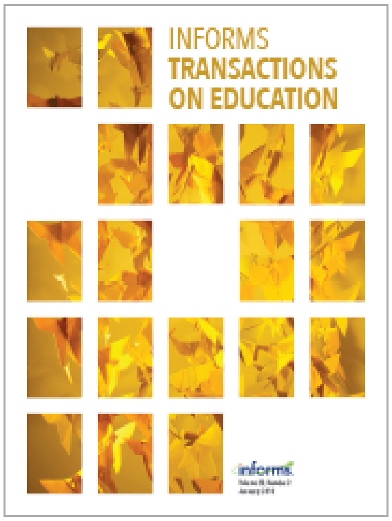

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To cite this article:
Sophie D'Amours, Philippe Marier, Mikael Rönnqvist, Riadh Azouzi, Dag Fjeld (2017) Game—The Online Wood Supply Game. INFORMS Transactions on Education 18(1):71-87. https://doi.org/10.1287/ited.2017.0174

informs
http://pubsonline.informs.org/journal/ited/
INFORMS TRANSACTIONS ON EDUCATION
Vol. 18, No. 1, September 2017, pp. 71–87
ISSN 1532-0545 (online)

Game

The Online Wood Supply Game

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Received: January 20, 2016
Revised: September 28, 2016; January 12, 2017; January 25, 2017
Accepted: February 23, 2017
Published Online in Articles in Advance: July 24, 2017

https://doi.org/10.1287/ited.2017.0174

Abstract. This paper describes the Wood Supply Game (WSG), a prize-winning e-learning tool that is freely available for players all over the world. The game effectively helps students and managers realize the challenges in managing demand and supply in wood supply chains, and gain insight into the types of measures required to make these divergent chains effective. The WSG is an adaptation of the Beer game, a popular didactic tool used to empirically demonstrate demand amplification in a simple and generic context. The supply chain modeled by the Beer game does not involve co-products, and thus is very different from the wood supply chain, which is divergent by nature. The WSG presented in this paper models a supply network with one point of divergence and demand for two products. This preserves the simplicity of the game but enables it to offer a base for supply network simulation in a large number of industrial sectors with divergent processes. We describe an online version of the WSG, discuss our experiences playing it with students and managers, and provide hints to the instructor.

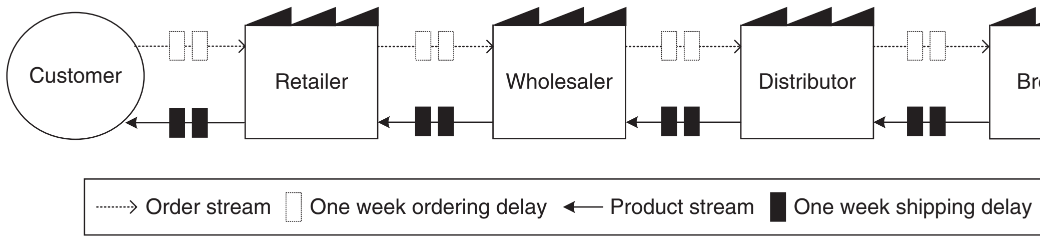
Keywords: teaching supply chain management • teaching production/operations management • classroom games • collaborative learning • online learning

1. Introduction

The production of forest products usually involves co-products (i.e., trees are broken down into many products). In such divergent supply chains, many issues are interrelated such as product-mix planning, constraints of the supply chain, forecasting and risk management, and the competitive advantage (Rönnqvist et al. 2015, Hung 2011). Each actor in the supply chain seeks a detailed view of the whole supply chain. From a system perspective, and similar to other industries, the wood supply chain can be defined through the goal-oriented networks of processes and stock points used to deliver goods to customers. Wood material flows from the forest, to sawing facilities, to value-added mills, and through the many channels of distributors, including wholesalers and retailers, to finally reach the end customers (D'Amours et al. 2009). Each component in the supply network is an independent decision-making unit; this can result in a lack of synchronization of operations. More specifically, a process manager not receiving accurate demand data from the customer will adjust the demand forecast and, as a result, the parameters of the inventory replenishment rule. This may cause an overreaction to short-run fluctuations, thus inducing variance amplification at other stages upstream in the value chain (Dejonckheere et al. 2004). This variance or demand amplification is known as the bullwhip effect. It has been observed across other industries (Simchi-Levi et al. 2003), and is identified as one of the main causes for high buffer inventories, poor customer service, missed production schedules, wrong capacity plans, inefficient shipping, and high costs observed in many supply chains. According to Lee et al. (1997), there are four other important causes for the Bullwhip effect. These are non-zero lead times, order batching, supply shortages, and price fluctuation. The Bullwhip effect was originally studied by Forrester (1958). That work inspired several other authors to develop didactical games to illustrate the effect and facilitate understanding its causes and economics consequences.

The well known "Beer production and distribution game" (Beer game) was developed by the MIT Sloan System Dynamics Group in the 1960s (Sterman 1984). It is a role-playing game where the participants experience the negative impacts of the Bullwhip effect and realize the importance of information sharing in supply chains. The game models a simple serial four-stage

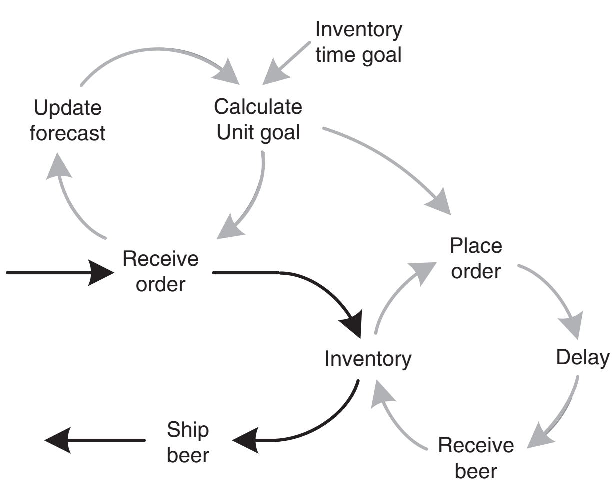
Figure 1. Structure of the Supply Network Used in the Beer Game



Notes. The demand signals move from left to right while the products flow from right to left.

supply chain network (see Figure 1). Each stage is controlled by one player, who receives demand from the stage downstream and decides how much to order from the stage upstream. The model depicted in Figure 2 was adapted from Jacobs (2000) to illustrate the decision process that the player is expected to use when playing the Beer game. There are four stages in this process, with emphasis on the fact that the player determines the appropriate stocking level goal based on the best guess of the demand forecast which is, in turn, determined based on the actual demand from the player in the preceding stage. Based on the estimated desired stocking level goal and keeping in mind that there could be long delays before this stocking level is built, the player sets the quantity to be ordered. Note that at each stage, there are order and shipment delays; inventory-carrying and stock-out costs can be incurred. As noted by Dominguez et al. (2014, p. 2194), "one of the most common simplifying assumptions in the literature is to assume that the supply chain network adopts a serial structure." Despite the fact that real supply networks rarely adopt such a simple "serial" structure (this is the case in most industries, from automobiles to leather shoes), the Beer game was heavily used in training; for over 50 years the game has been used by people at all levels, from students in university-level logistics to high-level managers of big multinational groups.

Figure 2. Illustration of the Decision Process When Playing at a Given Stage of the Beer Game

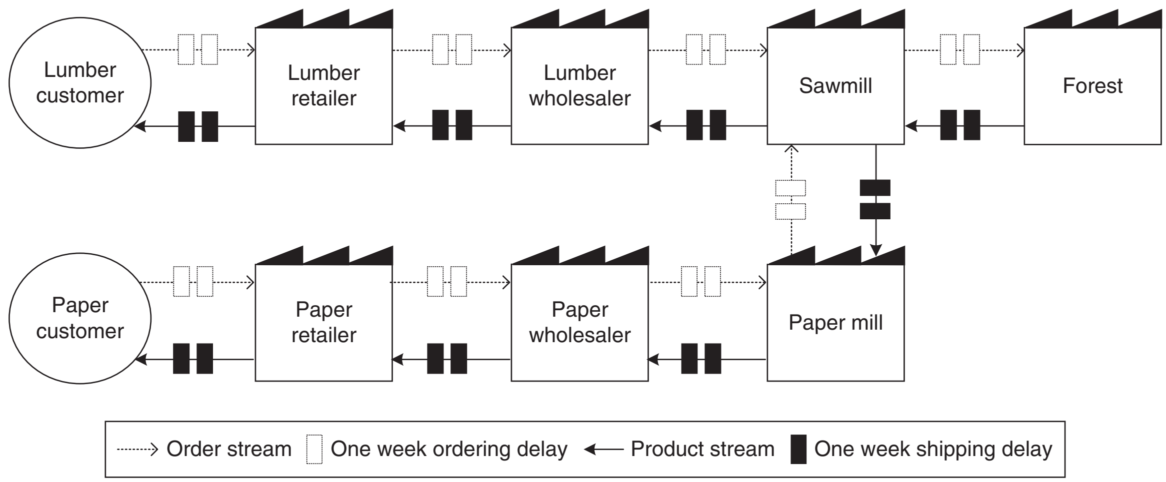


The simplification described above is one important reason that the Beer game is unsuitable for use in the forestry and forest industries sectors. The supply chain structure is similar in other natural resources industries, such as mining and petroleum. The fact that the Beer game does not consider changing product identity is another important reason. Indeed, being a simple distribution game (or a case of simple replenishment), the Beer game handles only one product and the identity of this product does not change throughout the supply chain. The Wood Supply Game (WSG) presented in this paper models a supply network with seven stages or companies arranged into two interrelated supply chains, i.e., a lumber chain (including the lumber retailer, the wholesaler, the sawmill, and the forest), and a paper chain (including the paper retailer, the wholesaler, the mill, the sawmill, and the forest). Downstream each chain has an external customer whose demand, although determined in advance, is not known by the players (see Figure 3). Lumber and paper demand are not correlated and can vary considerably.

