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Abstract. The significant contribution of raw materials inbound logistics to the reduction of the procurement cost have motivated several recent studies, particularly in the forestry sector. New routing and truck scheduling techniques have been proposed to plan in advance the arrival of the trucks to the mill's gates. Yet, little attention has been given to the trucks reception, unloading and internal movements until exiting the facilities. Consequently, congestion and queuing of the trucks at the mill gate often occur, increasing the duration and costs of the transportation services. This paper introduces the Raw Materials Reception Problem (RMRP) and presents an innovative solution approach anchored on Revenue Management principles often used in for example airline and hotel booking systems. The solution builds on segmenting carriers/trucks and their dynamic assignment to the time slots available at the unloading docks, awarding on-time arrivals. Direct unload at the production lines is further preferred. It avoids, whenever is possible, the passage in the intermediate stockyard, therefore leading to a reduction of the material handling cost. Results of the application of this solution approach to the wood supply of a Portuguese pulp mill are presented. The case study encompasses 120 pulpwood daily deliveries on 6 possible unloading docks inside the mill. The proposed approach led to a reduction of 55% on the daily raw material reception cost when compared to the FIFO approach used today. The maximum waiting time for each truck was also reduced, particularly for the trucks on higher priority segments. This approach was implemented in the Wood Delivery System prototype and then used for conducting a trade-off analysis that provided valuable information to support decision-making in respect to the design of the reception process.

Keywords: Raw materials reception, inbound logistics, revenue management, congestion, queuing, assignment problems.

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1 Introduction

The transportation and reception of the raw materials at the mills are key problems of the inbound logistics in most of the industries that transform natural resources. We will generally describe the raw materials reception process at a transformation mill, but the case study is the pulpwood reception in a Portuguese pulp mill. This problem encompasses few active extraction sites where large amounts of resources are obtained, sorted and bundled into fewer loading piles that are often located at the proximity of the road network. The extraction of raw materials is managed directly by the industry but the transportation is outsourced to third party carriers. The carriers assigned to the extraction sites, manage the raw materials transportation according to the availability of their specially adapted trucks. There are business imperatives that dictate the rapid movement of the resources from the extraction sites, such as avoiding degradation of the resources conditions, the risk of natural hazards (e.g. wildfires), lack of space in the loading piles or inaccessibility of the extraction sites during parts of the year due to the seasonal weather conditions. Consequently, there are multiple trucks starting the day loading at the same extraction site and traveling identical routes. This leads to congestion and queuing at the extraction site and at the mills, particularly at certain rush hours.

At the mill, congestion occurs both at the entrance gate and at the unloading locations. The trucks coming from the extraction sites are managed along side with the trucks carrying raw materials from other market suppliers. The truck is directed to an unloading dock inside the mill according the the freight characteristics (i.e. assortment transported) and the materials accepted in each dock. Unloading often takes place at the stockyard where the raw materials are temporarily stored. Later, they will be transported to the industrial production lines to be transformed into intermediate or finished products. The truck may need several hours to complete the delivery process, while it could take less than 1 hour in no-traffic conditions.

The prolonged delivery time of the trucks increases inefficiencies of the supply chain. The main economical effect is the increase in the duration and cost of the transportation services, leading the the increase of the raw materials procurement cost and consequently impacting on the price paid by the customers of the finished products. Particularly in the forestry sector, it is often suggested that the wood transportation and reception processes may account for 30% to 50% of its procurement cost payed by pulp mills (e.g. [10]). Another important effect of the delays in the delivery process is the non-compliance with the routes and schedules planned for the day. Furthermore, it may instigate the drivers frustration and fatigue caused by longer working hours. The lack of reception planning precludes the possibility of advanced scheduling of the stockyard operations that may reduce the raw materials handling cost through the direct unloading at the production lines.

