The timber transport order smoothing problem as part of the three-stage planning approach for round timber transport

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Abstract. This paper presents a three-stage planning approach for round timber transport. At first a Transportation Problem (TPP) is solved to optimize the flow of round timber from wood storage locations to industrial sites. In order to guarantee that the transported quantities are evenly distributed among the single days of the planning horizon with respect to the workload of the carriers and/or industrial sites, the Timber Transport Order Smoothing Problem (TTOSP) is introduced. The daily routing decisions are then made by solving the Timber Transport Vehicle Routing Problem (TTVRP). This paper focuses on the TTOSP and shows the outcome of different strategies and the advantages of cooperation. The presented numerical studies are based on real-life data.

Keywords: log-truck scheduling; timber transport order smoothing problem; wood transport; wood supply chain

Introduction

Round wood supply is an ongoing challenge in the forest based industry and it is exposed to strong competition between the companies. In Austria it can be observed that the wood demand per wood-processing facility is increasing due to a replacement of small- and medium sized mills by bigger ones (Hirsch, 2011). This trend implies also longer transport distances for round timber. In Central Europe transportation accounts for an estimated 30 % of the total costs of round timber (Hirsch, 2011); this percentage can also be found in an international context (see e.g. Audy et al., 2012). Usually, round timber is directly delivered from wood storage locations to industrial sites by log-trucks. In Austria it can be estimated that about 520,000 of these transports take place each year (Hirsch and Gronalt, 2008). This mode of transport implies a lot of empty runnings, since log-trucks cannot be used for backloads from industrial sites, due to their specific construction.

In order to reduce empty movements the use of foldable containers for log transport is an ongoing discussion. While the importance of using foldable containers is growing steadily in several supply chains, they are still used seldom in round timber transport. This is mainly because of technical reasons, since there is a strong mechanical load of the containers. But the producers of the containers are currently working on technical improvements and so one can expect an increase of the use of foldable containers in the forest-wood supply chain in future. As shown in Zazgornik et al. (2012) employing foldable containers avoids a lot of empty runnings and may therefore

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reduce the transport costs significantly. In order to lower transport costs in the forest-wood supply chain with traditional log-truck use, it is necessary to look at this scheduling problem from a tactical and operational viewpoint. In a first step delivery quantities from wood storage locations to industrial sites must be determined. This problem can be formulated as Standard Transportation Problem (TPP). Epstein et al. (2007) state that the TPP formulation is the basis for many other, more complicated and integrated, models in round timber transport.

After the determination of the wood flows, detailed transport orders can be deduced that define a certain transported quantity between a wood storage location and an industrial site. Typically, wood-processing companies wish to have a stable supply of round timber to keep their storage areas small. Hence, the transported quantities to each industrial site should be evenly distributed among each day of the planning horizon. Contrary, carriers aim to have a constant workload in terms of covered kilometers or working hours per day in order to avoid an inefficient utilization of their fleets. Therefore, an efficient distribution of transport orders should be guaranteed. For this purpose we introduce a problem formulation denoted as Timber Transport Order Smoothing Problem (TTOSP).

The TTOSP can be applied to ensure an evenly distributed workload either for the carriers or for the wood-processing companies. If these actors cooperate, it is also possible to optimize the workload of both simultaneously.

When the TTOSP is solved and the transport orders are allocated to specific days, the next step is to connect these orders in an efficient manner. Gronalt and Hirsch (2007) denote the optimization problem of the daily scheduling of log-trucks as Timber Transport Vehicle Routing Problem (TTVRP). This term was introduced by Karanta et al. (2000), who describe the needs for vehicle routing in the forest sector. The TTVRP takes into account maximum drive times, loading constraints, weight limits on the forest road network, multi-depots, a heterogeneous truck fleet, full-truck loads, and time windows of the drivers as well as at the industrial sites. Each wood storage location or industrial site can also be visited more than once in the TTVRP during a day. Gronalt and Hirsch (2007) present a mathematical model formulation and Tabu Search based methods for solving the TTVRP. Hirsch (2011) and Derigs et al. (2012) provide additional solution procedures for the TTVRP. Flisberg et al. (2009) state that log-truck planning has traditionally been a manual process performed by transport planners responsible for a small number of trucks over a specified and limited region. The same is true for the companies that we have worked with in Austria. This highlights the need for efficient decision support systems (DSS) in round timber transport.

