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Accelerated learning for wood supply managers – the next generation of on-line training tools

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ABSTRACT

The Virtual Wood Supply Arena is an on-line training environment for managing roundwood purchase, production and transport in cut-to-length supply systems. The purpose of its development was accelerated training for coordination of these functions under realistic operating conditions. It offers 8- and 12-week scenarios for supplying five mills. Weekly planning is done for 10 harvesting teams and 10 trucks in a Swedish case geography while tracking mill delivery fulfillment under weekly trafficability restrictions. The purpose of this paper is to introduce the training environment and report the progression of student performance after 2 years of use in university-level training. Student teams reached full delivery fulfillment within three training runs. After familiarization during an introductory run, a complete 12-week scenario took four effective hours to complete. Delivery fulfillment increased from 82 to 95 and 100% between the first, second and third training runs. The progression of team performance included a 36% reduction of relocation distances for harvesting teams and 11% reduction of transport distances for hauling from forest to mill. By the third training run these performance levels were attained with less than 2 weeks of inventory for both the purchase bank and roadside stocks.

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Industrial gamification; learning curves; forest operations; trafficability; management processes; performance metrics

Introduction to interactive training exercises for wood supply

Many university-level forestry programs now include courses in wood supply or forest logistics. The transition from a pure forest engineering perspective to include forest operations management has increased the focus on interactions in the supply network. MITs development of the Beer Distribution Game (Forrester 1958) was an early step to support understanding and management of dynamics and information sharing in demand-driven supply chains. Later on, new variants of the beer game configuration were developed for forest sector material flows (Fjeld 2001a, 2001b; Haartveit and Fjeld 2003a, 2003b). Competition between student supply chains has proved to be effective for increasing engagement. The arrival of the on-line wood supply game (D'Amours et al. 2017) increased the opportunity to run varying supply- and demand scenarios to improve supply chain coordination and synchronization. Further experimentation with the on-line wood supply game by Herath et al. (2021) examined student performance in relation to their academic results and noted that game-based learning often provided a better understanding of theoretical concepts than conventional learning. The first forestry transportation game provided a competitive context for wood sourcing between teams in the same geography while aiming to develop spatial planning skills for subsequent truck routing (Fjeld and Hedlinger 2004, 2005). Another variant of flow planning; the collaboration game (D'Amours and Rönnqvist 2013) was developed to demonstrate the potential for transport cost savings in a specific case study of geographical roundwood barter between suppliers. This game gives an understanding of how important information and market shares are in negotiations, while understanding the nature of collaborative negotiations when players have different goals. Collaboration functionality has been included in the on-line version of the transport game (Abasian et al. 2019). The on-line version provides a more flexible configuration and has proven to be considerably more time-efficient for both instructors and students. The game extends student understanding of hierarchical planning with the sequential steps of purchase, bartering, transport allocation and backhaul routing.

While these early games have a high level of abstraction, they increased student engagement for learning more complex principles of stock management and transport planning. Later work has documented the general effects of gaming on student engagement (Markopoulos et al. 2015; Buckley and Doyle 2016; Bouchrika et al. 2021) and elaborated a pedagogical framework to guide the achievement of learning outcomes (Rivera and Palmer Garden 2021). Reis et al. (2020) and Korn (2023) provide further recommendations for using gamification in industrial production contexts.

University training in wood supply generally includes task-based exercises, and for professional training a high degree of realism is necessary. In this context, production scheduling and truck fleet management are standard exercises (Fjeld et al. 2014), however, a key development challenge has been the

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realistic representation of seasonality and varying trafficability. Westlund et al. (2019) presented a framework for seasonality comparing weekly weather and corresponding wood flows between contrasting climates in northern Europe. Such weekly patterns were then used to create pc-based laboratory environments for interactive testing of harvesting and transport responses (Fjeld et al. 2022). One variant integrated weekly production and transport decisions with weather and trafficability over a coastal-interior gradient of three climate subzones (Fjeld and Marier 2022). Integrating manager roles in such test environments gave the opportunity for collaborative planning with discussion of various stock development alternatives for periods of varying trafficability. Interactive stakeholder workshops proved to be a demanding but promising path to finding improvements in supply chain processes. Exploiting such interactive opportunities for student training requires an on-line platform, such as those developed in earlier collaborations between SLU and the FORAC Research Consortium at Université Laval (Quebec) for the wood supply and transport games.

