The Wood Supply Game - A Logistics Flight Simulator for the Forest Sector

Erlend Ystrøm Haartveit*

and Dag E. Fjeld**

*) Department of Production, Technology, and Processing, Norwegian Forest Research Institute, N-1432 Ås, Norway. E-mail: erlend.haartveit@skogforsk.no, Tel: +47 64949095; Fax: + +47 64949080

**) Division of Forest Technology, Swedish University of Agricultural Sciences, 901 83, Umeå, Sweden. E-mail: dag.fjeld@ssko.slu.se, Tel: +46 90 786 5856; Fax: + 46 90 786 7669

ABSTRACT

"The Wood Supply Games", have been developed based on the structure and dynamics of the Beer Game. By introducing divergent and convergent flows into the game, the relevance to situations in supply chains is increased. Complexity of the game has increased by increasing dependency between players. In WSG companies are affected by decisions made in a different supply chain. Using 10-12 players in each run, the game is, in essence, a simulation tool that includes the human aspect in decision making.

In the extended, (Monster), version of the wood supply game, dependency between supply chains is incorporated by connecting three individual wood supply games through a common source of raw materials (a forest). This reflects well the situation in the Scandinavian forest industries in recent years, where there has been a shortage of raw materials compared to the manufacturing capacity, leading to a situation where supply chains are competing for the raw materials.

WSG is used in courses in forestry logistics, and give a demonstration of how profitability of companies is interdependent where each player's decisions contribute to the development of the supply chain.

Key Words: Forest industries, supply chain performance, divergent flows, multiple feedback, demand amplification, parallel interactions

1. INTRODUCTION

In this chapter the Beer Game, and the transition to the Wood Supply Game is briefly presented. In addition to the proposed modifications, the rationale behind the changes is also explained.

1.1. Demand amplification in supply chains

The potential consequences of demand uncertainty and feedback control in industrial supply chains, termed *industrial dynamics,* were first analysed by Forrester (1958). Using simulation models he demonstrated how small variations in consumer demand can be amplified upstream in the supply chain, initiated by slow order handling, lack of downstream sales information and immediate corrective actions for inventory discrepancies (Forrester 1958).

The ”Beer Distribution Game”, developed by Sloan School of Management (Sterman 1984), is used in many university-level logistics programs to empirically demonstrate demand amplification in a simple context. The Beer Game (BG) convincingly demonstrates how instability can arise in managerial systems as a result of decisions made by individuals, and the structure of the system (Sterman 1989). The game has since its origination been used as a generic laboratory for various types of investigations including applications of business process redesign (van Ackere*, et al.* 1993) and analysis of decision making in chaotic environments (Mosekilde and Larsen 1988; Sterman 1988; 1989)

Material flows can be classified according to their degree of convergence and divergence (Machbeth and Ferguson 1994). Forestry and forest industries largely consist of diverging (V-type) material flows where few raw materials create a greater variety of products, producing logs from trees, and lumber from logs. Converging flows also occur, *eg.* when mixing several raw materials for paper production. However, most models of supply chains are unable to take into account effects of divergence and convergence as they often represent straight (I-type) flows, e.g. (Forrester 1958; van Ackere*, et al.* 1993; Towill 1996)

This paper presents student exercises, Wood Supply Games (WSG), where divergent and convergent flows are incorporated, and which are developed from the basic ideas of the BG. Generally, including different flow structures in supply chain modelling potentially contributes to a better basic understanding of the influence of industrial dynamics in supply chains. The proposed structure introduces parallel interactions (Wilding 1998) to the supply chain, where players are affected by decisions made in other branches of the supply chain.

A second characteristic of the forest industry is the spatial distribution of the raw materials. The production machinery is continuously moved throughout the landscape, and hence, the location of the vendor, and thereby the cost of raw material transportation, is continuously changing, strongly affecting wood procurement costs. This has been incorporated to the game by connecting several individual supply chains through a common source of raw materials – thereby creating the Monster version of WSG.

Effects of multiple decisions made by independent individuals are difficult to include in computer simulation models. One of the few ways to include this additional uncertainty in simulation models is to use independent human decisions as a part of the model structure. In the Wood Supply Game 7-8 individuals are used as independent decision makers with the task to manage and control a supply chain based on the forest industries. Results from these games are presented and compared with results using the original BG, published by John Sterman (1988; 1989).