The literature on raw materials reception planning is scarce. Recent studies ([5]) coordinate the wood trucks schedules with the time slots available at the service gate in order to spread arrivals across its working hours. However, even in this case, the increased traffic due to unplanned trucks and out-of-time arrivals may cause congestion during rush hours.

This paper aims to improve the raw materials reception process trough advanced scheduling and just-in-time re-scheduling of the deliveries arriving at the mill. The emphasis is on improving the efficiency on the supply chain by reducing congestion and queuing while assuring minimum delivery time for the trucks arriving on-time. It further intents to promote the direct unload at the industrial production lines, avoiding the passage on the intermediate stockyard, therefore leading to a reduction of the material handling cost.

The paper firstly introduces the Raw Materials Reception Problem (RMRP) and then proposes one modeling and solution approach. The similarities among this problem and other airline and hotel booking problems suggested the use of Revenue Management (RM) techniques. The reader is directed to [6], [9] and [7] for a complete overview of RM principles. In general terms, the capacity-based RM techniques in use in these problems rely on clustering the resources into price segments and managing over time the amount of resources available at each class. The application of this approach to the airline booking problem encompasses the definition of fare segments and setting the number of seats in each class. The seats on the highest fare class are kept available for the customers as long as possible. Yet, some seats may be assigned to lower fare segments some time before the flight, depending on the prognosis and the actual sales. Similar techniques were recently applied by [1] to the softwood lumber industry. The authors conduct customer segmentation based on their profitability and other priority measures and progressively allocated not yet reserved stock and planned production quantities to different customer segments. Revenue gains of 3-5% were reported in these several applications (e.g. [1], [6]).

The proposed solution method based on Revenue Management principles consists in classifying the trucks/carriers into priority segments and progressively assigning them to time slots at the gate and at the unloading location, currently available for its segment. This approach was implemented in a $3-$phase method that runs in distinct time frames Before the delivery day, the Time Slot Allocation Planning finds the best time slot/unloading docks for the planned deliveries, minimizing the overall daily reception extra-cost. It acknowledges both the cost of materials handling at the stockyard related with the internal stock movements from there to the unloading dock at the line) and the cost of having the trucks stationary inside the mill waiting for service or delivery. Consequently, the direct unload at the production lines is privileged.

During the delivery day, the time slots reserved are kept available as long as possible. Each time a truck arrives (planned and unplanned) the Time Slot Order Promising assigns the truck to the best time slot/unloading dock that are available for its segment. Planned trucks arriving on-time have direct access to the mill. Delayed trucks in higher segments will have a large range of slots available, therefore will have lower waiting time.

Nevertheless, just before starting the time slot at the line, Time Slot Order Allocation selects the best truck in queue according to the minimum cost criteria. Consequently, if the slot was still reserved for a higher priority truck, it will be assigned to another truck waiting in the queue.

The proposed solution approach was implemented on a computerized tool - Wood Reception System - and tested on a Portuguese pulp mill with 120 deliveries (72 planned and 48 unplanned) of 3 distinct wood assortments and 496 time slots on 6 possible unloading docks inside the mill. The daily delivery schedules obtained with the 3-Phase solution method were compared with the results of the FIFO approach used today. The daily wood reception costs were reduced in 55%. Significant reductions were also reported for the maximum waiting time to unload, particularly for the trucks within higher priority segments. The solution method was further used to solve several "what-if" scenarios that provided valuable information to support decision-making in respect to the design of the reception process. The paper further discusses the real-life implications of the technique under the mill's and the carriers perspectives.

2 Problem statement

The reception of raw materials at the transformation mill encompasses four main stages that occur simultaneously during the mill opening hours. The service stage starts when the loaded truck arrives at the mill's facilities and accesses the service gate. The truck arrival time to the mill (A_v) and the freight characteristics are used to establish its priority segment and set its position at the service queue outside the mill's facilities (figure 1). The deliveries previously planned may have priority in respect to unplanned. Likewise, deliveries coming form market suppliers or trucks with additional deliveries on that day may be placed at the head of the queue.