The virtual wood supply arena

One of the drawbacks with the training exercises described above is that they are simplified to enable completion in short training modules. In 2020, the development of the Virtual Wood Supply Arena was initiated by SLU, FORAC, The Forestry Research Institute of Sweden, and Creative Optimization. The ambition was to develop an on-line training environment, which would be closer to the real situation faced by purchase-, production- and transport managers (Fjeld et al. 2022). It simulates the effects of operational decisions on supply system performance where the main learning objective is to improve coordination between these functions. Each training run tracks team key performance indicators (KPIs) such as monthly mill delivery fulfillment, capacity utilization for harvesting and hauling as well as relocation- and hauling distances (overview in Figure 1). The arena is available via FORAC at Université Laval (Educational games | FORAC – Forest to customer (ulaval.ca)), complete with instructional videos.

The arena has three roles per team; purchase, production and transport. A team can consist of one to three participants, since participants can log on to multiple roles. Each team manages 10 harvesting teams and 10 trucks for supply of 5 assortments to 5 mills (3 sawmills, 2 pulp mills). The assortments include: spruce sawlogs, pine sawlogs, spruce pulpwood, coniferous pulpwood (typically mixed coniferous species, but exclusively pine in this exercise) and deciduous pulpwood. The supply case is situated in southwestern Sweden, with 29 supply areas distributed across 2 climate zones (northern highlands, southern lowlands). Eight- and twelve-week trafficability scenarios can be selected from four annual time series of 52 weeks, where each climate zone has its own weekly trafficability restrictions (Figure 2).

The 29 supply areas are aggregated into four supply regions and each month starts with setting monthly purchase-, production- and transport targets (m^3/assortment) for the respective regions. Setting targets begins with matching mill demand with corresponding transport volumes, before coordinating transport with production and purchase. Team are provided with a rolling four-week prognosis for soil moisture state (winter frost or snow; thawing; typical moisture for frost-free periods; wet conditions during frost-free periods). Purchase and production managers select sites based on four trafficability classes (1; for spring thaw, 2; for wet conditions during frost-free periods, 3; for typical conditions during frost-free periods, 4; requiring winter frost or snow). Weekly purchase and production decisions may be done in parallel, and harvest scheduling may be done up to 4 weeks ahead of time. Both purchase and production functions are supported by map interfaces displaying site locations with volume per assortment and color coding according to terrain and road trafficability and harvesting type (thinning, final felling).

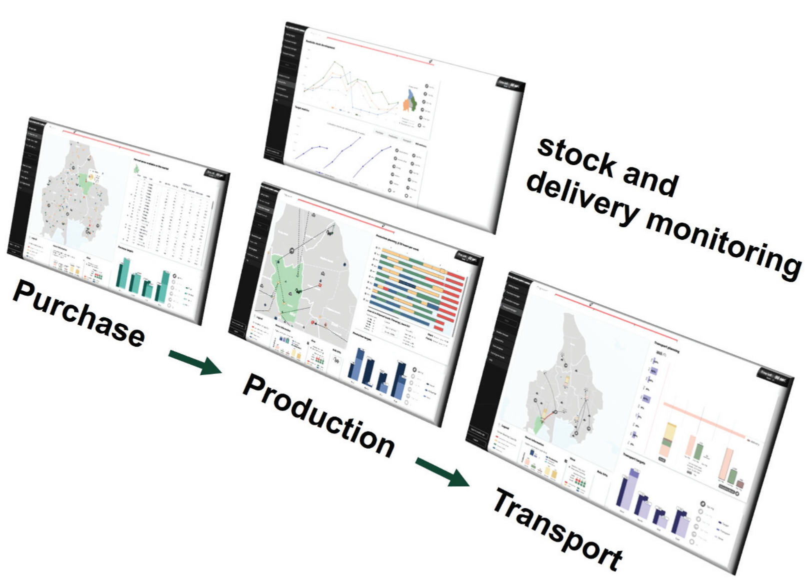

Figure 1. An overview of the three user interfaces in the virtual wood supply arena (below) with team KPI dashboard (above).