Like the Beer game, the WSG is also a role-playing game where each player must minimize cost by managing inventory level in a simulated business unit. As might be expected, the players' decision processes at the different stages in the WSG and in the Beer game are similar; the only difference is that the player at the sawmill stage must balance two interdependent products inventories, i.e., lumber and chips (see Figure 4). For chips, as for lumber, this player estimates the desired stocking level goal that seems appropriate based on the player's best guess of the demand forecast, which is, in turn, based on the actual demand from the player upstream. The player sets the quantity of wood to order from the forest based on the estimated desired stocking level goals for lumber and chips, and considering possible long delays before these stocking levels are built.

Thus, the player at the sawmill stage must consider a larger number of parameters. Note that the decision process appears to be more sophisticated. However, this does not enhance learning about how to more

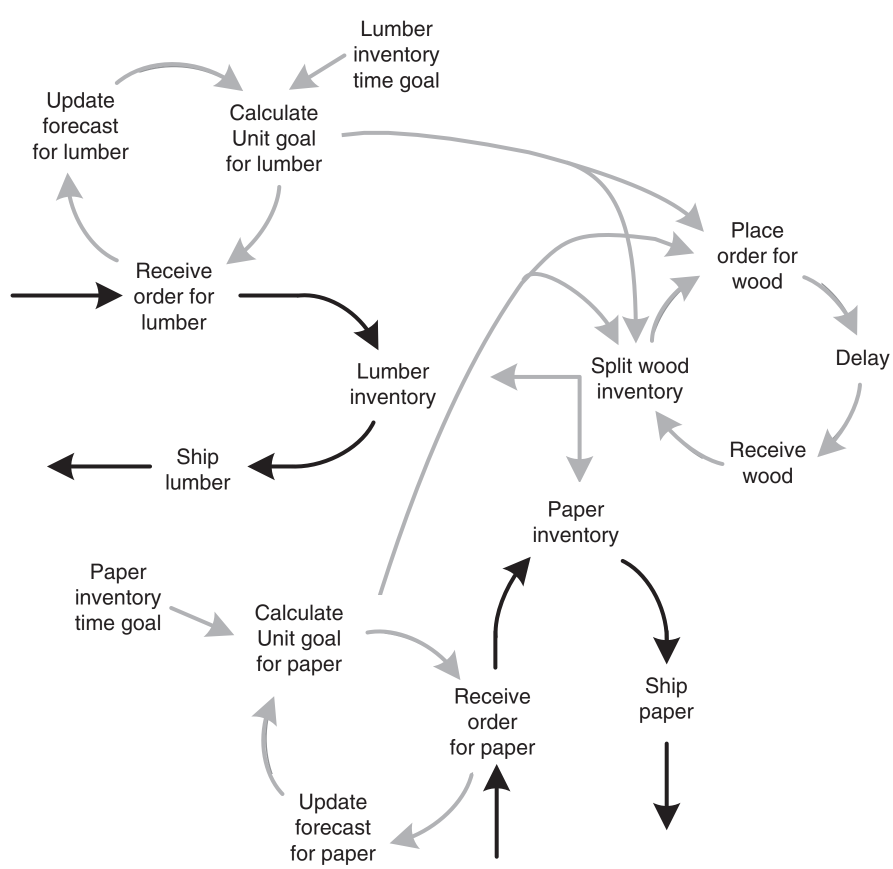
Figure 3. Structure of the Supply Network Used in the Wood Supply Game: Two Types of Products Are Produced



Notes. The demand signals (flowing from left to right) converge at the sawmill. The flow of products (right to left) diverge at the sawmill.

effectively manage the supply chain. Although the players have this same learning objective, they are not acquiring it in the same way. In fact, the sawmill position is critical for all players to learn the challenges of divergent processes in a supply chain. This is an intrinsic characteristic of the forest products industry. The simplified strategy selected for the game helps all players appreciate the challenges. Also, the forest has limited supply, and during some periods may be closed for production to better showcase the fact that inventory must be planned in advance. The divergent point in the product flow is introduced to bring more relevance to the supply chain game. From the Theory of constraints management philosophy, this divergence can be cate-

Figure 4. The Decision Process for the Player at the Sawmill Stage of the Wood Supply Game



gorized as a V-structure, where the divergent points should be controlled for cross-functional coordination, cross-enterprise integration, effective product flow, and timely and relevant information sharing (Lockamy III 2008). Thus, the WSG gives students and managers an environment more relevant to divergent industries where they can understand the impact of the Bullwhip effect, and gain insight into the type of measures needed to control the divergent points that characterize wood supply chains. Also, with two products, inventory management becomes more difficult compared to the Beer game.

The paper is organized as follows. In Section 2, we present a review of the background of the game. In Section 3, we provide explanations about game administration, and describe several critical parameters the administrator must set before a game is started. In Section 4, we describe the WSG, detailing the game start up, management of each business unit, and analysis of the results. In Section 5, we report on our experiences using the game with students and managers. Section 6 presents concluding remarks.

2. Game Background

Wright (2015) provides a good review of educational games developed to illustrate concepts in operations management courses and other fields, such as supply chain management. Among the games cited, the Beer game is identified as a classic and probably the best known. While for a long time, the Beer game was played using a board and tokens that are physically moved on the board to represent orders and stock, electronic versions are now available on the web (e.g., www.beergame.org). Ease of implementation is one of the key factors in the success of the Beer game. . The other key factor, according to Griffin (2007), is the game's encouragement of interaction.

Haartveit and Fjeld (2002) made the first attempt to adapt the Beer game to the forest industries (see also Haartveit and Fjeld 2003a). Inspired by the North-European forest sector, these authors introduced divergent and convergent branching to the basic Beer game structure. They connected a four-stage supply chain delivering lumber with a four-stage chain delivering paper through introduction of the forest as a common source of raw materials (Fjeld 2001a, b). At the first position (wood supply group), the flow diverges into two branches as pulpwood and saw logs are distributed to a paper mill and a sawmill. The two mills correspond to the distributor position in the Beer game, and supply wholesalers and retailers with their respective products. At the sawmill, chips are separated from lumber products, delivered to the paper mill, and mixed with pulpwood for paper production. Finally, the paper mill produces paper and by-products. Thus, the resulting supply network comprises three points of divergence and one point of convergence, and is managed by eight individuals. Those at the points of convergence or divergence handle two products under specific restrictions as to product-mix flexibility. The game was played on paper; other variants were tested including a "monster version" consisting of three networks, such as the one described above, arranged such that the first positions (wood supply group) converge and order wood from the same forest. This forest is structured to translate high wood demand into long transport distances and thus high transport costs. More details on this variant are available in (Haartveit and Fjeld 2003b).

It is critical at this point to understand the main differences between the forest sectors in North-Europe and in the province of Québec, eastern Canada, which led us to development of the WSG. In Québec, the round wood (i.e., pulpwood) harvested in the forest is a secondary source of fiber for the paper mills. In fact, the majority of the raw materials used to make paper comes from sawmills, i.e., chips, sawdust, and shavings. For instance, this proportion exceeds 80% for sawmills in the province of Québec (Québec Forest Industry Council 2013). Often a paper mill is part of an integrated complex (a sawmill and a paper mill owned by the same company), but could also receive supply from independent sawmills. In today's markets, chip revenues are important for the survival of sawmills. When the lumber market is low or the demand at the paper mills is high, a sawmill might chip all logs even if these logs are good for lumber production.

Based on the discussion above, it is clear that a WSG, adapted to the North-American context, would not include a link between the forest and the paper mill. This eliminates the point of convergence and one of the two points of divergence all of which were added by Haartveit and Fjeld to the supply network of the Beer game. This is exactly what the researchers at Forest to Customer (FORAC), a research consortium based at the Université Laval in Québec City, Canada, did. They also removed the point of divergence at the paper mill output as there is no customer demand to be managed for the pulp mill products. Through these changes, FORAC's researchers not only adapted the Beer game to forestry and forest industries sectors in North-America, they also ensured that the game remains simple and generic. As discussed earlier, simplicity is key to the success of a game. On the other hand, by adding only one point of divergence to the supply network, the game offers a base for supply network simulation in a large number of industrial sectors.

