p\in P: m\in M^t_p} z_{wltp} \le x_{wlm} \quad \forall w\in W, l\in L, m\in M^t_p, \tag{25}$$

$$\sum_{t\in T} z_{wltp} = \sum_{t\in T} i_{wltp} \quad \forall w\in W, l\in L, p\in P, \tag{26}$$

$$\sum_{l\in L} z_{wltp} = \sum_{l\in L} i_{wltp} \quad \forall w\in W, t\in T, p\in P, \tag{27}$$

$$\sum_{t2\in T\setminus\{t\}} s_{wltpt2} \le 1 - z_{wltp} \quad \forall w\in W, l\in L, t\in T, p\in P, \tag{28}$$

$$\sum_{t2\in T\setminus\{t\}} s_{wltpt2} \le 1 - i_{wltp} \quad \forall w\in W, l\in L, t\in T, p\in P, \tag{29}$$

$$z_{wltp} = i_{wltp} - \sum_{t2\in T\setminus\{t\}} s_{wltpt2} + \sum_{t3\in T\setminus\{t\}} s_{wltpt3} \quad \forall w\in W, l\in L, t\in T, p\in P, \tag{30}$$

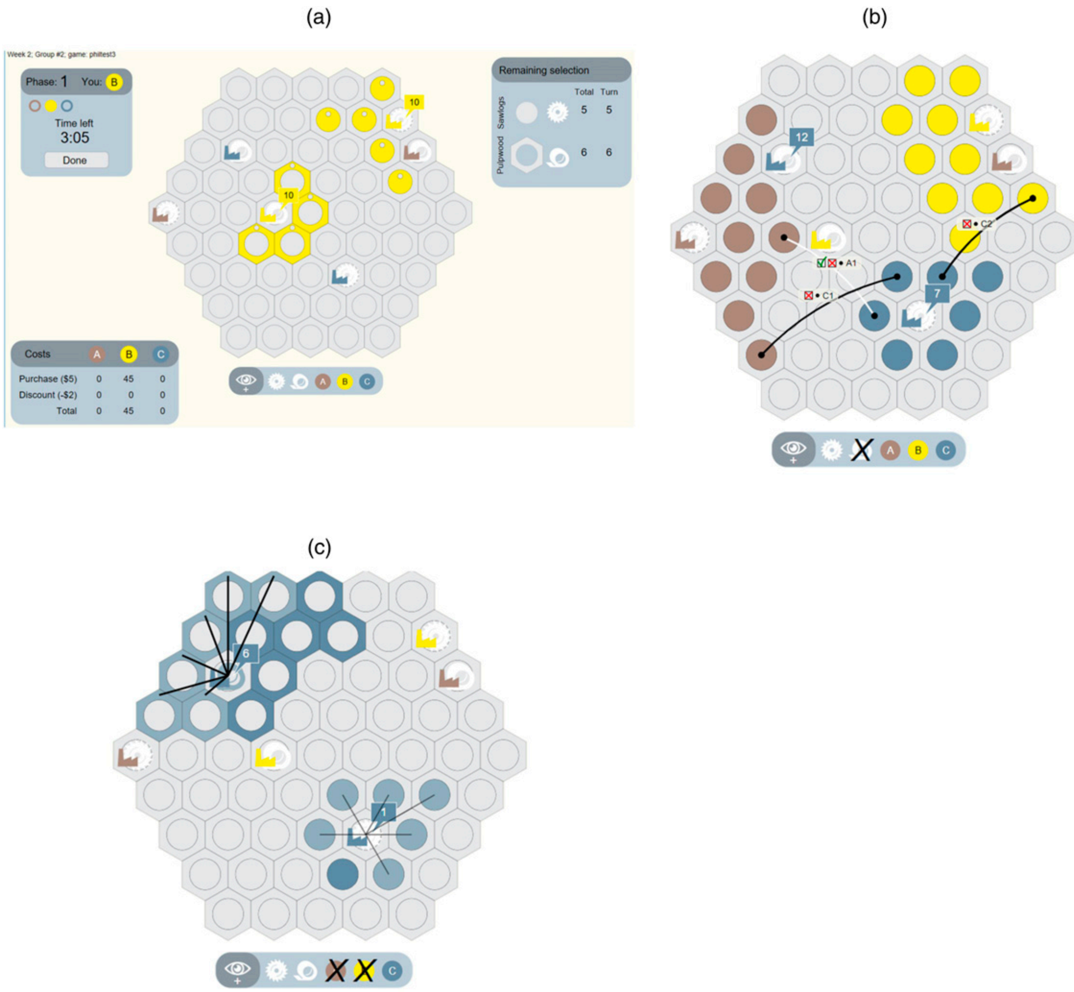
$$\sum_{t,t2\in T} s_{wltpt2} \le 1 \quad \forall w\in W, l\in L, p\in P, \tag{31}$$