The service stage starts when the truck reaches the service gate. Its entrance time is recorded (E_v). There, the receptionist verifies the transportation documentation, performs security controls and the freight quantitative and qualitative evaluation. The receptionist further determines its internal unloading dock. The active storage cells in the stockyard are often preferred, mainly by logistics reasons. Yet, unloading may occur directly at the docks that feed the industrial production lines.

The delivery stage starts when the trucks passes the gate and drives to its assigned docking location. Its arrival time to the unloading dock correspond to its entrance time plus the average duration of the ride between the gate and an unloading location (t_d). The truck waits on the delivery queue until the previous truck is fully unloaded. The truck unloading start time is recorded (U_v).

Unloading usually takes place on an first-in-first-out (FIFO) basis. Stationary unloading equipment are often used. The efficiency of the equipment used conditions the average duration of the unloading operations (L).

The exit stage starts when unloading is complete and the truck drives back in the same track to the service gate. The rive takes t_d minutes as before. The unloaded truck quickly passes trough the service gate and there is no queuing for departure. Its exit time is further recorded (B_v).

The line supply stage does not focus on the trucks movements but instead on the raw materials deliveries in the production lines. This stage aims to assure the continuous supply of raw materials to the production lines, either by direct freights or internal movements of the stocked material. Therefore, it starts just before the beginning of each time slot at the production lines and is repeated during their entire working hours.

The Raw Materials Reception Problem (RMRP) addresses all of these stages. It consists in ordering the trucks arriving at the mill and establishing the best unloading location for each truck, while assuring continuous supply to the production lines.

The most common approach to this problem orders the trucks arriving at the mill in First-in-First-Out according to their arrival time. Unloading occurs exclusively in the active cell at