The first version of FORAC's WSG was tested using boards and tokens (see Figure 5). Each board portrays a specific business unit in the supply network used

Figure 5. Boards and Tokens Version of the First WSG

in the game. Tokens represent the distributed products; customer demand and supply orders are represented using two decks of cards. During one year, several training sessions were conducted at the sites of some FORAC industrial partners. One requested three copies of this board and tokens version to conduct employee training. This paper presents an online version of the WSG adapted to the North-American context. The game consists of a Flash web interface as the front end, and a vb.net server developed using Visual Studio as the back end. Each player (using a web interface) is a user; they communicate with each other via the server, using an SQL database.

3. Game Administration

The WSG is openly available for people around the world on the following website: http://www.forac.ulaval.ca/woodsupplygame. This site offers useful game information including a general introduction and detailed instructions on how to play and how to personalize the game. Any standard Internet web browser can be used to access the game, which is available in French and English. Up to seven people can play a complete game; the computer can manage zero, one or more stages by fixed ordering rules. Decisions on which stage(s) will be assigned to the computer can only be made by the administrator.

As shown in Figure 6, game sessions can be started on three servers available at different places in the world. These are Canada, Sweden, and Hong-Kong. Users are expected to select the server nearest to their location to obtain faster connections. While it should be straightforward to associate the choices of the Canadian and European locations of the first two servers with the origins of the game authors, we provide an explanation of the location of the third server. This location came at the request of an organization headquartered in Hong Kong. A large original equipment manufacturer (OEM) of apparel, the organization has

Figure 6. FORAC's Wood Supply Game Website and Access Servers

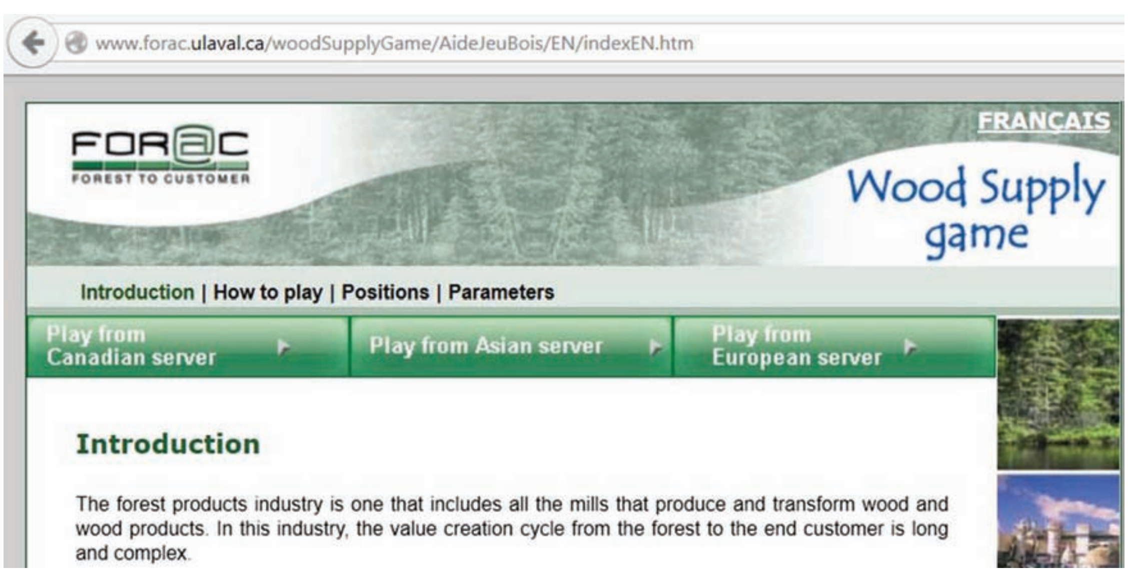
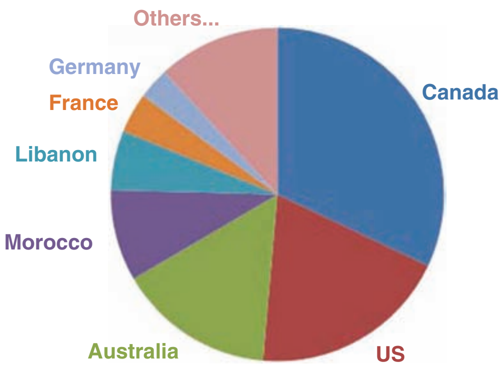


Figure 7. Geographical Distribution of WSG Played Online in 2014



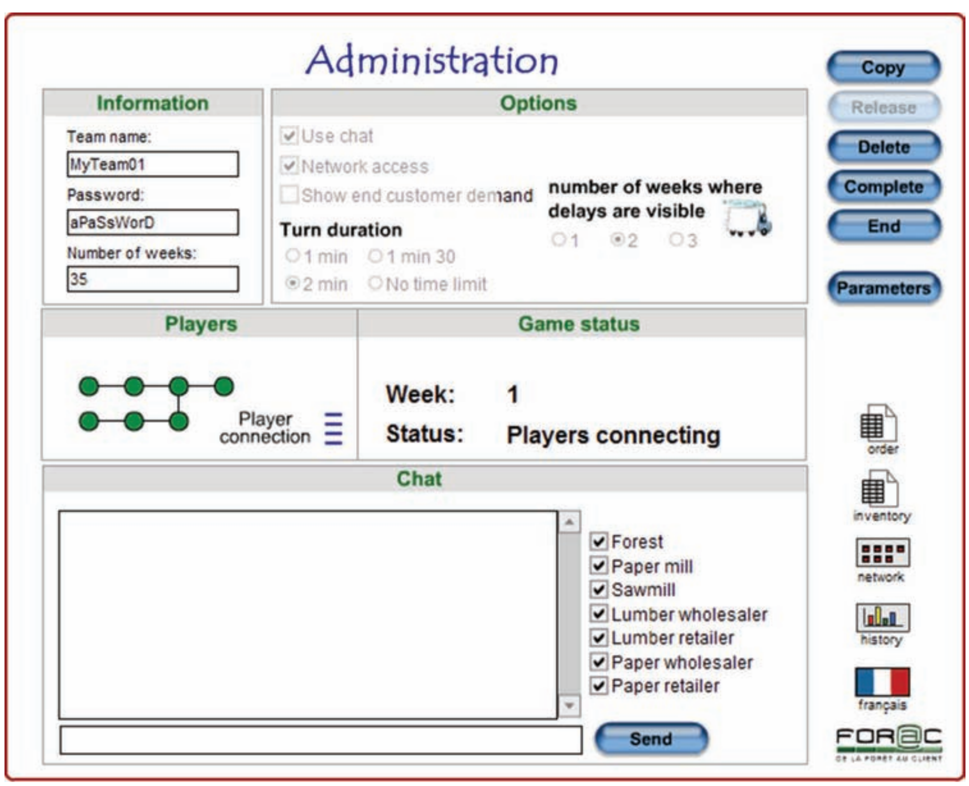
plants in Asia, and supplies brands and retailers worldwide. It is known for its supply chain services and had been using the game for internal training for several years from the Canadian server. They suggested that we offer an extra hosting site for the online WSG in Asia for those companies (including itself) that would like faster access to the game.

Since the launch of the WSG online in 2004, more than 4,250 games have been created and played all over the world. This corresponds to an average of approximately 50 games per month. The graph in Figure 7 shows the geographical distribution of WSG played online in 2014. An international WSG competition normally takes place twice a year with six to eight teams of students from universities in the United States, Canada, South Africa, and Europe. In 2011, the WSG won the prestigious OCTAS prize for the best e-learning tool. The OCTAS competition (OCTAS is a neologism created based on the French words "octet" and "as", meaning "byte" and "master") is a unique opportunity to recognize excellence in the field of information technology in Québec, Canada. It pays tribute to individuals, businesses or organizations for their creativity, vitality, and exceptional contribution to the growth of the industry.

Some preparations are needed before a group of players could connect and start playing. These preparations must be done by a game administrator, usually a member of the group or the group instructor in a course or training. The game administrator must create a new game including setting options and parameters; this is done through the administration windows (see Figures 8 and 9). These windows are not available for the players, unless a player is designated as the administrator. They can be used for several purposes before, during, and at the end of a game. It is recommended that the administrator prepare one or two back-up games to save time in case a new game must be started due to some player mistake. The instructor may also use an existing game to conduct different tests and demonstrations.