The goal of this paper is to present the WSGs, exercises used in courses in forest sector logistics, and explain why the development increases the relevance concerning supply chain management. Some of the results from pilot experiments using this simulation tool are also reported and discussed.

2. METHODS

The development of the WSG is described in this chapter, along with the rules for operating and playing the game. Additionally, the metrics used to evaluate performance in the supply chain is briefly explained.

2.1. The development from Beer to Wood

A complete description of the Beer Game (BG) has been provided by Sterman (1984). The Beer Game represents a distribution chain with four companies; retailer, wholesaler, distributor and brewery, each managed by one or two players (Figure 1). The task of the chain is to supply consumers with beer according to demand, while minimising inventory and stock-out costs.

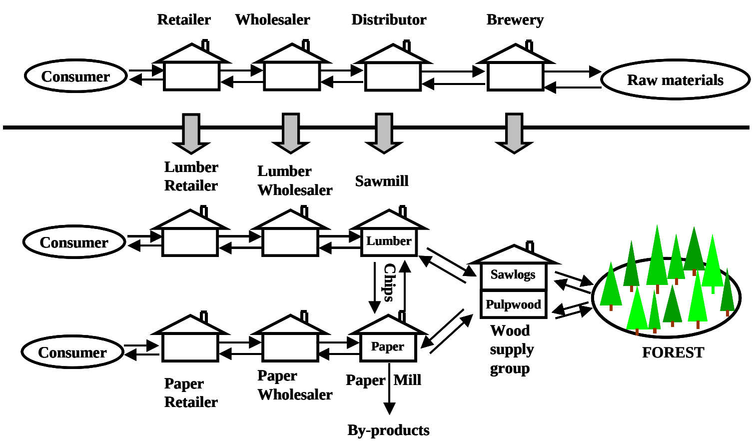

Figure 1. The structure of the Beer Game, compared to the structure of the Wood supply game.

The modification of BG into the Wood Supply Game (WSG) involves connecting a four-stage supply chain delivering lumber with a four-stage chain delivering paper through the introduction of the forest as a common source of raw materials (Fjeld 2001b; 2001a). A wood supply group, corresponding to the brewery in BG, diverges the material flow. Sawlogs is delivered to a sawmill that supplies the lumber chain, and delivers chips to the paper mill. Pulpwood, on the other hand, is delivered to a paper mill supplying the paper chain. The mills correspond to the distributor position in the BG (Figure 1).

For the mills, mixing of chips and pulpwood for paper production constitute a point of convergence. There are three points of divergence: production of sawlogs and pulpwood from in the wood supply group, producing lumber and chips at the sawmill, producing paper and by-products in the paper mill.

2.2. Extending competition – supply chain against supply chain

Evidently, transport costs in wood procurement are determined from the spatial location of the forest. In the Monster WSG, three individual WSGs are integrated through a common source of raw materials (Figure 2). Depending on where a particular wood supply group are able to purchase wood, different transportation costs apply.