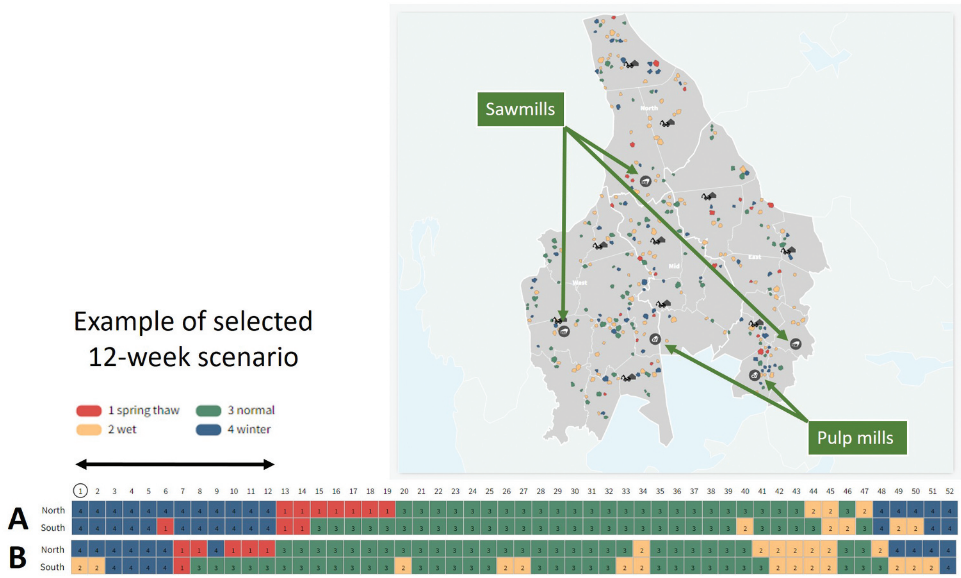

Figure 2. The case study area showing 5 mills, 4 supply regions (west, mid, east, north) and 29 supply areas with two examples of annual time series for weekly trafficability (A, B). The trafficability scenarios represent varying soil moisture states in two climate zones (northern highlands, southern lowlands) where a 12-week scenario may be selected to start at any time between weeks 1 and 52.

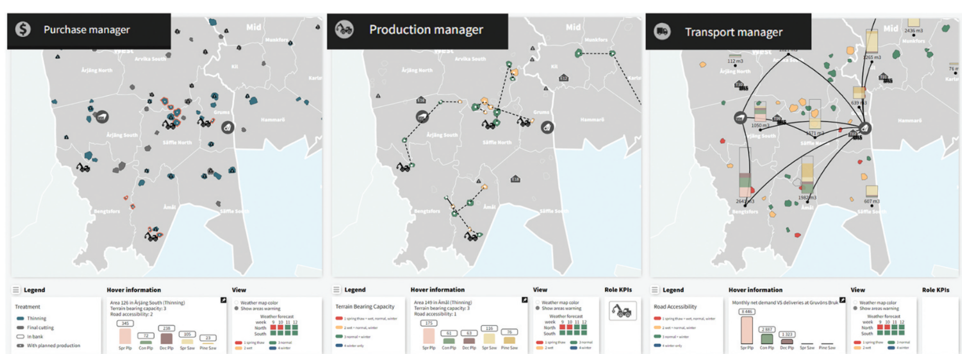

Figure 3. Detail view of user-interfaces for weekly purchase (left), production (middle) and transport (right). The four-week soil moisture prognosis is shown in the lower right-hand corner of each interface.