Next, we describe the critical parameters that the administrator must set before the game begins. These

Figure 8. Options-Setting Window



parameters are set using the window shown on Figure 8. The first parameter is the total number of rounds to be played; the game is played during a specific number of rounds, each round corresponding to a period of one week. The second parameter is the maximum time duration of one round. In other words, this is the simulation time for one week (The administrator decides if players have one, one and a half or two minutes to play each round). During the game, the next round/period/week does not begin until all the players have entered their quantities to order from their suppliers, or when the elapsed time has reached the maximum time duration of a round. The default order quantity is zero. The third parameter corresponds to the number of weeks (1, 2 or 3 weeks) during which the players can see the goods in transit. The goods in transit could be quantities arriving from the supplier (Reception of goods), and/or quantities going to the customer(s) (Shipment of goods). Note that the default values are also set by the administrator. Some other parameters can take different values from one stage to another. These include ordering delay, transport delay, inventory, and backorder costs. All delays are specified in number of weeks. For example, assume a given stage where the ordering time is two weeks and the transport time is three weeks. Then, for an order placed at week 1, the earliest date that the player at this stage could expect to receive some, or all, of the ordered materials (depending on the availability of the materials at the supplier) would be at week 5.

Additionally, the administrator determines if the players are allowed to use the chat windows of their interfaces to communicate with each other, and if these interfaces should give the players a view on the entire supply network and/or the end customer(s) demand(s). Figure 10 gives a glimpse of the value creation network. The player can use this interface to get an overview on the state of the entire network and the overall performance; it displays the inventory and/or backorder quantities, the incurred total costs, and the customers demand satisfaction levels recorded by all the players since the beginning of the game. Note that the backorders are recorded as negative inventory, and the satisfaction levels reflect the proportions of the products delivered on time to the customers (stages downstream) since the beginning of the game. The total incurred cost is calculated by summing the inventory costs and the backorder costs for the completed rounds.

For the stages managed by the computer, the administrator selects an ordering rule from a list of pre-established rules (see Figure 9 and Table 1). The ordering rule is the logic the computer uses to determine the

Figure 9. Parameters-Setting Window

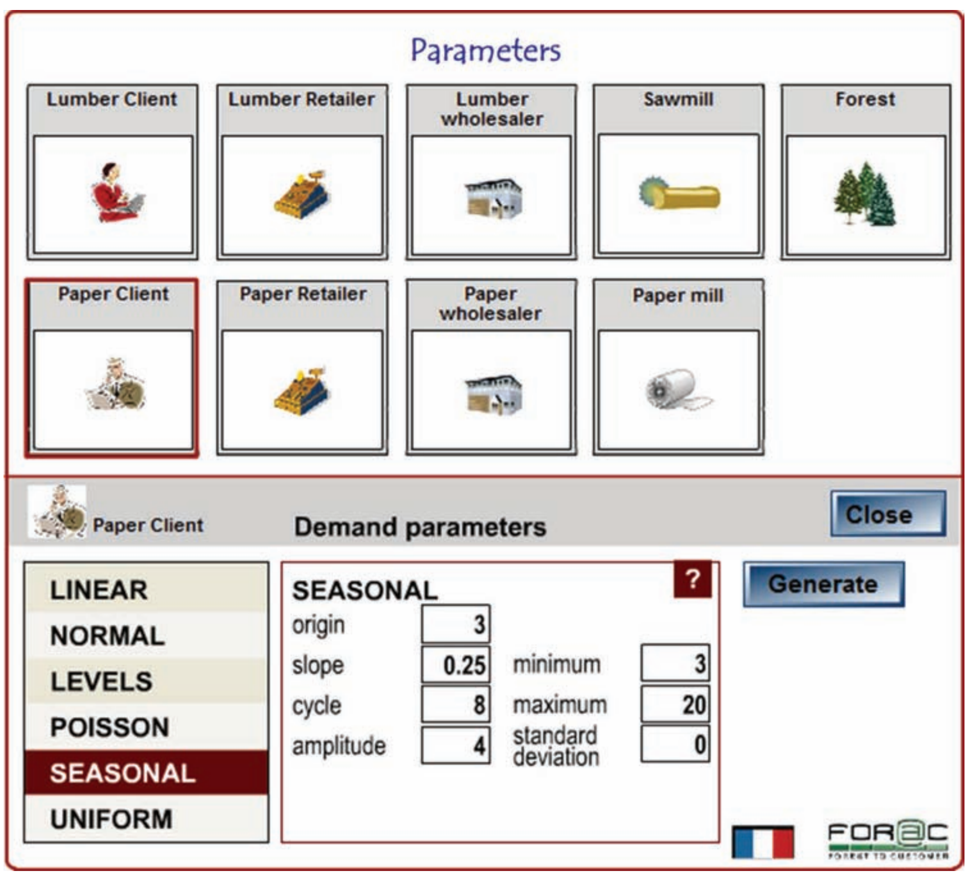


Table 1. Automatic Ordering Rules for Stages Directly Managed by the Computer

Rule	Quantity to order (q) at a given period i	
(1)	*if* $s < S$ *then* $q = Q$ *else* $q = 0$	Replenish stocks based on preset minimum quantity and order quantity.
(2)	*if* $s < s_{\min}$ *then* $q = \max(0, S - s)$ *else* $q = 0$	Replenish stocks based on preset minimum quantity and up to a preset maximum quantity.
(3)	*if* $s < S$ *then* $q = \max(0, S - s)$ *else* $q = 0$	Replenish stocks up to a preset maximum quantity.
(4)	$q = Q$	Order a fixed quantity each week.
(5)	*if* $s < s_{\min}$ *then* $q = \min(P * L + M * \sqrt{L} * K, S)$ *else* $q = 0$	Replenish stocks based on preset minimum quantity and an order quantity that depends on previous demand quantities, ordering delay and transport time.
(6)	$q = d$	Order the same quantity as the client ordered each week.
(7)	$q = d + (s_i - s_{i-1})$	Order the same quantity as the client ordered plus the variation of inventory levels since the last period.

Notes. s_i, s_{i-1}: Inventory levels at the current and previous periods respectively; Q: Quantity of units defined by the administrator; S: Desired inventory level defined by the administrator; $s_{\min}$: Inventory threshold defined by the administrator; P: Average demand over the last 10 periods; K: Estimated standard deviation of the actual demand over the last 10 periods; L: Lead time (ordering time + transportation time); M: Multiplier defined by the administrator; d: Actual demand (from downstream stage).

quantity to order from the supplier. For the external customer (lumber and paper), the administrator sets the ordering pattern. More specifically, the administrator generates a demand pattern based on one of the six available standard distribution functions parameterized as desired. Subsequently, the generated demand pattern can be modified as desired and demand manually entered for the remaining periods of the duration of the game. The forest has a section called "Supply plan," where the administrator enters the minimum and maximum values to be harvested each week. The maximum quantity that can be harvested during the game is also entered here. If the forest is managed by the computer, the harvest will be generated according to the rules chosen by the administrator. During the game, the administrator can communicate with the players as well as changing the ordering rules for the stages managed by the computer. If a player quits before the end of the game, the administrator can replace the player with the computer. All of the ordering data and inventory levels are available to the administrator in real time during the game. Normally, the game ends once the total number of weeks is reached, however, the administrator can end the game at any time. Finally, at the end of the game, the administrator and the players have access to the comparison results. If the administrator is the instructor of a group of learning players, these results can be used in a discussion lead by the administrator.

4. Game Description

4.1. Connecting to the Game

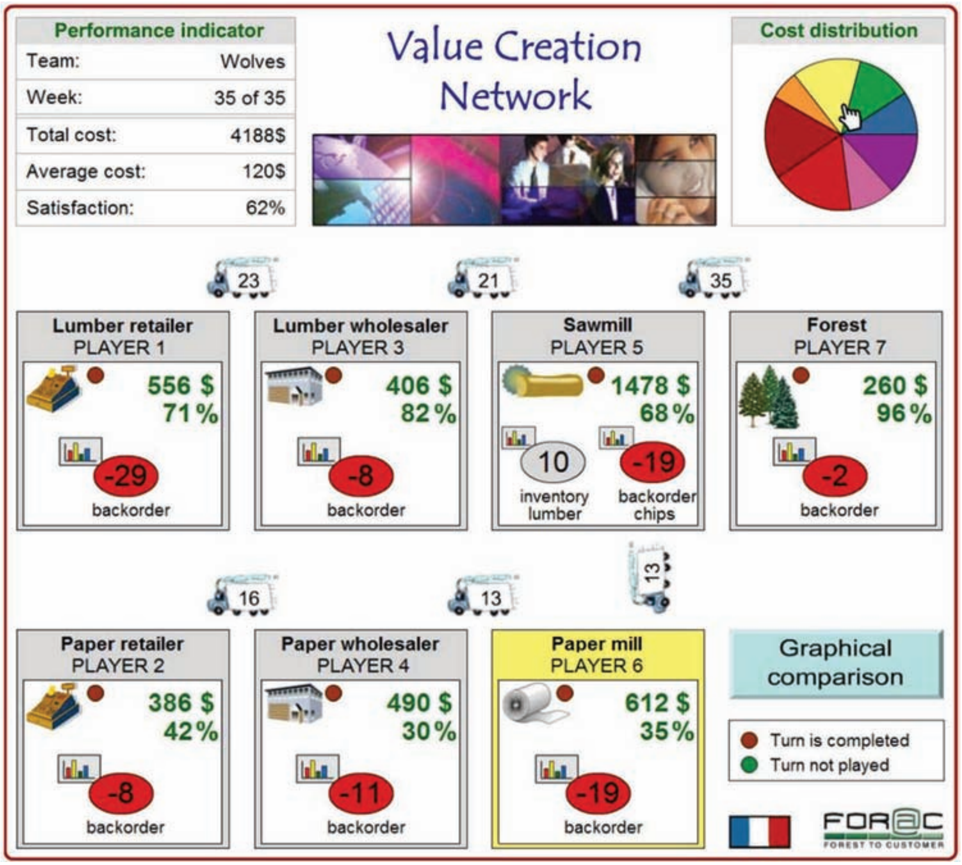
Once a game is created and made public by the administrator, the group members can connect. When a player connects to the game (Figure 11, left side), the player must first select the stage to be managed (Figure 11, right side). In a typical course, the instructor, who is also the game administrator, can assign stages to the players; the players should select these stages when connecting to the game. A game cannot start until a manager is identified for each stage.