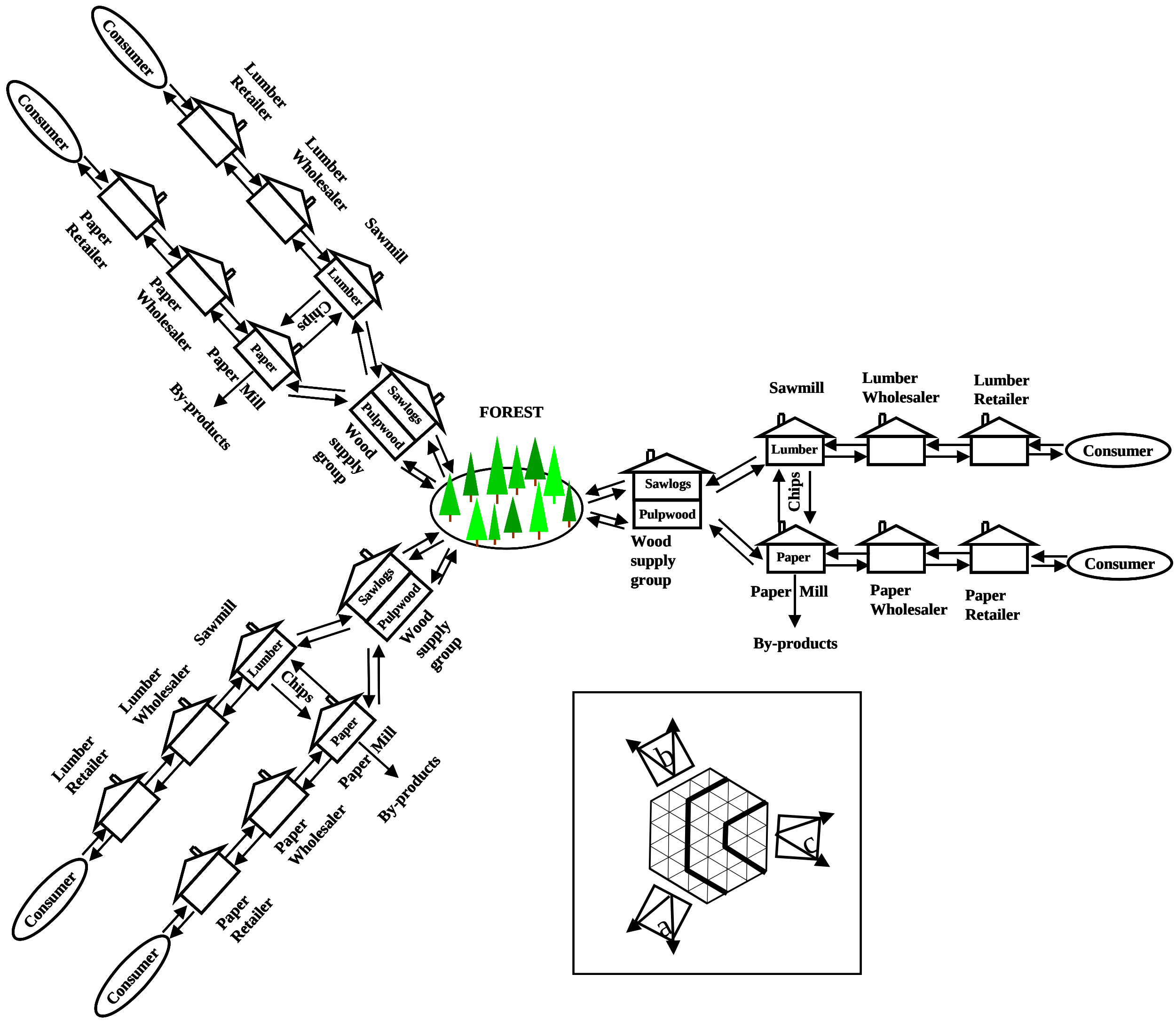

Figure 2. Illustrating how the three WSGs are combined to a full class version, where the 3 chain competes against each other. The frame shows an example of how supply nodes in forest is. The thick lines represent changes in wood transport costs for chain C, while each node represent a supply point.

The three chains in the Monster WSG are not affecting each other when supplying products to markets, but wood procurement costs of the chains are inter-dependent, since the three chains are supplied from the same forest (Figure 2).

2.3. Rules of the WSG

One or two individuals manage each position in the game. Prior to the game, each retailer is supplied with a deck of cards representing final consumer demand. The first two orders for each position are placed as a part of the initial settings of the game.

WSG is played for 35 cycles (weeks). Each cycle involves certain activities: Receiving raw materials, production (paper mill and sawmill), order processing, shipping products, inventory control and placing new orders. All orders, no more, no less, must be satisfied implying that if a player is out of stock he/she is required to deliver the backlog as soon as replenishment arrives from the vendor.

The overall supply chain goal is cost minimisation, and the chain which manages operations with the lowest costs wins. There are two main cost drivers to consider:

- A weekly unit cost of keeping inventory of 0.5 USD.
- A weekly unit cost of accumulating a backlog of orders of 1 USD.

Inventories and goods in transit are visible to all players. Order levels, on the other hand, must be kept secret for others than the sender and the receiver. Hence, the retailer is the only player with knowledge of consumer demand. The lead time between positions is 4 weeks, two weeks to transfer and process orders and two additional weeks to ship products back to the customer.

The players record their weekly orders and inventory levels (inventory or unfilled orders), and these records are later used to describe the dynamics of the chain.