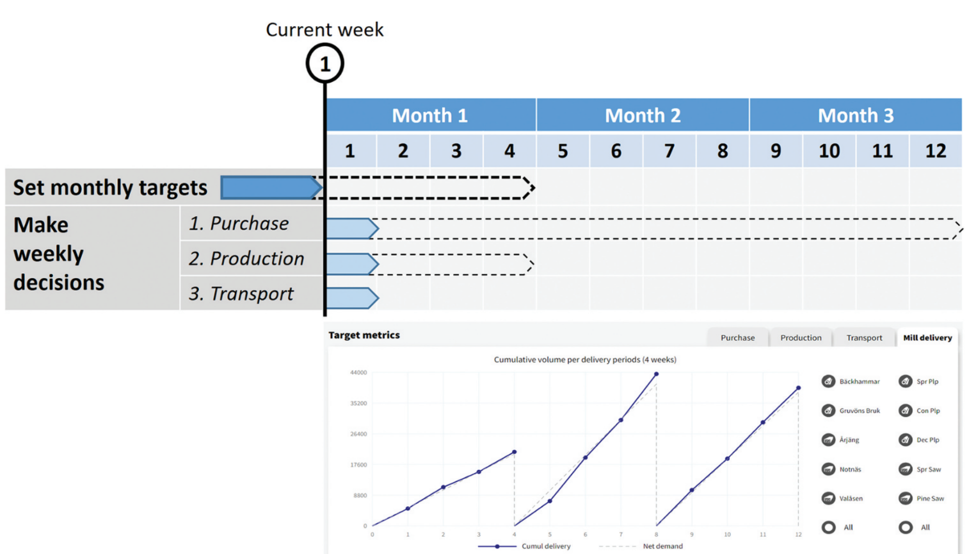

Figure 4. Monthly and weekly manager decisions with planning horizons (dashed line) starting at week 1. An example of the accumulated delivery fulfilment per four-week period for a completed 12 week scenario is shown below.

The *purchase manager* selects sites to be entered in the purchase bank for production planning. This can be done by click-selection, either from the map (Figure 3, left) or from a sorted table. The *production manager* routes the respective harvesting teams between the sites in the purchase bank with a click-and-drag function on the map interface (Figure 3, middle). Production routing generates a scheduling of sites per harvesting team which fills the roadside stocks per supply area. The *transport manager* then selects the mill destination for the respective assortment stocks and assigns trucks to the resulting wood flows (Figure 3, right). The hauling volumes can also be re-balanced between the assigned trucks. Each manager interface is supported by a weekly follow-up of progress in relation to monthly targets. Each team has a common KPI dashboard where weekly purchase, production and deliveries are plotted against monthly targets, and accumulated deliveries are plotted against monthly mill demand (Figure 4).

The arena is designed for participants who have a basic understanding of production and transport management in cut-to-length supply systems. The click-and-drag functionality shortens the time per planning cycle and increases the number of trafficability scenarios possible to run per day of student training. By varying trafficability scenarios participants can experience different combinations of weather ranging from stable winter and summer conditions to more challenging scenarios such as spring thaw or wet autumn periods while waiting for winter frost.

Since its completion, the supply arena has been run with student groups in the Nordic countries, using both 8- and 12-week trafficability scenarios. *The goal of this paper is to introduce the training environment and present the progression of student performance as an example of learning curves enabled by an on-line training environment.*

Materials and methods

12-week scenarios were run in masters-level courses in Sweden (SLU), Norway (NMBU) and Finland (U.Helsinki). The first test (SLU 2022) ran two consecutive 12-week scenarios while the second test (2023) ran two 12-week scenarios after an introductory 8-week scenario. At NMBU and U.Helsinki single 12-week scenarios were run after an introduction with a short test of functionality. Each team consisted of two to three students. The total number of teams with consecutive first-, second- and third runs was 11, 7 and 4, respectively (Table 1).

The exercises were presented as a competition between student teams. The trafficability scenarios selected varied between training runs, but the mill demand was always identical.

The main KPIs tracked include monthly demand fulfillment (proportion of 11 mill assortment demands fulfilled ±10%), capacity utilization for harvesting and hauling (proportion of available hours), as well as average relocation- and hauling distances (Table 2). Monthly stock levels were tracked for sawlogs and pulpwood in both the purchase bank (purchased volumes awaiting harvesting) as well as roadside stocks (harvested volume awaiting transport).

In a training context, the KPI of primary interest is monthly delivery fulfillment. As teams progress various game scores can be calculated from the basic KPIs to focus on the remaining aspects in need of improvement.

The development of end-of-game KPIs between training runs is presented as box plots comparing the medians and quartiles. The relationships between end-of-game KPIs were explored with multivariate principal component analysis (PCA). Multivariate correlations are quantified by loading coefficients for the respective principal components (PC1, PC2). All data analysis and presentation was done in Minitab v18.