4.2. Managing the Paper Mill and the Client, Retailer or Wholesaler Stages in the Lumber and Paper Supply Chains

The players managing the paper mill and the client, retailer or wholesaler stages in the lumber and paper supply chains use an interface similar to the one shown in Figure 12. This standardized interface provides the player with information about the position of the player's company in the supply network and the incoming and outgoing goods at a given period and over the delivery lead times. There is also a delay between the period during which an order is placed and the period when the order arrives. Note that the supplier cannot see the incoming customer orders during this delay. In other words, the interface informs the supplier only about the customer order arriving during the current period. Also, if enabled by the game administrator, the interface can provide the player with a view of the entire network (via the interface shown in Figure 10) and of end customer demand. The latter will appear in the customer order section of the interface.

During any given period and before the elapsed time reaches the maximum round duration (the interface displays a time counter), the player must enter the quantity to order from the supplier. In each period, the system dispatches as many units as possible to satisfy the customer order received at the beginning of the period. With this intention, the system uses the units available in inventory as well as the units to be received during the period (these units are those of the first truck representing the quantities in transit from the supplier). To determine the quantity to order, the player uses the information provided by the interface. In certain game scenarios, the player may also interact with other players through a chat window. The interface gives the player a snapshot of the player's current performance in matching supply to demand. A player

Figure 10. Interface Displaying the Value Creation Network

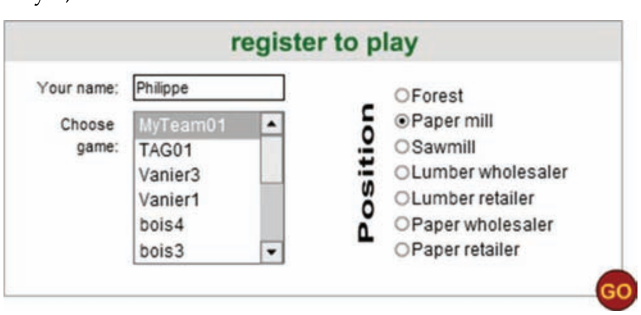


can assess that performance by looking at the indicators on inventory and backorder quantity, and the corresponding incurred cost. Depending on how the game was configured, the interface might also give the player an overview of the performance of other players, the state of the entire network, and the end customers' demands (see Figure 10).

4.3. Managing the Sawmill

The logic described in the previous section applies to the sawmill interface; the only difference is that the sawmill has two clients and thus, two customers' demands to fulfill and two inventories to manage. In addition, when new supply arrives, the player must decide how to allocate this supply to lumber and paper production. Using the knob control in the center of the interface (see Figure 13), it is possible to use the proportions 25%–75%, 50%–50%, and 75%–25% between lumber and paper.

Figure 11. Interface to Connect to a Game, Register as a Player, and Select a Position



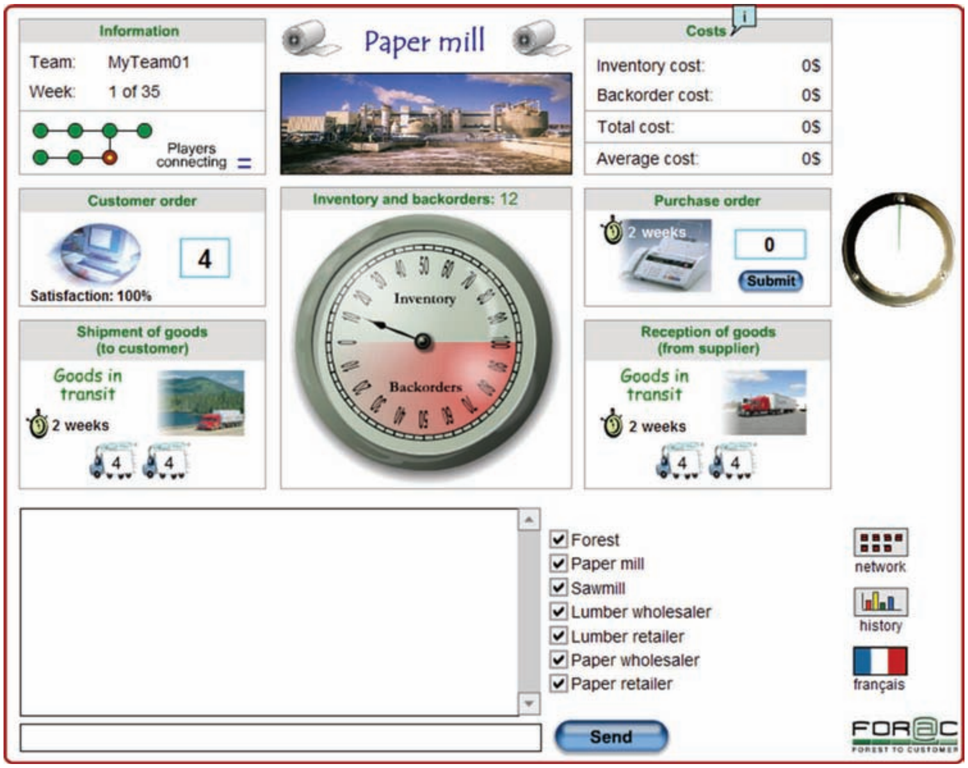
4.4. Managing the Forest

By contrast to the other players, the player managing the forest has no supplier. Instead, the player must harvest wood from the forest in the minimum (maximum) harvest volume allowed for each period. These constraints are displayed by the supply plan section in the forest interface (see Figure 14). There is also a limit on the total harvest volume during the duration of the game. At a given period, the player can see the goods and orders in the supply plan for a number of periods to come, and choose a value in the range allowed for the current period. Note also that there may be periods where it is not possible to access volumes due to, e.g., closed roads.

4.5. Analyzing the Results

After all the periods are completed, players are given access to comparison results such as those shown in Figures 15–17 (Note that the detailed results can be displayed in a tabular form). Essentially, the players are given detailed insight into their performances, expressed in terms of order history (including placed

Figure 12. Interface Used by the Player at the Paper Mill Stage



Note. Similar interfaces are used by the players at the clients, retailers, and wholesaler stages in the lumber and paper supply chains.