Transportation costs in wood procurement

The forest resources are represented by a hexagon supplied with a network of nodes. Each node illustrates a supply point for which a fixed quantity of wood can be bought each week (Figure 2). Orders from the wood supply group, are submitted to a "forest manager" who is responsible purchasing wood so that transportation costs are minimised. In Figure 2 (the frame) it is company *c* that orders wood. The zones are numbered from 1 to 4, where 1 is the closest zone and zone 4 is used when there are not sufficient wood supply on the board, and wood has to be imported. Transportation costs in the four zones are 0.5 for zone 1, 0.75 for zone 2, 1 for zone 3 and 1.5 for zone 4. All costs are measured in USD/load. The order in which the managers decide where to buy is randomly determined for each cycle.

Flow restrictions in WSG

For the points of convergence and divergence (Figure 1) the following restrictions apply:

- The wood supply group: the product mix from the forest must contain 30 - 40% pulpwood and 60-70% sawlogs.
- The sawmill: sawlogs are converted to 50% lumber and 50% chips (for paper mill)
- The paper mill: the mix of raw materials must contain 40-60% of each of the raw materials chips and pulpwood. Excess raw materials are stored and give inventory costs.
- The paper mill: Production yields 50% paper and 50% by-products. By-products are removed from the game.

Variations of consumer demand.

Two patterns of demand have been applied:

- 4 units the first 4 weeks, 8 units per week for 31 weeks (identical to BG).
- The first 10 weeks is identical to BG, but the last 25 weeks varies between 2 and 12. The total volume demanded during the 35 weeks is identical to the BG

The basic playing rules and ordering procedures are similar for all games Table 1. In most, standard demand patterns have been applied, but experiments using random demand have been introduced improve the game from a pedagogical point of view.

Table 1. Summary of properties for the BeerGame and the Wood supply games.

	Competition	Restrictions	# stock positions	Demand	Flow type[1]
BeerGame	independent distribution chains	None	4	Standard/ varying	I
WSG	parallel interactions	volume mix yield varying lag time	9	Standard/ varying	V, A, I
Monster WSG	parallel interactions dependencies between supply chains	volume mix yield varying lag time transport cost penalties	27	Standard/ varying	V, A, I

For the paper mill, the lag time for supply is different for the two raw materials chips and pulpwood. There is an additional 4 weeks time lag for chips to be supplied in situations where the sawmill has a depleted inventory.

Comparing performance for different structures

For relevant comparisons with BG, results from WSG are corrected for:

- WSG having two positions at each tier. This is done using the average result of the two positions in one game
- Discrepancies concerning expected flow of products for the sawmill and wood supply group (double flow of sawlogs). For these positions orders for sawlogs are reduced by 50% before comparisons. For the sawmill (handling two products), average costs for the two products chips and lumber are used.

The performance metric that determines the winning chain is the total supply chain costs consisting of cost for inventory, backlog and transportation.

Quantification of demand amplification

To quantify demand amplification, two measures was used:

[1] (Machbeth and Ferguson 1994)

1. w_{std} = the ratio of the sample standard deviation of outgoing orders and the sample standard deviation of incoming orders (1).
2. w_{mean} = the same ratio as (1), but using the sample means instead of sample standard deviations.

$$w_{std} = s_{out} / s_{in} \qquad (1)$$

where w_{std} is the demand amplification based on standard deviations, s_{out} is the stample standard deviation of the sequence of placed orders, and s_{in} is the sample standard deviation of orders received.

Demand amplification estimated according to (1) provides a relative measure of how the variation of orders has changed for any tier. Estimation of w_{std} for the wood supply group, yields a measure describing relative change of demand variation for the complete supply chain. When using means rather than standard deviations in (1) gives a measure that reveals whether a particular player has overreacted to changes in demand over the playing period.

Deriving goals for pedagogical game development

When running WSG, students are carefully observed with respect to how they solve the problem of regaining control of the system. Learning the mechanics of the game require 10 cycles, which adds up to almost 1 hour. Later in the game, the students start developing a strategy in order to win the competition. Applied strategies and the rationale behind are presented during the game debriefing session. This input for further game development is important in order to ensure that the game develops to structures where strategic decisions reflect situations in the forest industry.

3. RESULTS FROM PLAYING THE GAMES

In this section we initially present some comparisons showing how results from pilot experiments using WSG compare to results of running BG (Sterman 1989). Furthermore, results from runs using higher variation in consumer demand are presented. Finally, effects on transportation costs in wood procurement resulting from the mutual dependency of the chains in the Monster WSG are presented.

3.1. Supply chain performance

A summary of average performance metrics for comparisons between BG and WSG is provided in Table 2.