Up to now, there are only few quantitative approaches to solve optimization problems in the forest-wood supply chain. A brief review of further literature is presented below. Weintraub et al. (1996) present their log-truck scheduling system ASICAM (Asignador de Camiones) that is based on a simulation process with heuristic rules. It was developed to reduce the transport cost of Chilean forest firms. Weintraub et al. (1996) conclude that their approach has brought a reduction in the truck fleet size, numbers of cranes, operational cost, and total transport cost at the companies. Murphy (2003) presents a model formulation that minimizes the total cost of round timber transport. The author also implies the fixed cost of log-trucks and uses a commercial optimization package to solve his problem instances. Murphy (2003) states that his approach is not suitable as an aid for dispatching log-trucks or for use with large and complex transport operations. It should be seen mainly as a tactical planning tool to reduce the truck fleet sizes in round timber transport.

Palmgren et al. (2003) present a model formulation for the Log-truck Scheduling Problem (LTSP), which unites tactical and operational planning in round timber transport. The authors provide a column generation approach to solve this problem. The main difference between the LTSP and the TTVRP is that the pick-up quantities at the wood storage locations are not determined in advance. Palmgren et al. (2003) also assume time windows at the wood storage locations, homogenous log-trucks, and no full truck loads. Their objective function minimizes the total cost of transport. An extension of their solution approach can be found in Palmgren et al. (2004). Flisberg et al. (2009) introduce a hybrid method based on linear programming and Tabu Search for routing log-trucks. The authors present a two-phase solution approach. In the first phase an LP problem is solved in order to find a destination of flow from supply points to demand points. Based on this solution Flisberg et al. (2009) make use of a standard Tabu Search method to solve the LTSP. Flisberg et al. (2009) use similar basic assumptions as Palmgren et al. (2003) and Palmgren et al. (2004) that are not applicable to the situation in Central Europe. El Hachemi et al. (2010) propose a solution method based on constraint programming and mathematical programming for the LTSP.

Oberscheider et al. (2013) show that the selection of the objective of minimizing fuel consumption leads to a significant reduction of carbon dioxide equivalent (CO₂e) emissions compared to a minimization of driving times in round timber transport. The authors provide a matheuristic solution approach for solving the TTVRP. Zazgornik et al. (2013) present Tabu Search based solution methods to solve the combined vehicle routing and foldable container scheduling problem with time windows (FCVRPTW). The authors include the echelons forest,
industrial site, and wholesaler in the wood supply chain. They optimize the routing of empty foldable containers, round timber, and sawn wood, simultaneously.

Audy et al. (2012) present a comprehensive review on planning methods and DSS in vehicle routing problems for timber transport. The authors also formulate future requirements for DSS in round wood procurement and transportation.

The main contribution of this paper is the introduction of a three-stage approach for optimizing round timber transport with log-trucks. The focus is on the TTOSP, which was not presented in the literature up to now. The paper provides numerical studies based on real-life data from Austria to proof the applicability of the TTOSP. We formulate different objective functions for the TTOSP depending on the actor who is applying the model. With that it can be clearly shown how cooperation in the forest-wood supply chain may reduce overall costs and that the application of the three-stage approach supports planning in round timber transport efficiently.

The paper is structured as follows: Section 2 introduces the three-stage planning approach and the model formulations for the TPP and the different TTOSP strategies. Section 3 presents the numerical studies and Section 4 closes with the conclusions and an outlook on future research.

### Three-stage planning approach for round timber transport

In this section the tactical and operational planning horizon in round timber transport are explained and solution methods are shown. Figure 1 gives an overview of the presented optimization problems, their objectives, and required data.