Results

The delivery fulfillment for the first run teams varied considerably (lower to upper quartile 67–97%, median 82%). The variation decreased for the second run (lower to upper quartile 83–100%, median 96%) and all third run teams had 100% delivery fulfillment (Figure 5).

The medians for relocation distance decreased from 39 to 32 and 25 km for the first, second and third runs, respectively. The corresponding medians for (two-way) transport distance were

Table 1. The number of complete 12-week scenarios which were run by student teams as their first-, second- or third consecutive training runs.

Year	School	First run	Second run	Third run
2022	SLU	4	3	
	NMBU	4		
2023	SLU	*(8 week intro scenario)*	4	4
	U. Helsinki	3		
	Sum no. teams	11	7	4

Table 2. The end-of-game KPIs used to compare team performance.

KPI	Unit	Definition
Delivery fulfilment (%DF)	%	Proportion of monthly mill deliveries within ± 10 % of mill demand
Volume in purchase bank (PB)	m^3	Stock balance at end of each month
Volume in roadside stocks (RS)	m^3	Stock balance at end of each month
Relocation distance (rd)	Km	Relocation distance between harvesting sites
Transport distance (td)	Km	Transport distance from forest to mill (loaded + unloaded)
Capacity utilization - production (%PR)	%	Proportion of available hours (600 hrs/harvesting team/month)
Capacity utilization - transport (%TR)	%	Proportion of available hours (1020 hrs/truck/month)

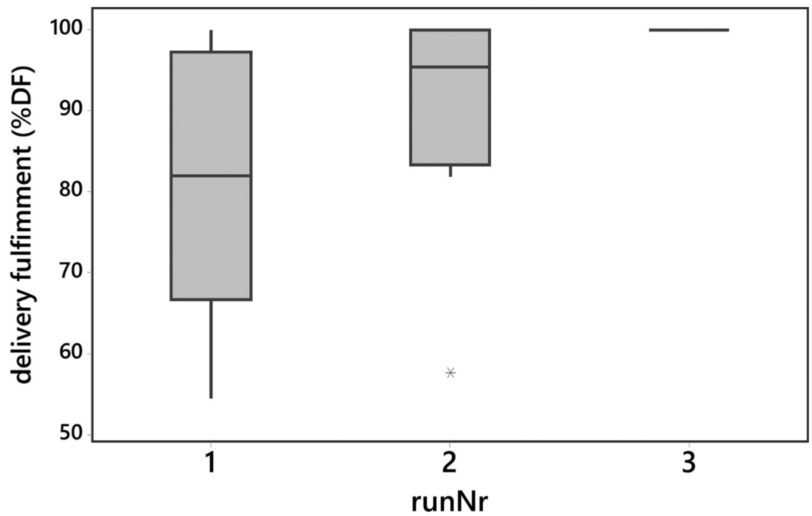

Figure 5. Development of delivery fulfilment (%DF) between the first, second and third training runs (runNr) for student teams.

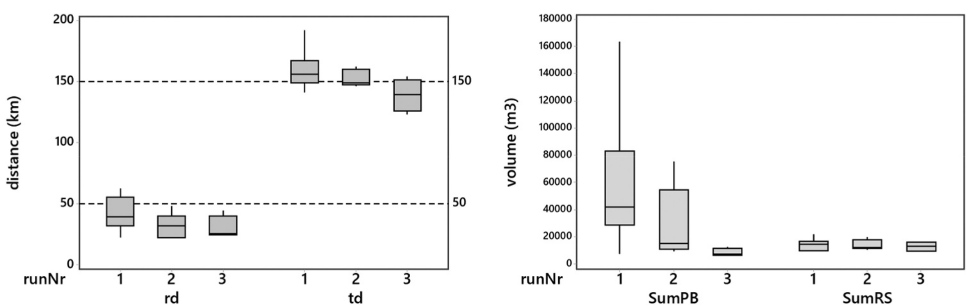

Figure 6. Development of relocation distances (rd in km) and transport distances (td in km) at left, as well as average stock levels (m^3) in the purchase bank (SumPB) and at roadside (SumRS) at right. First, second and third consecutive training runs (runNr) for student teams.

156, 149 and 139 km, respectively (Figure 6). These results correspond to a 36% reduction in average relocation distance and 11% reduction of average transport distance.