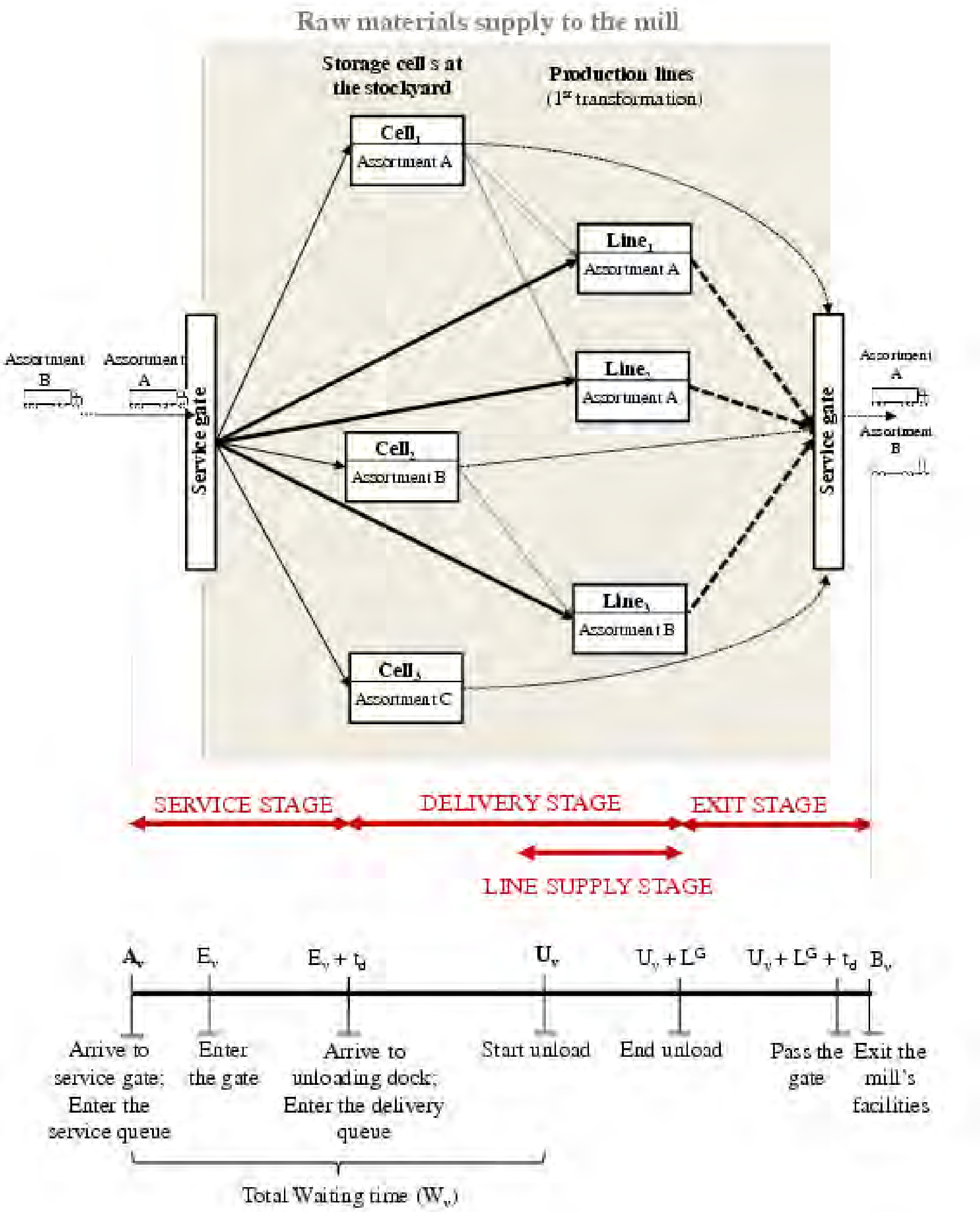

Figure 1: Graphical representation of the raw materials reception problem, considering 3 product assortments A, B, C, 1 service gate, 3 active cells at the stockyard $Cell_1, Cell_2, Cell_3$ and 3 production lines $Line_1, Line_2, Line_3$

the stockyard that receives the product assortment transported by the truck. Congestion and queuing are frequent, particularly in certain rush hours, leading to long waiting time at the mill. The lines are continuously supplied by stocked material from the stockyard, leading to the high material handling cost.

3 Solution method based on Revenue Management principles

The initialization of the 3-phase method for the RMRP consists in computing the time slots at the gate and at the unloading locations. For this purpose, the stockyard working shift is divided into hourly time windows that in turn are split into time slots with a few minutes duration. The length of the time slots may be set according to the maximum duration of the operations that take place during the service stage and the delivery stage for a generic truck.

Initialization further imports the list of expected daily deliveries consisting in transportation service given to a carrier/truck, usually from an extraction site to the mill, with a certain amount of raw material assortment at a given delivery day. There may be an preferable arrival time to the mill, established in the routing plan and/or negotiated with the carrier (e.g.[5]).

Phase 1 - **Time Slot Allocation Planning** - segments the carriers/trucks into a closed-set of priority segments, according to its priority index (figure 2). The truck priority index (P_v^i) is a pondered sum of several criteria (σ_i) that may address the historical behavior of the carrier/truck over the last deliveries, its number of next scheduled trips for the same day, the freight/truck specific characteristics or the truck compliance with the arrival time previously set by the routing plans and/or negotiated with the carriers (1). It takes values between 0 and 1. The weights of the criteria (λ_i) are set by the user as they express his policy for evaluating the carriers transportation services. Furthermore, threshold parameters γ_{n-1} are used to set the minimum value of the priority index above which the truck is classified into a priority segment.

$$P_v^i \ = \ \sum_i \lambda_i \sigma_i, \sum_i \lambda_i = 1, 0 \leq \lambda_i \leq 1 \quad (1)$$