![Three-stage approach for scheduling log-trucks](Fig. 1. Three-stage approach for scheduling log-trucks (cf. Hirsch, 2011))
At first the TPP generates transport quantities for the log-trucks. In relation to round timber transport, it can be characterized as follows: $W$ is defined as the set of wood storage locations and $I$ is defined as the set of industrial sites (e.g. sawmills, pulpmills, biomass power plants, etc.). Based on supply contracts, wood storage locations $w$ ($w = 1, ..., a$) provide a quantity $s_w$ of a certain assortment of round timber in a given time span. The length of this time span could be for example one month. An industrial site $i$ ($i = 1, ..., b$) needs a quantity $d_i$ of a certain assortment of round timber during that time span according to the contract. The transport costs per quantity unit from $w$ to $i$ are $c_{wi}$ monetary units and $x_{wi}$ denotes the decision variable that presents the transported quantity. The objective is to find a transport pattern that minimizes the total transport costs and satisfies all demands. Therefore, the TPP can be formulated as follows:

The objective function (1) minimizes the total transport costs.

$$\min \sum_{w \in W} \sum_{i \in I} c_{wi} \cdot x_{wi}$$

Subject to:

$$\sum_{i \in I} x_{wi} = s_w \quad (w \in W)$$

$$\sum_{w \in W} x_{wi} = d_i \quad (i \in I)$$

$$x_{wi} \geq 0 \quad (w \in W, i \in I)$$

Constraints (2) guarantee that all demands at the industrial sites are met. It is also possible to consider supply demand mismatch; then (3) needs to be transformed in appropriate inequalities. The non-negativity constraints for the decision variables are given in (4).

The TPP is solvable with standard solver software like FICO Xpress in reasonable computing time, even for large problem instances. After having solved the TPP, one obtains a cost-optimal flow of round timber from wood storage locations to industrial sites. The solution of the TPP serves as a starting point for the operational planning problems TTOSP and TTVRP. It is now possible to construct transport orders for the planning period. These transport orders must be assigned to the single days of the planning period in order to solve the TTVRP afterwards.

A stable daily supply of raw wood is necessary for efficient production at the industrial sites. For carriers an imbalance in the daily routes for the log-trucks can lead to organizational problems and increasing costs. The TTOSP is introduced to obtain a smooth distribution of the workload between the single days of the planning horizon. It is used to balance the workload of the carriers and industrial sites separately or simultaneously. The TTOSP is modeled as a linear optimization problem. It minimizes the maximum deviation from a mean value over all sub-periods of a planning period. If the transport order duration is smoothed, the mean value is represented by the average duration of transport orders per day. In the case of transport order quantity smoothing, it is equal to the average supply quantity, delivered to a specific industrial site per day.

If a carrier smooths its workload separately, it is not interested in the distribution of the workload at the industrial sites. By smoothing its workload the carrier can reduce for example cost for overtime and additional equipment. On the other hand, if an industrial site smooths its workload separately, it is neither interested in the distribution of the workload of the carrier nor in that of the other industrial sites. The industrial site is therefore able to reduce its storage cost. Hence, a carrier needs to know all transport orders for its optimization problem, whereas an industrial site only needs to know the transport orders that belong to it.

$T$ is the number of days during a planning period. The duration of a transport order $o$ is denoted as $d_o$; this is the traveling time from the respective wood storage location to the industrial site. The transported quantity of transport order $o$ is denoted as $q_o$. The transport orders are sorted in an ascending order. The number of transport orders that supply an industrial site $i$ is denoted as $n_i$. This means that $o = 1, ..., n_i$ are all transport orders that lead to industrial site 1, $o = n_i + 1, ..., n_i + n_j$ are all transport orders that lead to industrial site 2, and so on. The constant $n$ is defined as the total number of transport orders.