$$\sum_{t2\in T}\sum_{l\in L}\sum_{p\in P} s_{wtlpt2} \le h_s \quad \forall w\in W, t\in T, \tag{32}$$

$$AB_{wp} \ge \sum_{l\in L} s_{wltpt2} + \sum_{l\in L} s_{wlt2pt} \quad \forall w\in W, p\in P, \tag{33}$$

$$x_{wlm} \ge 0; y_{wlt}, i_{wltp}, z_{wltp}, s_{wltpt2}, AB_{wp} \in \{0,1\} \quad \forall w\in W, l\in L, t\in T, p\in P, m\in M^t_p. \tag{34}$$

Figure 10. Summary of the Three Game Phases with Explanation About Decision Time and Playing Environment in Each Phase



Notes. (a) Decision: supply area selection satisfies associated demand to each mill, thereby minimizing purchasing and transportation cost. Time: dependent on the setting. Teams play in turns. They play noncollaboratively. (b) Decision: exchange of supply areas to reduce transportation cost. Time: dependent on the setting. Teams play parallel. They should play collaboratively. (c) Decision: assign selected supply areas to the mills in shortest path to minimize transportation cost. Time: dependent on the setting. Teams play parallel. They play noncollaboratively.

4. Discussion and Experience

Players can adopt several strategies to achieve success during the game. First, players should always collaborate with each other in a competitive environment, for supply points will be selected as early as the game's first phase. Here's an example of a successful collaboration: Players agree with selecting a supply bundle having a low purchasing cost. During the next phase, players may propose excellent exchange proposals. Second, players are encouraged to play individually to stimulate hierarchical thinking. Individual players are often successful because they select areas with high interest in exchanging during the first phase. Afterward, the players assign the supply to demand points—making the backhauling process interesting.

When players recognize that their first-stage design could affect improvement proposals during each phase, they understand the importance of hierarchical planning at the end of the first phase. Because each phase limits next-phase decisions, the game should be played twice to give players the opportunity to apply their theoretical and practical experiences. In this way, players can see how their performance improves with hierarchical thinking from the beginning. Figure 10 illustrates the three game phases. Each includes timing and decisions.

We run the game in several summer schools, undergraduate and graduate industrial engineering or operations research classes. Playing the game in class has convinced us to design the game in such a way that students can easily familiarize themselves with the interface. With the help of ongoing support and guidance, students will accelerate their understanding of the three phases, hence performing better in the future. Finally, we follow up on game education with lectures on practical and related planning problems and optimization models, and we explain how we developed optimization models for each phase.

5. Conclusion

Hierarchical transportation planning in forest supply chains attracts much attention from academic and industrial standpoints. In this regard, collaboration concept in the forest industry could directly have an effect on this type of planning. Our online transportation game combines these key aspects within three phases to tackle this problem. In the game, students need to anticipate the local planning phases and should consider the overall planning problem. Throughout the game, students will be able to realize local optimization. Students can also achieve large potential cost saving through collaboration with wood exchange, even when they are acting as competitors. The game provides an illustrative visualization for each of the phases, making it easy to understand the game rules and cost structure. The result windows are clear and informative. Lastly, the game provides an understanding of planning at various decision levels and a vision of collaboration. Integrated optimization models in the game display the effect of optimization on cost reduction—or, in other words, good planning.

Although the transportation game only simulates procurement planning in the forest supply chain, it is powerful enough to be used as an educational tool to support hierarchical planning in any supply chain, although harvest-area selection, which is the beginning of forest industry planning, may be perceived as supplier selection in other industries. The exchange of resources to optimize resource utilizations and costs is common between many forestry organizations, which is also the case in many other industries. The resource-assignment phase, bearing the least possible cost, is available in all industries. The visual interaction and detailed result analysis support the understanding and experience of the game.

Acknowledgments

We thank the FORAC (de la Foret au Client) consortium and the faculty of Engineering and Science at Université Laval for support in developing the transporta-tion game.

Appendix. Game Description

Transportation systems have a significant impact at several planning levels in the forest supply chain. To have an efficient transportation cost, hierarchical planning at the strategic, tactical, and operational levels in a collaborative environment is required. The transportation game was developed considering these two realities. The game is a simplistic forest supply chain with three companies (players) and restricted resources. The goal is to satisfy mill demand at the least cost. Strategic decisions in the game are concentrated on the harvest-area selection that determines the network structure during the game. This structure is built on a competitive situation between players. In a collaborative network, however, wood exchange could yield little improvement on the network. Irrespective of the network structure, tactical planning, including assignment of selected harvest areas to mills, will take place.