Table 2. Summary of performance (costs, mean order, standard deviation of orders) for BeerGame (BG) compared to Wood supply game using standard demand (WSG_{st}), and Wood supply games with varying demand (WSG_{var}).

	Costs			Mean of order rate			Sd. of order rate		
	BG[2]	WSG_{st}	WSG_{var}	BG[3]	WSG_{st}	WSG_{var}	BG[4]	WSG_{st}	WSG_{var}
Demand	-	-	-	7.5	7.5	7.5	1.3	1.3	2.4
Retailer	383	372	686	7.4	8.1	12.0	3.6	8.5	11.4
Wholesaler	635	691	1097	8.6	9.8	12.5	4.8	11.1	22.9
Mills	630	1465	2024	9.1	13.2	14.7	6.7	17.1	26.5
W. S. group	380	886	2135	9.0	13.9	15.7	8.5	22.4	53.7
Team total	2028	3414	5943	-	-	-	-	-	-

Results for WSG are the mean of 6 complete WSGs, 3 of which were run as one Monster WSG. Varying demand has been used in 3 WSGs, run as one Monster WSG.

For the presented games the average cost for the positions in WSG were higher than average costs for BG, while the average costs increased further in the games using varying demand. This particularly concerns the two upstream positions – mills and wood supply group (Table 2). The same pattern concerning game structures is observed for mean order and standard deviation of orders. Also the between-game variation might is high for WSG with varying demand (Table 2).

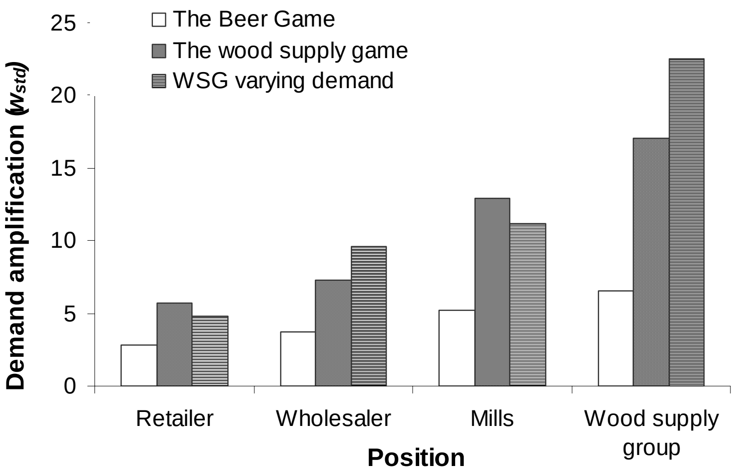

Figure 3. The accumulated demand amplification for the different positions in BG and WSG. Demand amplification is estimated as the standard deviation of the order rates placed by an individual player relative to standard deviation of the initial demand.

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[2] (Sterman 1989)

[3] (Fjeld 2001a)

[4] (Sterman 1989)

The accumulated demand amplification (w_{std}) shows the degree to which the complete chain has developed with respect to variation of order rates relative to consumer demand (Figure 3). Despite higher variation in consumer demand, the demand amplification is similar or higher for increases for WSG with varying demand.

3.2. Competing for raw materials – effects on transportation costs

Because of the spatial distribution of the raw materials, transportation costs are affected by the quantity of wood procured each week. When demand is high and large orders are received the wood procurement area have to be extended.

Table 3. The unit and total cost of transportation experienced, the demand amplification based on standard deviation of order (w_{std}), and on mean order (w_{mean}) for each chain of two Monster WSGs.

	Standard demand			Varying demand		
Supply Chain	A	B	C	A	B	C
Total transport costs	1925	1855	1414	8491	1049	2137
Unit cost of transportation (USD/load)	1.19	1.12	1.05	1.32	0.88	1.02
Demand amplification (w_{std}) chain	20.13	19.34	12.53	52.20	4.34	11.12
Demand amplification (w_{mean}) chain	2.08	2.10	1.69	7.96	1.48	2.69

Pilot experiments using the Monster WSG indicate that the chains with the highest variances of order rates are also penalised with increased unit costs of transportation. Table 3 shows that supply chains with higher values of the chain demand amplification based on increases of the mean (w_{mean}) and the standard deviation (w_{std}), moreover has a higher total and unit cost of transportation.