The volume in the purchase bank for the first-run teams varied considerably (lower to upper quartile 29–83 10^3 m^3, median 42 10^3 m^3). The range decreased for the second run (lower to upper quartile 11–55 10^3 m^3, median 15 10^3 m^3). The third-run teams had a limited variation around a median of 7 300 m^3. The median roadside stocks had limited variation; 14 500 to 12 350 and 13 000 m^3 for the first, second and third runs, respectively (Figure 6). These levels are more relevant when seen in terms of inventory coverage times by relating them to the average mill demand (approx. 33 000 m^3/month). The third-run teams had relatively lean stocks, corresponding to under 2 weeks of mill consumption for purchase bank and roadside stocks.

The development of capacity utilization for harvesting and transport was not as clear as for the other KPIs. A principal component analysis (PCA) of delivery fulfillment, capacity utilization, relocation and transport distances captured 44 and 27% of the total variation with the first two principal components (Figure 7, left). In the first principal component, production capacity utilization (PC1 loading –0.477) was anti-correlated with both relocation distance (PC1 loading 0.455), transport distance (PC1 loading 0.595) and transport capacity utilization (PC1 loading 0.459). Delivery fulfillment appeared

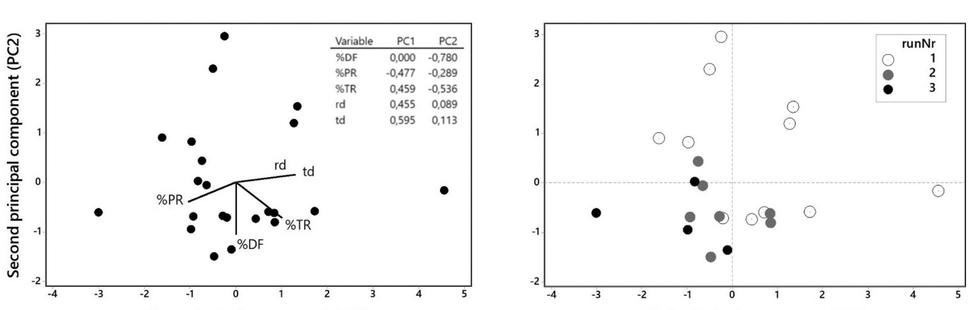

Figure 7. Principal components biplot (left) for end-of-game KPIs showing loadings for delivery fulfilment (%DF), capacity utilization (%PR, %TR) and relocation/transport distances (rd, td). The score plot (right) displays the distribution of first-, second- and third-run observations.

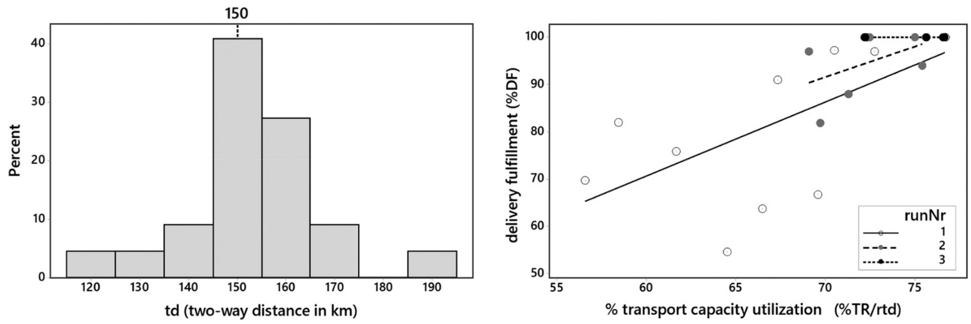

Figure 8. Histogram of average transport distances (td at left). The relative transport distance (td/150 km) was then used to scale transport capacity utilization (%TR/rtd) for the scatter plot against delivery fulfilment (%DF at right).

first in the second component (PC2 loading −0.780) where it was primarily correlated to transport capacity utilization (PC2 loading −0.536).

The associations between delivery fulfillment (%DF) and transport capacity utilization (%TR) as well as between transport capacity utilization and transport distance (td) were to be expected. However, since the production capacity utilization (%PR) was also linked to average transport distance (td), the transport utilization required to ensure delivery fulfillment varied accordingly. After adjustment of transport utilization for the relative transport distance (rtd=td/150 km) the resulting progression of delivery fulfillment with transport capacity utilization is shown in Figure 8 (right).