Equation (5) computes the average duration of transport orders per day; the associated constant is denoted as $ad$. Equations (6) compute the average transported quantity to each industrial site $i$ per day; the associated constant is denoted as $aq_i$. 
The constants are defined in the following way:

$$ad = \frac{\sum_{o=1}^{n} do}{T}$$  \hspace{1cm} (5)

$$aq = \frac{\sum_{o=1+m}^{n+m} qo}{T} \quad (i = 1, \ldots, b)$$  \hspace{1cm} (6)

If the workload of the log-trucks should be smoothed, the following model formulation is used:

$$\text{min} Y$$  \hspace{1cm} (7)

Subject to:

$$UD_t \geq ad - \sum_{o=1}^{n} do \cdot y_{ot} \quad (t = 1, \ldots, T)$$  \hspace{1cm} (8)

$$OD_t \geq \sum_{o=1}^{n} do \cdot y_{ot} - ad \quad (t = 1, \ldots, T)$$  \hspace{1cm} (9)

$$\sum_{t=1}^{T} y_{ot} = 1 \quad (o = 1, \ldots, n)$$  \hspace{1cm} (10)

$$lb_d \cdot ad \leq \sum_{o=1}^{n} do \cdot y_{ot} \leq ub_d \cdot ad \quad (t = 1, \ldots, T)$$  \hspace{1cm} (11)

$$Y \geq UD_t + OD_t \quad (t = 1, \ldots, T)$$  \hspace{1cm} (12)

$$UD_t, OD_t \geq 0 \quad (t = 1, \ldots, T)$$  \hspace{1cm} (13)

$$y_{ot} \in \{0, 1\} \quad (o = 1, \ldots, n; \ t = 1, \ldots, T)$$  \hspace{1cm} (14)

$UD_t$, $OD_t$ and $Y$ are used as non-negative auxiliary variables. The objective function (7) minimizes the maximum of the sum of $UD_t$ and $OD_t$, which represents the absolute deviation from the average duration of transport orders at day $t$. Inequations (8) compute the deviation from the mean value if the sum of the durations of transport orders at day $t$ is less than the average. Inequations (9) compute the deviation from the mean value if the sum of the durations of transport orders at day $t$ is bigger than the average. Each transport order must be executed (10). Constraints (11) define bounds for the total daily duration of transport orders. The constant $lb_d$ stands for a positive number smaller than 1 and the constant $ub_d$ is a number bigger than 1. The users of the model can decide on the values of $lb_d$ and $ub_d$, the closer their values are to 1 the harder it is to find feasible solutions for the problem. Since the objective function (7) already minimizes the maximum deviation, (11) is an additional bounding for the solution space. Inequations (12) define the objective function. The non-negativity constraints are given in (13). $y_{ot}$ are binary decision variables that are equal to 1 if transport order $o$ is executed on day $t$ and 0 otherwise (14).

The outcome of this model is an evenly distributed workload for the carriers among the single days of the planning horizon. The workload at the industrial sites is not considered in this model.

For smoothing the daily workload of the industrial sites, a similar model can be formulated:

$$\text{min} Y$$  \hspace{1cm} (15)

Subject to:

$$UQ_{ot} \geq aq - \sum_{o=1+m}^{n+m} qo \cdot y_{ot} \quad (i = 1, \ldots, b; \ t = 1, \ldots, T)$$  \hspace{1cm} (16)

$$OQ_{ot} \geq \sum_{o=1+m}^{n+m} qo \cdot y_{ot} - aq \quad (i = 1, \ldots, b; \ t = 1, \ldots, T)$$  \hspace{1cm} (17)

$$\sum_{t=1}^{T} y_{ot} = 1 \quad (o = 1, \ldots, n)$$  \hspace{1cm} (18)
\[ \text{lb} \cdot aq \leq \sum_{o=1}^{n+m-1} q_o \cdot y_{ot} \leq \text{ub} \cdot aq \quad (i = 1, \ldots, b; \ t = 1, \ldots, T) \]  

(19)

\[ Y \geq \text{UQ}_o + \text{OQ}_o \quad (i = 1, \ldots, b; \ t = 1, \ldots, T) \]  

(20)

\[ \text{UQ}_o, \text{OU}_o \geq 0 \quad (i = 1, \ldots, b; \ t = 1, \ldots, T) \]  

(21)

\[ y_{ot} \in [0,1] \quad (o = 1, \ldots, n; \ t = 1, \ldots, T) \]  

(22)

This model works in analogy to the smoothing model for the carriers. An additional index \( i \) is necessary for the auxiliary variables \( \text{UQ}_i \) and \( \text{OQ}_o \), since the workload per day has to be smoothed for each industrial site \( i \). The constant \( \text{lb} \cdot aq \) stands for a positive number smaller than 1 and the constant \( \text{ub} \cdot aq \) is a number bigger than 1. The outcome of this model is an evenly distributed supply quantity for each industrial site among the single days of the planning horizon. The workload of the carrier is not considered in this model.