The phase proceeds with the optimal minimum cost assignment of the v expected daily deliveries to the s time slots available at each unloading dock d. The decision variables of this Integer Programming problem X_{vsd} are set to 1 if truck $v \in V$ is assigned to time slot $s \in S$ at the unloading dock $d \in D$ and 0 otherwise. It can be described as:

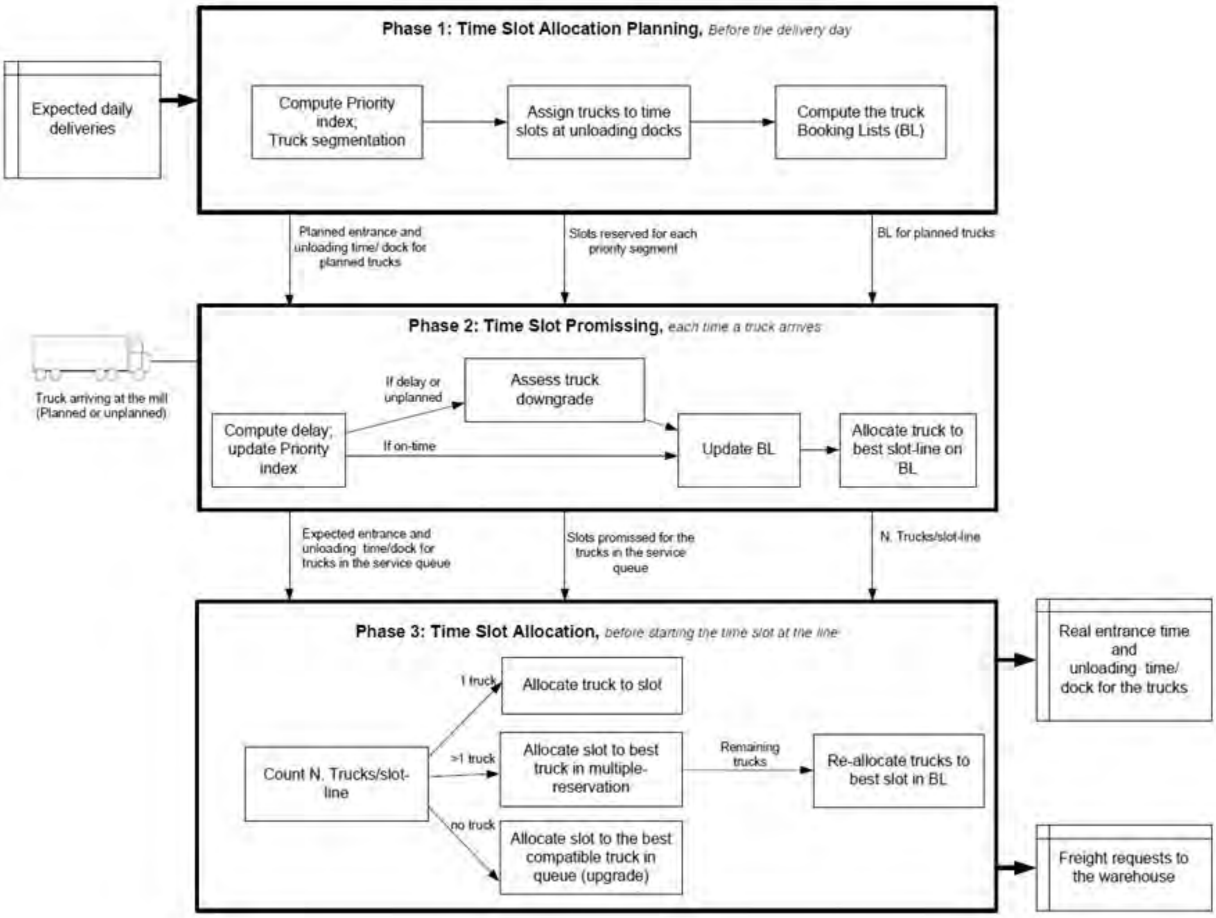

Figure 2: Structure of the proposed solution method for the RMRP

Table 1: Nomenclature table

Input data:	
W	Set of time windows used to plan the entrance at the service gate
V	Set of trucks expected to arrive at the service gate, including deliveries from market suppliers (V^M) or from self-managed forests (V^F)
V^N	Set of trucks unplanned trucks that arrive at the service gate
D	Set of unloading locations, including the unloading docks at the production lines (D^L) and at the storage cells in the stockyard (D^Y)
S^G	Set of time slots available at the gate
S	Set of time slots available at the unloading docks including the lines (S^L) and at the stockyard (S^Y)
L^G	Length of the time slots at the service gate (min)
L^L	Length of the time slots at the production lines (min)
L^Y	Length of the time slots at the storage cells at the stockyard (min)
b^S	Shift opening hours at the unloading docks
b^E	Shift closing hours at the unloading docks
g^S	Shift opening hours at the service gate and stockyard
g^E	Shift closing hours at the service gate and stockyard
t_d	Duration of the ride between the service gate and the unloading dock d (min)
p_d	Raw material assortment accepted at the unloading dock d
p_v	Raw material assortment transported by truck $v \in V \bigcup V_N$
l_v	Weight of the raw material load delivered by truck $v \in V \bigcup V_N$ (ton)
C^W	Cost per minute spent by a loaded truck at the queue (Euro/min)
C^M	Handling cost per ton of raw materials (Euro/ton)
C^O	Cost per minute of overtime work at the stockyard (Euro/min)
Parameters used in the solution method:	
n	Number of segments considered for trucks classification using a Revenue Management approach