Discussion

The ambition of the development project was to create an on-line environment where it would be possible to experience management of 12 weeks of wood supply in four hours. The short cycle time (4 h) for the training runs was desired to enable participants to reach the minimum delivery fulfillment levels and analyze their improvements within a maximum of three days training.

Delivery fulfillment increased from 82 to 95 and 100% between the first, second and third runs (Figure 5). The user interfaces proved to be efficient, enabling the completion of the first 12-week scenario in 4–6 h and the second run in under 4 h. The time invested by student teams in the final competition, however, was proportional to the ambition to win. The progression of other KPIs with 36% reduction of relocation distances for harvesting teams and 11% reduction of transport distances for hauling (Figure 6) represent considerable improvements. The analysis also captured an association between varying production levels and relocation/transport distances (Figure 7), with the subsequent transport capacity utilization necessary to reach higher delivery fulfillment (Figure 8).

Regarding the placement of such an exercise in relation to the rest of the wood supply or logistics curriculum, most of the student teams had already worked with production and transport scheduling during earlier but separate exercises. In most cases, the teams had also worked with the wood supply game and were therefore already familiar with principles for managing stocks along the supply chain. This may have been a contributing factor for the large reduction of purchase bank stocks as training progressed (Figure 6). With the final stock levels corresponding to under two weeks of mill demand (inventory cover time) these levels would be considered extremely lean for the purchase bank (typically 2–3 months), but within the typical margin for roadside stocks (typically 1–4 weeks).

The classic trade-off within logistics is between service levels and costs. In this study, there was a simultaneous increase in delivery fulfillment and reduction of relocation/transport distances and purchase bank levels. The deviation from this trend was the generally low level of roadside stocks throughout. This was probably driven by the game configuration where each scenario started with null stocks. While this situation may well reflect conditions typical for the start of the wood supply year (after Christmas or summer holidays) this requires an initial focus on rebuilding roadside stocks. Although mill demand was correspondingly reduced during the first 4 weeks, limited production capacity made this challenging. Otherwise the high scores for delivery fulfillment can be linked to the threshold for delivery fulfillment (±10% for each of the 11 mill assortments) applied in the training runs. In practice, the 10% limits mean that a team could receive full points for deliveries anywhere between 90 and 110% of monthly mill demand for the particular assortment. Reducing this margin to ±5% (via the administrator interface) increases the challenge and would drive greater variation in delivery fulfillment.

In most cases, the exercise was run near the end of the respective courses, and served to indicate which student team was "best" in practice. The mapping of KPI development can help instructors to identify when "best-in-class" is also "excellent," taking into consideration the number of practice runs allowed. Regarding the learning curves presented here, the weakness of the current study is the low number of observations for the third consecutive training run (only four teams). The third-run teams already had roughly 800 h of training within strategic, tactical and operational management in industrial wood supply (30 ECTS master's level credits). This may have given them a higher skill level than other student groups. Further quantification of the frontier between service and efficiency will require more observations with multiple training runs.

Reflections on learning in the on-line environment

The on-line environment allowed students to experience wood supply management in a realistic environment within a limited

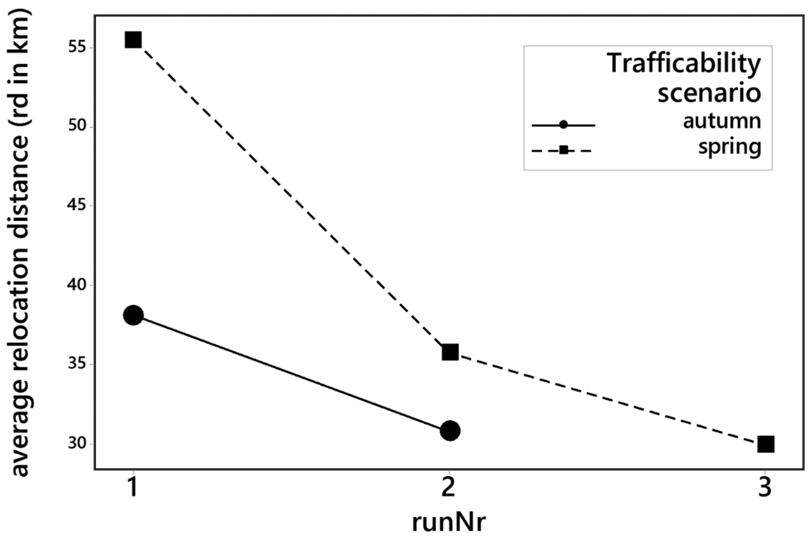

Figure 9. Development of average relocation distance between production sites (rd in km) and training runs (runNr) for spring and autumn trafficability scenarios.