The above mentioned optimization models smooth either the workload of the carriers or the industrial sites. This may cause huge fluctuations for the actor whose workload is not smoothed. Therefore, an adapted model formulation which optimizes the workload of both players simultaneously is introduced.

The average duration of transport orders per day and industrial site is computed with equation (23).

\[ \text{ad} = \frac{\sum_{o=1}^{n+m-1} d_o}{T} \quad (i = 1, \ldots, b) \]  

(23)

Simultaneous optimization of the workload of the carrier and the industrial sites can be assured with the following model formulation:

\[ \text{min} Y \]  

(24)

Subject to:

\[ \text{UQ}_o \geq \text{ad} - \sum_{o=1}^{n+m-1} d_o \cdot y_{ot} \quad (i = 1, \ldots, b; \ t = 1, \ldots, T) \]  

(25)

\[ \text{OD}_o \geq \sum_{o=1}^{n+m-1} d_o \cdot y_{ot} - \text{ad} \quad (i = 1, \ldots, b; \ t = 1, \ldots, T) \]  

(26)

\[ \text{UQ}_o \geq \text{aq} - \sum_{o=1}^{n+m-1} q_o \cdot y_{ot} \quad (i = 1, \ldots, b; \ t = 1, \ldots, T) \]  

(27)

\[ \text{OQ}_o \geq \sum_{o=1}^{n+m-1} q_o \cdot y_{ot} - \text{aq} \quad (i = 1, \ldots, b; \ t = 1, \ldots, T) \]  

(28)

\[ \sum_{i=1}^{T} y_{ot} = 1 \quad (o = 1, \ldots, n) \]  

(29)

\[ \text{lb} \cdot \text{ad} \leq \sum_{o=1}^{n+m-1} d_o \cdot y_{ot} \leq \text{ub} \cdot \text{ad} \quad (i = 1, \ldots, b; \ t = 1, \ldots, T) \]  

(30)

\[ \text{ub} \cdot \text{aq} \leq \sum_{o=1}^{n+m-1} q_o \cdot y_{ot} \leq \text{ub} \cdot \text{aq} \quad (i = 1, \ldots, b; \ t = 1, \ldots, T) \]  

(31)

\[ Y \geq \text{wd} \cdot (\text{UQ}_o + \text{OD}_o) + \text{wq} \cdot (\text{UQ}_o + \text{OQ}_o) \quad (i = 1, \ldots, b; \ t = 1, \ldots, T) \]  

(32)

\[ \text{UQ}_o, \text{OD}_o, \text{UQ}_o, \text{OQ}_o \geq 0 \quad (i = 1, \ldots, b; \ t = 1, \ldots, T) \]  

(33)

\[ y_{ot} \in [0,1] \quad (o = 1, \ldots, n; \ t = 1, \ldots, T) \]  

(34)

The objective function (24) minimizes the absolute deviation from \( \text{ad} \) and \( \text{aq} \) for each industrial site \( i \) at day \( t \). Constraints (25) and (26) are similar to (8) and (9). The difference is that the deviation from the mean value of the durations of transport orders at day \( t \) is now evaluated separately for each industrial site \( i \). Constraints (27) and (28) are equal to (16) and (17). Each transport order must be executed (29). (30) and (31) define bounds for the daily sum.
of \( d_i \) and \( q_o \) for each industrial site \( i \). (32) define the objective function. The deviations can be weighted with the factors \( w_d \) and \( w_q \). These weighting factors can be used to normalize the measurement for quantity and time. (33) are non-negativity restrictions. Constraints (34) define the binary decision variables \( y_{ot} \) that are equal to 1 if transport order \( o \) is executed at day \( t \) and 0 otherwise. Instead of evaluating both deviations in the objective function it is also possible to use only additional constraints like (30) and (31) in the optimization models, which smooth the workloads separately. With this strategy huge fluctuations for the other part can be avoided too. The TTOSP can be solved with standard solver software in reasonable computing time.