4. DISCUSSION

The discussion first justifies the selection of method for measuring demand amplification. Thereafter the presented results from WSG and Monster WSG with different demand patterns are commented before the pedagogical effects of the game development are discussed. Finally the discussion ends with some thoughts concerning further development of the games including measuring effects of parallel interactions.

4.1. Methods for measuring demand amplification

Different definitions on demand amplification exist (Sterman 1988; 1989; Fransoo and Wouters 2000). One method used to quantify demand amplification uses the coefficient of variation of incoming and outgoing orders according to (2) (Fransoo and Wouters 2000).

$$w = \frac{s_{out}/\mu_{out}}{s_{in}/\mu_{in}} = \frac{CV_{out}}{CV_{in}} \qquad (2)$$

where, w is an unit-less measure of demand amplification, s is the standard sample deviation, μ is the sample mean, and CV is the coefficient of variation. Index *out* denotes placed orders, while index *in* denotes incoming orders.

Generally, a change in any of the *CV*s (2) can result from a change in s, μ, or both. Additionally, changes in s and μ can occur without changing the value of CV. Hence, when data are available and are comparable reporting changes in the mean and the standard deviation separately provide a better description of the dynamics.

The observed increase in demand (the peak order less the initial order) relative to the increase in consumer demand can also be used to quantify demand amplification (Sterman 1989). This measure was not used due to the high variation of results produced by WSGs combined with the fact that the measurement relies the peak order only.

4.2. Comparisons between structures and demand patterns

Sensitivity of presented results

It is expected that complex supply chain structures, to a larger degree accumulate costs when the game is out of the player's control. Even when two games with considerable costs are excluded from the data, the rank of the different structures does not change. As the variation of orders within and between WSGs are considerable for both demand patterns, it is not possible, given the available data, to evaluate whether the introduction of varying consumer demand adds to the variation in placed orders.

Relative measures of demand amplification

There is no distinct pattern concerning which position that contributed most to the increase of variation. Hence, the combined result of the complete chain is a more stable and meaningful measure of performance. The variation between different runs of WSG is, however, considerable. The variation in development of individual WSGs is impressing. Although no statistical testing has been performed, it appears that the introduced changes in WSG has made the outcome of the games harder to predict, and reduced the performance, particularly for the upstream positions. It is likely that a significant part of the effects can be attributed to the restrictions applied at the points of convergence and divergence. When the two chains are not synchronised, the sawmill and the wood supply group will face large orders for only one product, but are forced to order both. The same effect is seen for the paper mill, which cannot produce paper without access to chips and pulpwood.

Effect of demand amplification effect on transport costs

All games have resulted in amplification of initial demand, however, to varying degree. When evaluating results from the game, supply chains that are strongly affected by demand amplification, through high values of w_{std} and w_{mean}, also have higher transport costs per load. This is reasonable since the high variation of orders will lead to wood procurement far from the wood supply group. This indicates that the Monster WSG provides a realistic environment concerning development of transportation costs as the total and weekly volume procured changes.

4.3. WSG - exploiting pedagogical possibilities

In relation to a generic stock management system the three games described in this paper enable the players to experience three levels of complexity for stock order decisions. The generic stock order decision rule as presented in Sterman (1988; 1989) is based on only locally available information and recognises three motives for placing a specific order at a given time. These include: replacing expected losses from stock, reducing discrepancies between desired and actual stock, and reducing discrepancies between desired and actual supply line of unfilled orders. This model also takes into consideration the player's expected acquisition time lag to receive adjustments.

Often, the WSG is used in a third year course in Forest Sector Logistics. Thus, players will already have a basic understanding of inventory theory, including effect of variation in demand and lead times on the required size of safety stocks. Basic principles of operations control based on feed-back and feed-forward mechanisms are also familiar.

Learning phases

In addition to demonstrating the demand amplification in supply chains, the latest version of WSG has a pedagogic goal to enhance student's skills in development of global control mechanisms for regaining control or reduce costs.

Commonly three phases of learning may be seen during the wood supply game.

- **Position Mechanics** (Weeks 1-10): players focus on mastering the mechanics of the game and largely focus on their own positions
- **System observation** (Weeks 10-20): players begin to observe the other positions and are working to understand the dynamics of the system.
- **Global mechanism development** (Weeka 20 -): players master the mechanics and have a simple perception of the dynamics in the system. Development often involves discussing and developing global control mechanisms to avoid further demand distortion and/or reduce its negative economic effects.