time frame for training. The feedback from students has been positive and company representatives who have tested the arena have also expressed satisfaction with the increasing realism. Since both the on-line wood supply game and the virtual wood supply arena allow consecutive unique training scenarios, difficulty can be adjusted to meet proficiency levels for different groups. In contrast to earlier analyses of student performance in generic supply chain stock management, Sterman (1988) provided quantitative modeling of participant behavior for the original Beer Distribution Game with applications for other sectors. The early Beer Game, however, typically used standardized demand patterns so the population for earlier studies consisted primarily of first-time players. While later wood supply game configurations have quantified the effect of system complexity on system dynamics (as did Dominguez et al. 2014), learning curves have yet to be documented. The initial versions of the forestry transport game tracked KPI progression over three cycles. Here, it was noted that less challenging mill demand patterns provided a more rapid development of transport efficiency (backhauling savings, see Fjeld and Hedlinger 2005). In terms of a learning experience, the main advance offered by the transport games as well as the more realistic Collaboration Game (D'Amours and Rönnqvist 2013) has been the interaction between competing teams when sourcing wood in the same supply geography. As an ultimate interaction experiment, an integration of the earlier wood supply- and transport board games was used for a single test at SLU. This "mega" board game integrated three divergent wood supply games, arranged radially around a common transport game for sourcing (Haartveit and Fjeld 2003a, 2003b). This variant required synchronization of 21 participants (3 supply chains with 7 participants per chain) with 3 central sourcing managers, where the main challenge for the sourcing managers was keeping pace with fluctuating wood demands from the respective supply chains. Without explicit coordination processes the high level of complexity and ensuing dynamics contributed more to classroom chaos than a constructive learning experience.

Seen in relation to these earlier examples, a significant feature of the virtual wood supply arena is that it starts with coordinating monthly team targets before progressing to weekly management. This facilitates a pro-active discussion of the need for purchase bank development (difference between purchase and production pace) and road stock development (difference between harvesting and transport pace). Regarding the development of instructor routines, the final tests at SLU (Table 1, 2023) started with an obligatory pre-game analysis of seasonal wood availability. This was useful to identify expected challenges and consider feasible responses for periods of varying trafficability (i.e. spring and autumn) between climate zones. Although most teams had already worked with annual supply and stock planning, the setting of monthly targets to guide stock development still represented an initial conceptual challenge.

As noted earlier, the selection of trafficability scenarios varied between consecutive training runs. Spring scenarios were selected for the final competition because of the higher complexity in the transition between 3 seasons (winter-spring-summer). As shown in Figure 9 spring scenarios were associated with longer average relocation distances than autumn scenarios. The low proportion of sites with sufficient trafficability required more relocation to accumulate the necessary production volumes and the differences decreased as student experience increased.

The trends reported here are most relevant to the Nordic wood supply, which features relatively small harvesting sites on varying post-glacial surface deposit types. Future developments include new case studies from other countries and benchmarking of student results in relation to theoretically optimal results. Otherwise, the trafficability scenarios used here were based on weather data and thresholds values for the transitions between the respective soil moisture states. New scenarios can also be added to represent future trajectories of climate change. The arena can then be used to test alternative managerial responses to future climate scenarios.

Conclusions

Student teams reached full delivery fulfillment within 3 consecutive training runs. Delivery fulfillment increased from 82 to 95 and 100% between the first-, second- and third training runs. The progression of team performance included a 36% reduction of relocation distances for harvesting teams and 11% reduction of transport distances for hauling from forest to mill. By the final training run the student teams reached these performance levels while holding less than 2 weeks of inventory in their purchase banks and roadside stocks.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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