After having solved the TTOSP one can start scheduling the daily trips of the log-trucks. The transport orders per day are fixed and should now be linked in a cost-efficient manner. Since the transport orders (full truck loads) are predefined, the objective is to minimize the empty-truck movements. This problem is denoted as TTVRP and can be summarized as follows (cf. Hirsch, 2011):

- A fleet of heterogeneous log-trucks that are situated at the respective homes of the truck drivers has to fulfill a number of transports of round timber from wood storage locations to industrial sites. The log-trucks differ in their capacity and size.
- Each route starts at the home of the truck driver, who leaves with an empty truck for loading round timber at a wood storage location. Subsequently, she/he drives to the designated industrial site and completes the transport order. The truck driver can now finish her/his tour and return back home or start a new transport order. Each wood storage location and industrial site can be visited more than once during the planning horizon. Since the home locations of the drivers are not the same, the TTVP can be characterized as multi-depot problem.
- The log-truck is fully loaded at the wood storage location and totally unloaded at the industrial site. Therefore, full truck loads can be assumed.
- There are no transport orders from a wood storage location to another one or from an industrial site to another one.
- A feasible solution has to meet tour length- and capacity constraints like in the classical VRP.
- Some parts of the forest road networks are unsuitable for larger trucks due to weight restrictions or tight curve radiiuses. Hence, some wood storage locations can only be reached by trucks with a certain capacity or size. Since the capacity and size of a log-truck correlate, these constraints are denoted as route weight limits.
- Time windows occur at the industrial sites and home locations of the truck drivers. Industrial sites have specified operating hours, and drivers are only on duty at certain times.
- There are service times at the wood storage locations (loading), industrial sites (unloading), and home locations (preparation of the log-trucks).

Standard solver software like FICO Xpress is only capable to solve small problem instances of the TTVRP. For a detailed description of the TTVRP the reader is referred to Gronalt and Hirsch (2007), who provide a mathematical model formulation of this problem. Gronalt and Hirsch (2007), Hirsch (2011), and Derigs et al. (2012) introduce Tabu Search and Variable Neighborhood Search based procedures to solve the TTVRP and test them in extensive numerical studies. Oberscheider et al. (2013) propose a matheuristic solution approach for a relaxed version of the TTVRP.

**Numerical Studies for the TTOSP**

The optimization models of the TTOSP were implemented with the standard solver software FICO Xpress. The TTOSP can be solved in reasonable computing time for real-life problem instances. All numerical studies were performed on workstations with a Pentium IV processor with 2.52 GHz and 512 MB RAM; their operating system is Windows XP with SP2.

A numerical study was performed to compare the outcome of the three smoothing variants of the TTOSP (transport order duration, transport order quantity, and simultaneous smoothing). For this reason, 1,000 transport orders were generated based on real-life data obtained from a wood-processing company that owns the given 3 sawmills; the transport orders lead from 401 different wood storage locations to these industrial sites. These
transport orders must be assigned to 5 days. The average duration of the transport orders equals 91.52 minutes, the average loads equal 31.24 / 32.31 / 30.50 tons for industrial sites 1 / 2 / 3.

Figure 2 shows the position of the industrial sites and wood storage locations. Two industrial sites are situated in western Lower Austria, whereas one is in the southeast. If two or more wood storage locations are in the area of the same village they are marked by just one green point in Figure 2.

In the numerical studies the maximum computing times were set to 1,200 seconds for all computations. Additional run times do not contribute to significant improvements of the solutions, since it is hard for the solver software to find good lower bounds for the problems and therefore prove global optima. As shown below, the obtained solution quality is very good and more than sufficient for real-life applications of the optimization models. The parameters $lbd$ and $lbq$ were set to 0.80, whereas $ubd$ and $ubq$ were set to 1.20. The weighting factors $wd$ and $wq$ were set to 1. Hence, a deviation from the average duration in minutes is treated the same as the deviation from the average load in tons. The setting was chosen in order to avoid biasing in the optimization model.