Figure 13. Interface Used by the Player at the Sawmill Stage

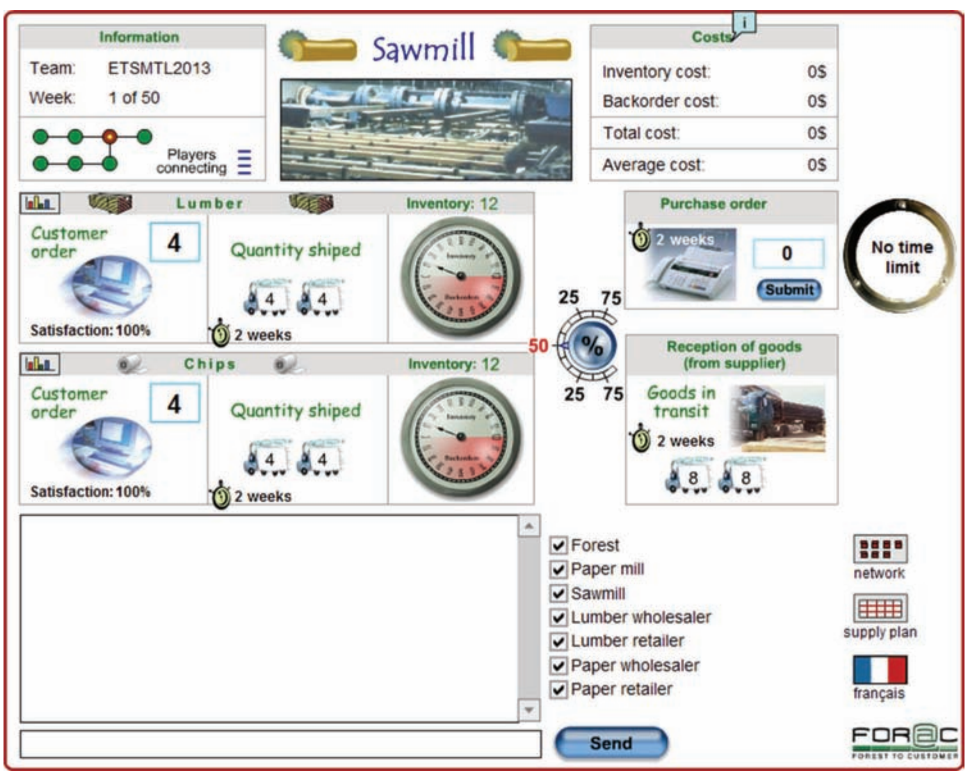
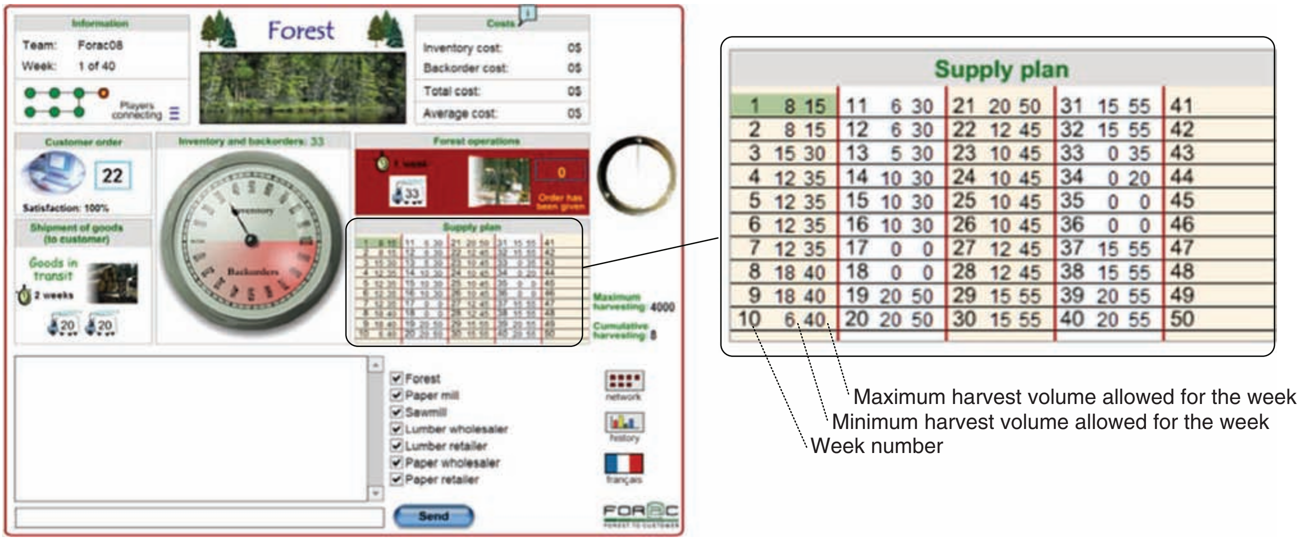


Figure 14. Interface Used by the Player at the Forest Stage

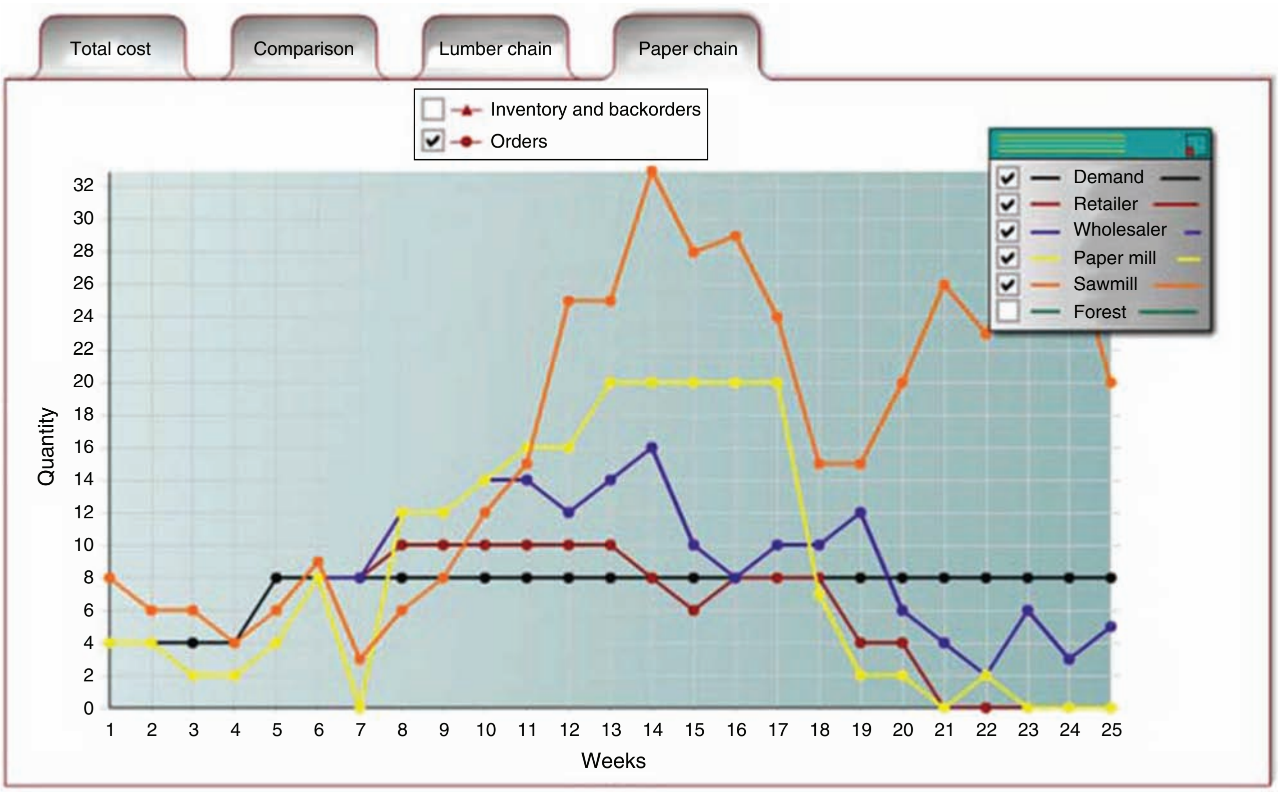


orders and/or inventory and backorders from the first period to the current period of the game), the evolution of total inventory and backorder costs, and the changes in the customers' satisfaction rates from period to period. In general, the players are often surprised to learn that the actual demands of the end customers were not quite what they expected. For instance, Figure 14 shows that the demand for paper was unchanged since period 5, however, the demands for the other units in the supply networks varied significantly from one period to the other.

5. Our Experience Using the Game

The online WSG is very appropriate in situations where several players should be placed in a virtual supply chain to experience supply management chal-

Figure 15. Order History for the Selected Stages in the Paper Chain



Note. The demand profile for paper is also shown.

Figure 16. Total Inventory and Backorder Costs Incurred at Each Stage in the Supply Network as Recorded at the Current Period