The game principal platform is a map with 61 or 91 nodes and three players (Figure A.1). Each team has its own sawmill(s) and/or pulp mill(s) differentiated by colours and shapes. Each node is a supplier of one unit of sawlog and pulpwood. The arcs connect neighbour nodes with one unit of transportation. The button of supply and teams under the map could remove other supply selections or teams from game view. The general idea is to select harvest areas and satisfy their mill demand, minimizing purchasing and transportation cost.

When the players log in to the game, they begin the first phase to satisfy their mill's demand in turn and within the time limit. Each team tends to select the nodes close to their mill to have a low transportation cost. Selecting a node as a supplier for sawlog and pulpwood entitles players to a purchasing rebate. Clicking on each node denotes a selection; the selection may be undone only during the player's turn. Once the players have selected their required nodes, they should click the **Ready for next phase** button, which will automatically direct them to the next phase.

The swap phase provides players the opportunity to exchange the harvest area to reduce transportation cost. The purchasing cost is fixed after the first phase, however.

Figure A.1. The Game Map

Swap is possible only between the same types of resources. Players could suggest their desired exchange by clicking on the nodes and adding them to swap-proposal windows. Collaboration between players to find the best exchange will reduce the network cost, thereby making collaboration beneficial for all players. Each player has a restricted number of swaps within a specific time limit. Once players have completed the second phase, they should click on the **Ready for next phase** button.

The players should assign selected nodes to their mills during the third phase. Players complete the assignment individually within a specific time limit. They should select a pulp mill or sawmill and assign pulpwood and sawlogs to minimize transportation cost. This cost is calculated by the number of arcs between node and mill multiplied by two for load and unload transporting.

Performance progress will be communicated to each player at the end of the three phases. The purchasing, transportation, total cost, and networks give players insight into their costs in different phases. Finally, the player with the least costs is declared the winner, while the group with the least total cost will receive a reward. We have developed optimization models for each game phase; these models will compare the players' results with optimal solutions.

References

Beaudoin D, Frayret JM, Lebel L (2008) Hierarchical forest management with anticipation: An application to tactical–operational planning integration. *Canadian J. Forest Res.* 38(8):2198–2211.

Bredström D, Jönsson P, Rönnqvist M (2010) Annual planning of harvesting resources in the forest industry. *Internat. Trans. Oper. Res.* 17(2):155–177.

D'Amours S, Rönnqvist M (2013) An educational game in collaborative logistics. *INFORMS Trans. Ed.* 13(2):102–113.

D'Amours S, Marier PH, Rönnqvist M, Azouzi R, Fjeld D (2017) Game—The online wood supply game. *INFORMS Trans. Ed.* 18(1):71–87.

D'Amours S, Rönnqvist M, Weintraub A (2008) Using operational research for supply chain planning in the forest product industry. *INFOR Inform. Systems Oper. Res.* 46(4):265–281.

Fjeld D, Hedlinger C (2005) The transport game—A tool for teaching the basics of transport decision proficiency. *Internat. J. Forest Engrg.* 16(2):57–65.

Forsberg M, Frisk M, Rönnqvist M (2005) FlowOpt—A decision support tool for strategic and tactical transportation planning in forestry. *Internat. J. Forest Engrg.* 16(2):101–114.

Frisk M, Flisberg P, Rönnqvist M, Andersson G (2016) Detailed scheduling of harvest teams and robust use of harvest and transportation resources. *Scandinavian J. Forest Res.* 31(7):681–690.

Frisk M, Göthe-Lundgren M, Jörnsten K, Rönnqvist M (2010) Cost allocation in collaborative forest transportation. *Eur. J. Oper. Res.* 205(2):448–458.

Kong J, Frisk M, Rönnqvist M (2015) Using mixed integer programming models to synchronously determine production levels and market prices in an integrated market for roundwood and forest biomass. *Ann. Oper. Res.* 232(1):179–199.

Paradis G, Bouchard M, LeBel L, D'Amours S (2018) A bi-level model formulation for the distributed wood supply problem. *Canadian J. Forest Res.* 48(2):160–171.

Rönnqvist M (2003) Optimization in forestry. *Math. Programming* 97(1):267–284.

Rönnqvist M, D'Amours S, Weintraub A, Jofre A, Gunn E, Haight RG, Martell D, Murray AT, Romero C (2015) Operations research challenges in forestry: 33 open problems. *Ann. Oper. Res.* 232(1):11–40.

Sterman J (1989) Modeling managerial behavior: Misperceptions of feedback in a dynamic decision making experiment. *Management Sci.* 35(3):321–339.