The gained results cannot be proved to be the global optimal ones, but offer a good solution quality with extremely small objective values. If the transport quantities are smoothed, the highest deviation from the average daily quantity at an industrial site is 2.20 tons (industrial site 1). The average daily quantities are 2,305.80 / 1,692.80 / 2,250.80 tons. If the transport durations are smoothed the highest deviation from the average daily duration is less than 1 minute. The average daily durations are 3,830.23 / 7,769.48 / 6,703.52 minutes. In case of simultaneous smoothing the objective values are smaller than 14.06 for all industrial sites (highest value for industrial site 2: 4.86 minutes and 9.20 tons).
Figure 3 shows the point of view of the carrier. The deviations from the average transport order duration per day are given for the different smoothing strategies. STOD denotes the smoothing of the transport order durations per day, STOQ denotes the smoothing of the transport order quantities per day, and SSIM stands for the simultaneous smoothing strategy. One can observe that the carrier is not highly affected if the industrial sites smooth their workload separately. The carrier only has fluctuations in its workload of up to about 7% on day 2, which is equivalent to 1,280 minutes. It can be estimated that the carrier needs to employ about three log-trucks more on day 2 compared to an average day. Hence, even a reduction of these relatively small fluctuations could lead to considerable cost reductions for the carrier. The carrier would almost lose nothing if SSIM is applied.

Fig. 3. Point of view of the carrier

Figure 4, Figure 5, and Figure 6 show the deviations from the average transport order quantity for each of the considered industrial sites. The values are given for the different smoothing strategies. These figures use the same abbreviations as Figure 3.

Fig. 4. Point of view of industrial site 1
When transport order durations per day are smoothed separately by the carrier, there are huge fluctuations in the transport order quantities per day. In the case of industrial site 1 a maximum deviation of about 29% can be observed on day 1, which is equivalent to 669 tons or about 21 additional log-truck visits. There are also considerable deviations at the other industrial sites as shown in Figures 5 and 6.

The model assumes that the durations of the transport orders are directly correlated with the durations of the associated empty truck movements. Further numerical studies with the TTVRP (see Hirsch, 2011) show that this assumption is true. The portion of full truck loads on the total duration stays quite constant over all test instances after solving the TTVRP.
Conclusions and outlook

The numerical studies with the TTOSP underline the importance of cooperation within the forest-wood supply chain. The current situation in Austria shows that industrial sites already smooth their workload separately in order to decrease their costs. Carriers are dependent on these decisions and therefore have to bear higher costs through additional equipment and staff. To reduce the total costs in the first part of the wood supply chain it seems to be advantageous to smooth the workload of carriers and industrial sites simultaneously. A separate optimization may decrease the costs of one actor even more, but it will likely lead to a much bigger cost increase for the other actor. Even though, the industrial sites need to store a negligible amount of round timber more in case of simultaneous smoothing, they may also save costs for round timber transport, if the carrier is able to reduce its cost level and therefore its price. If the carrier is able to determine the strategy, it could also have benefits from cooperation. Since Figures 4 to 6 show that the workload of the industrial sites is highly fluctuating in case that the workload of the log-trucks is smoothed separately, it may be also beneficial for the carrier to use simultaneous smoothing in order to avoid waiting times for unloading due to congestions at industrial sites. In the presented numerical studies this situation is very likely for example at industrial site 1, if about 21 log-trucks arrive extra on day 1.

The solution of the TTOSP is a relevant step after solving the TPP in order to reduce transport costs for round timber. It is the basis for optimizing the routing of log-trucks in the TTVP. The planning environment for this three-stage approach is usually highly deterministic and static, since there are long-term contracts between industrial sites and forest companies, which plan their harvesting activities a long time in advance.

Future research will concentrate on an adaption of the TTOSP to the FCVRPTW. In addition to the flow of round timber and sawn wood, these models will have to deal with the interdependent flows of empty foldable containers over three echelons in the wood supply chain. The authors will also concentrate on a cost analysis of carriers, industrial sites, and wholesalers, in order to find suitable weighting factors for deviations from the average transport duration and delivery quantity. Another important research topic are the different contract models in the wood supply chain, to evaluate how cost savings obtained by one actor will affect other parties.

References