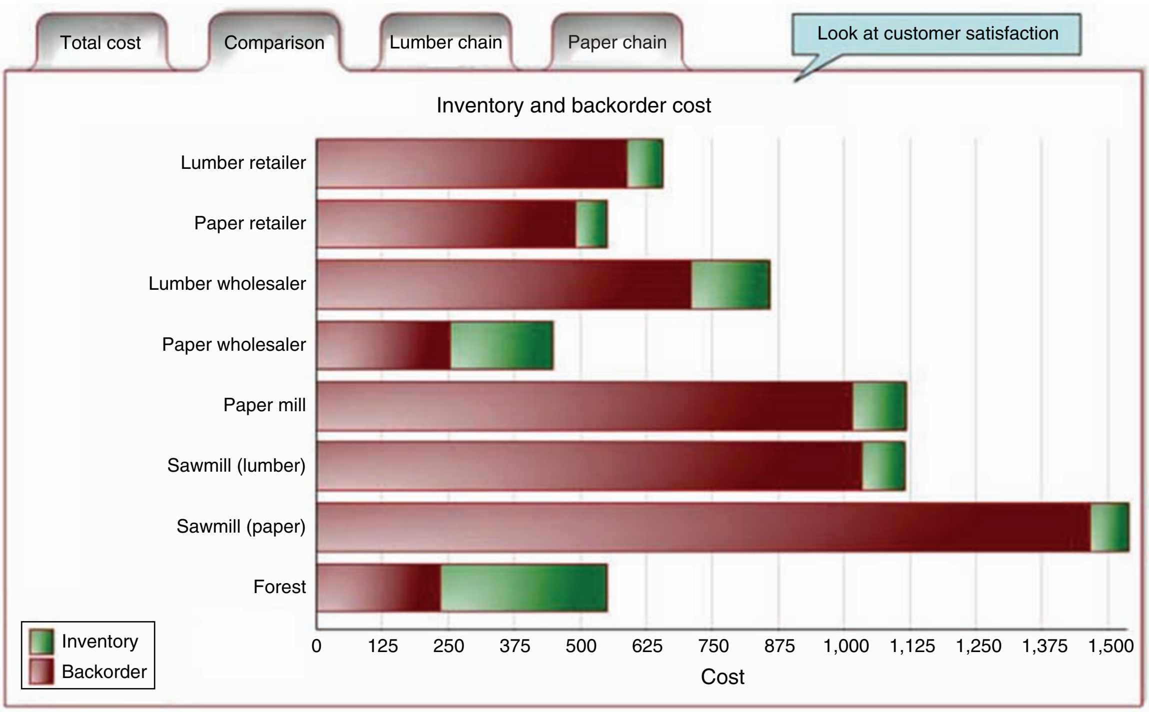
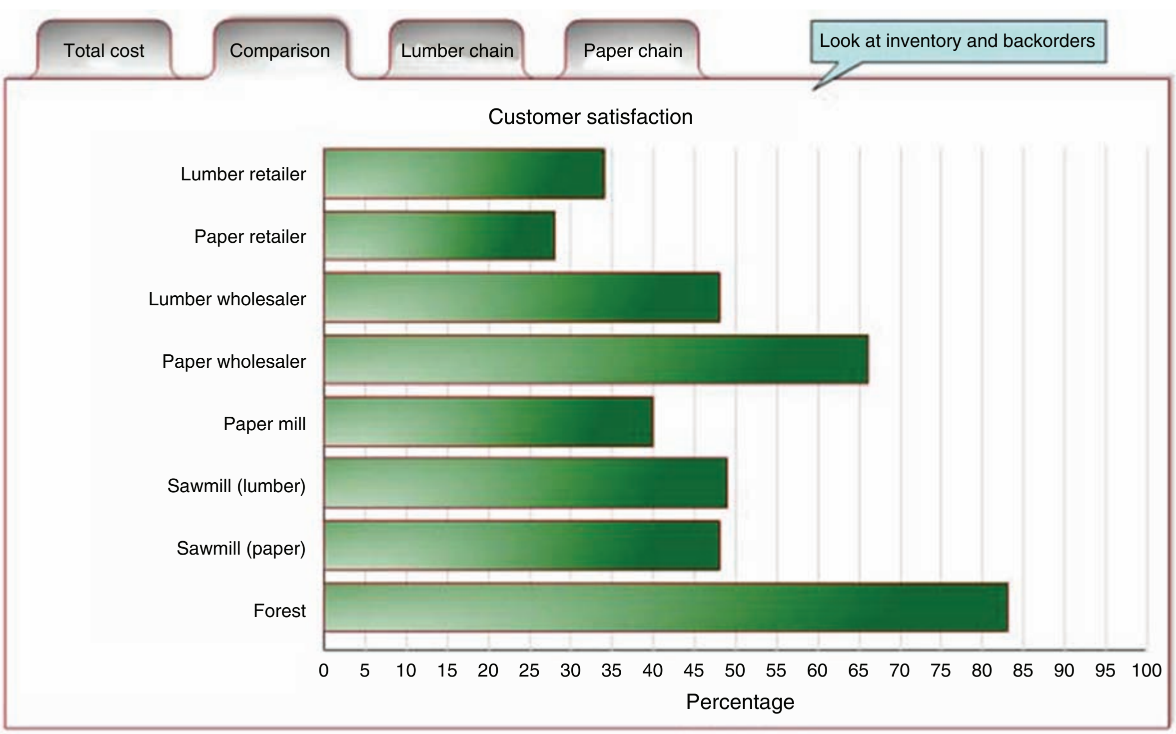


Figure 17. Customer Satisfaction at Each Stage in the Supply Network as Recorded at the Current Period



lenges. This explains why all the game sessions we have organized involved teams of players, including teams of students, teams of business people, and teams of researchers. The approach to using the game in class varies according to the teams involved. Still in every case the players are reminded that their roles in the supply chain are tightly linked; thus, they share responsibility for learning. They are encouraged to organize additional games after the course is finished. They are also invited to swap roles and try managing different stages in each new game; this ensures equivalent learning experiences. Note that post-game reviews offer another opportunity to equalize learning experiences among players.

The WSG is used in undergraduate industrial and mechanical engineering courses several times a year. We conduct one game session during one class. Before play, we give an overview of value chains and logistics networks, explain the rules of the game, and create the teams. To stimulate the players, the winning team at the end of the final session should receive a reward (e.g., 2 % towards final grade). We usually create three to eight teams of seven students per team. Then we play for 1.5 to 2 hours. After the game, we present the results, and interactively discuss the students' strategies. Although an experienced user can build a game in 5 minutes, setting up complex demand patterns can take up to 30 minutes per game. With high value demand, it is also necessary to increase the initial stocks and order levels. As the game progresses, the system automatically collects data. The instructor should check this data to ensure that play is moving smoothly and that no game must be discontinued because of playing errors. In addition, the instructor can post results during the game to stimulate competition. At the end of the game and the beginning of debriefing, the final results should not be visible. Then the instructor can ask students about their experiences before they are affected by the results. After that, the instructor reveals the results and leads a discussion in which students are given time to describe their decision strategies and reach their own conclusions about the game and the playing experience.

We have developed a training cycle comprised of three gaming sessions. The cycle involves a minimum of two teams, and requires a minimum of three days (Fjeld et al. 2014). Table 2 summarizes game parameters used in the sessions; Figure 18 illustrates examples of the supply plans for wood and the demand profiles for lumber and paper. The difficulty level increases from one session to the next, allowing greater opportunities for coordination.

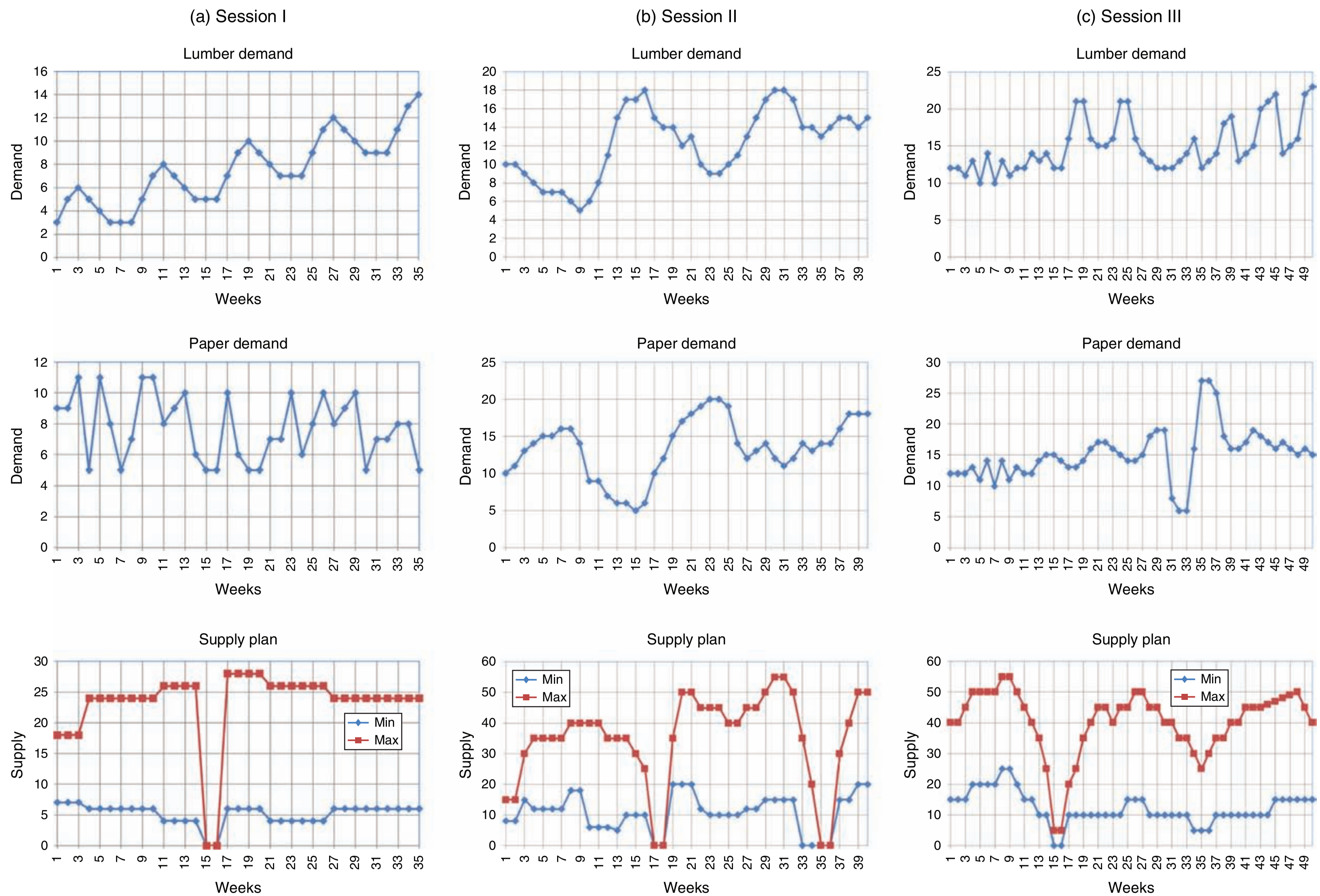
The first session should enable students to learn game mechanics; the second session helps them to develop responses to clear trends. In the third session, students are expected to develop a "calm team response". Sessions I and II conclude with immediate presentation and comparison of results between teams using the graphs and tables available online. The instructor shows each player's order history and identifies where the largest inventory and backorder costs were incurred. Then the instructor and the students try to explain these costs and identify the coordination mechanisms adopted by the team. The post-game analysis after session III is more formal. The players are given an afternoon to prepare a final presentation, which includes the following three parts:

First, the players visually map the changes in coordination processes and measure their effect on unnecessary variation in order rates across sessions. Each team presents a model of its final coordination process (explained as a step-by-step logic). In general, a gradual reduction in the degree of unnecessary variation of orders can be observed. Considering the trends for the development of coordination between sessions, typical errors from the first session include an isolated, single-position perspective with limited understanding of the lead times between positions. By

Table 2. Session Descriptions

	Session I	Session II	Session III
Learning goals	Learn how to play, understand the economic consequences, and think about possible remedies to the bullwhip effect.	Develop response to clear trends.	Grade the process improvement and results and develop a "calm team response."
Number of weeks	35 weeks	40 weeks	50 weeks
Maximum period duration	2 minutes	2 minutes	Unlimited
Information flow	Customer orders must remain secret.	All information can flow freely between the players.	All information can be discussed freely by all the players.
Costs	Use defaults.	Use defaults with higher backorder costs for retailers (3$).	Higher inventory costs (2$) and backorder costs (4$) for retail positions.
Lumber and paper demand profiles	Easily generated patterns with balance between supply and demand.	Administrator-defined demand level with clear trends.	Erratic trends with reduced margins between wood supply and lumber and paper demands.
Sawmill	Can adjust the proportion of wood going to lumber and chips between 25/75, 50/50 and 75/25		

Figure 18. Examples of Lumber and Paper Demand, and a Wood Supply Plan Used for Each of the Three Sessions in a Typical Training Cycle for Advanced Students



Note. Easily generated patterns with balance between supply and demand in session I (a), administrator-defined demand periods and levels in session II (b), and greater variations with reduced margins between supply and demand in session III.

session II, teams begin to understand the dynamics of the supply network, and tendencies toward over-ordering are reduced. In fact, repeated use of the online WSG facilitates transition from the panic observed in the simple Beer game structure to an (almost) orderly coordination of supply operations through the more complex WSG network. When this transition is complete, a number of key aspects for successful manual solutions appear. The primary key is a common team goal to move inventories downstream. This isolates the rest of the network from oscillations and allows them to focus on feeding an even flow to the retailer with a minimum of intermediate stocks. Another common key is team agreement on order intervals that must be held to avoid initiating oscillation, and never to order more than the supplier can deliver. Because the players at the sawmill and the forest positions have a full overview of supply limitations, successful collaboration between these two secures sufficient stocks to meet the communicated demand from the other entities.

In the second part, players explain the improvements in terms of system dynamics theory with reference to the generic stock management model (GSMM) described in Sterman (1988). Order data from all three sessions is downloaded from the game website. This data is used to quantify the dynamics of the lumber and paper supply chains by calculating the ratio ω for each stage in the network as follows:

$$\omega = CV_{stage}/CV_{demand}$$

where CV_{stage} is the relative variation of the order quantity at a given stage in the network, and CV_{demand} is the relative variation of the customer demand in the supply chain where the considered stage is located. Note that the relative variation of a variable is the standard deviation of the variable normed by its mean; this indicates the size of the standard deviation. Thus, the comparison of the ratio ω for a given stage from one session to the next provides a mean to assess how good a player or a team was at reducing unnecessary variations between the sessions. Figure 19 illustrates this analysis.

Finally, in the third part of the post-game analysis after session III, the teams present the key variables in Sterman's GSMM that could explain their order rates. Sterman hypothesized that "managers are assumed to choose orders so as to (1) replace expected losses from the stock; (2) reduce the discrepancy between the desired and actual stock; and (3) maintain an adequate supply line of unfilled orders" (Sterman 1988, p. 324). He formalized this heuristic in a generic decision rule that has a number of key variables. Each team is invited to estimate these variables by regression using its actual order rates and to identify the variables they consider most important for a stable supply chain. One variable that is usually recognized as critical for understanding ordering behavior is called β. This can be interpreted as the fraction of the supply line taken into account. As demonstrated in Sterman (1989), if $\beta = 1$, the players fully recognize the supply line and do not overorder. If $\beta = 0$, goods on order are ignored. Our experience showed that winning teams typically develop a spreadsheet for constant tracking of the supply chain line (volumes ordered, volumes in transit, and backlog volumes, together forming an Available-To-Promise function).

Figure 19. Illustration of the Analysis Conducted to Demonstrate Improvements in the Coordination Processes from One Game Session to Another

			Relative variation (CV in %)				
		Marked demand	Retail	Wholesale	Mill forest	Forest	Supply plan
WSG1	Lumber	0,391	0,663	0,861	0,441	0,416	0,267
	Paper	0,259	0,32	0,736	0,994		
WSG2	Lumber	0,176	0,222	0,189	0,386	0,455	0,327
	Paper	0,222	0,292	0,37	0,442		
WSG3	Lumber	0,36	0,341	0,454	0,416	0,366	0,304
	Paper	0,303	0,258	0,307	0,365		

ω = 0,994/0,259 = **3,83**

ω = 0,442/0,222 = **1,99**

ω = 0,365/0,303 = **1,20**

Notes. Typically, the ratios of the coefficient of variation between upstream orders and final customer demand decrease from 3.0 during session I to below 1.0 during session III. Below the table these ratios are calculated for the mill forest for session 1 (WSG1), session 2 (WSG2), and session 3 (WSG3), respectively.

This facilitates careful and coordinated adjustments of flows which, according to Sterman's GSMM, characterizes a decision heuristic with a high β value, empirically associated with stable system dynamics. For less experienced students, this third gaming session might be skipped as it involves advanced formal analysis of the results.

The training cycle described above is one of 16 exercises used to meet eight key learning outcomes that are targeted based on a structure of training currently used in Sweden to prepare Master's level foresters for managing wood supply operations. Among the eight targeted learning outcomes, one focuses on raw material requirements, three on securing supply, three on enabling delivery, and one on developing business processes and information systems to improve control and coordination of supply operations. Our training cycle contributes to the latter learning outcome. It precedes another exercise in which students are placed in the role of IT consultants who must specify a relevant architecture for a management information system for planning, control, coordination of purchase, harvesting, and transport for a specific company profile.

Several commercial companies have expressed interest in the WSG. Some have integrated it into their internal supply chain training programs; others have used it with their customers to "let them understand the importance of forecast collaboration." The game helps them "illustrate some of the root causes of the bullwhip effect very well." Although the game was designed for the forestry and forest industries sectors, we believe it can be useful in other industries with divergent supply chain networks. As previously stated, the divergent or arborescent supply chain network, is "one of the most common adopted supply chain network structures in the real world" (Dominguez et al. 2014, p. 2195). Such network structures can be found in biochemical, meat processing, mineral, apparel, and general consumer-oriented industries. For example, in biochemistry, wood chips are converted into sugars and hydrolysis lignin, via mechanical refining, mild chemical treatment, and enzymatic hydrolysis; in the meat industry, beef is cut into parts of different value; in consumer-oriented industries, products are configured, packaged, labeled, and branded differently). In each of these examples, the supply chain network is characterized by at least one branching, with two or more processes or business units on different branches. The idea is to group the branches and processes or business into units to fit the structure of the supply network used in the game.

6. Conclusion

In a supply chain, coordination is difficult and can result in the bullwhip effect when the variability in the ordering patterns is amplified as one moves up the supply chain towards the manufacturer and the suppliers. Distorted information from one end of a supply chain to the other can lead to tremendous inefficiencies and high costs. Because supply chains represent integrated systems, there is a need for a corresponding structure in training. Like the well known Beer game, the WSG presented in this paper offers such structure and helps students and managers understand the challenges of coordinating supply chains, and gain insight into the type of measures required to make these chains effective. The WSG does this in a realistic context for industries defined by divergent processes, such as the forest industry, as the supply network contains one branching of the material flow and is constrained in transforming the natural resources. To be efficient, serious business games must be simple and meaningful. The WSG proposed here focuses on understanding system dynamics and supply chain coordination. It is simple to explain and to run, and is openly available on the Internet. Although the title links it to the forest industry, the game can be used by forestry and nonforestry students, managers, and policy makers. It has been used at forest, engineering, and business schools, as well as in many industries. Moreover, participants may include bachelor, master's, doctoral students, and postdocs.

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