Increasing the pace of the game tends to increase stress for players and delays the discussion between positions and development of global control mechanism. Slowing the pace and allowing the players themselves to set the pace of the game after week 20 or 25 allows for better communication and development of control mechanisms.

To provide a challenging environment for development of control mechanisms, demand variation, which the players can react to, is required. Sterman (1988; 1989) shows that it is possible to quantify typical player reactions in relation to the terms of the generic stock decision model. This is based on the degree to which the players emphasise the adjustments in stock or adjustments in supply line when placing orders. The emphasis is quantified as the ratio (β) of the two following fractions:

$$\beta = \alpha_{SL} / \alpha_S \qquad (3)$$

where α_{SL} is the fraction of the supply line discrepancy ordered per period, and α_S is the fraction of the stock discrepancy (AS) ordered per period.

High values of β indicate, therefore that the order decision mainly considers supply line adjustments, while a low value of the ratio indicates a high emphasis on stock adjustments. In the BG, oscillation and initial instability is a result of initial orders with high emphasis on stock adjustments (giving a small ratio) and little consideration to supply-line adjustments. While not yet shown, it is likely possible to track an increase in β during a game where students are experiencing the different learning phases.

The generic stock model, however, does not presume that the manager has global knowledge on the structure of the system. By the third learning phase (global mechanism development) we may presume that the players are beginning to develop this knowledge.

Concerning development of global control mechanisms, three different responses have been noted in recent WSGs:

Deriving final customer demand – all positions are observing the weekly flow through retailer inventory. This, however, is only possible after the initial backlog is overcome. Keen observation of the movement of products out of retailer inventory tells the entire chain what the final customer demand is without having to wait for distorted demand signals (orders) from their customers.

Reducing acquisition lag time – a conscious movement of the existing inventories downstream. This reduces acquisition lag times for the consumer and improves the chains ability to respond to varying demand without accumulating backlog or initiating oscillation.

Supplier-focus – In some cases, when total failure to keep the system in control is accepted, some players choose to completely ignore demand signals. Then in order to avoid further increases in backlogs costs they just order whatever their suppliers have in inventory.

In a worst case scenario, players may start regaining control by responding with supplier focus. This will eventually lead to moving inventory downstream and reducing acquisition lag time.

4.4. Future development of Wood Supply Game

The cost of holding inventory in WSG is constant for all positions, and the cost of transportation between positions is zero. Since backlog are more costly than inventories, the strategy of moving products downstream leads to cost reductions as inventory costs are saved during transit and inventory unit costs are constant for all players. However, this strategy strongly contradicts with common practice in supply chain management where inventories should be held as far upstream as possible to avoid obsolescence and high costs of inventories resulting from the higher product value downstream in the supply chain. A similar argument can be suggested for backlog costs, as startup-costs for mills are considerable, and inventory depletion should be penalised.

Other possible changes of the game assumptions include:

- Introducing competition on the consumer market
- Increasing chaos by using different demand sequences on the two branches
- Development of new performance metrics for upstream positions

As the structure of the system is more complex, there is a need for new performance measures. For the papermill, the fraction of total inventory costs that stems from raw materials (indicating that the flows are different) might be used. Similarly for the sawmill and the wood supply group, the size of the largest inventory, can be evaluated against the order for new products. Orders for products when inventory would suffice for, say, 3-4 weeks can be regarded as orders resulting from dependencies in the chain.

5. CONCLUSION - COMPLEXITY VS. PEDAGOGICAL EFFECTS?

The first variants of the wood supply game were developed to give more realistic game conditions for the forest sector (Fjeld 2001a). At the same time, however, learning times increased and the pedagogical trade-off between time and learning was discussed (Fjeld 2001b). The latest versions with increasing parallel interactions and supply chains competing for raw materials have been accomplished with 40-50 minutes of initial explanation. After this initial explanation the position mechanics are often learned within 10 game weeks. Furthermore, introducing varying demand increases the challenge in developing strategies for individual players and complete supply chains. It is regarded as advantageous that it is still possible to complete a game within a few hours. Even though the exercise is stressful for students to attend the fact that the exercise are completed within half a day, has and a winner and a looser promotes discussions among students on how the game developed, and what strategies should have been applied ion order to perform better. The complexity of the game for each individual position seems acceptable and the potential for additional pedagogical functions have increased considerably.

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