π	Number of time slots kept available for unplanned trucks, considering all the lines
λ_i	Weight of the criteria Σ_i used to compute the priority index
γ_{n-1}	Threshold parameters of P_v^i used for truck segmentation
α	Admissible anticipation/delay given by the mill for on-time arrivals (min)
Δ	Maximum allowable delay for a truck at the limit of its segment (min)
δ_1	Weight of P_v^i used to compute the updated priority index
β	Number of minutes before starting the slot at the line when the real allocation occurs (min)

$$
\begin{aligned}
\text{[P1]} \qquad & \min z = \sum_{v \in V} \sum_{d \in D} \sum_{s \in S} c_{vsd} x_{vsd} && (2) \\
\text{s.t.} \qquad & \sum_{d \in D} \sum_{s \in S} x_{vsd} = 1, \quad \forall v \in V && (3) \\
& \sum_{v \in V} x_{vsd} \leq 1, \quad \forall s \in S, d \in D && (4) \\
& \sum_{d \in D^L} \sum_{s \in S} \sum_{v \in V^M} x_{vsd} + \sum_{d \in D^L} \sum_{s \in S} \sum_{v \in V^F} x_{vsd} \leq \pi' && (5) \\
& x_{vsd} \in \{0, 1\} \quad \forall v \in V, s \in S, d \in D && (6)
\end{aligned}
$$

The objective function of problem [P1] aims at minimizing the total daily raw materials reception cost through the optimal assignment of the trucks with the expected daily deliveries to the available time slots at the unloading docks (2).

The daily raw materials reception cost (C_{vsd}) corresponds to the extra-cost of the delivery process due to the inefficiencies of the supply chain. In particular, it acknowledges the cost of having the trucks stationary inside the mill waiting for service or delivery, the cost of handling the raw materials at the stockyard and the cost of keeping the unloading resources available overtime (7). Yet, it does not account for the actual cost of having the service gate and the unloading locations working during their regular working hours.

$$
\begin{aligned}
C_{vsd} &= \frac{C^W W_v + C^M l_v + C^O (U_{vsd} - b^E)}{P_v^i}, \forall v : p_v = p_d, s \in S && (7) \\
W_v &= (U_{vsd} - (A_v + L^G + t_d)) && (8)
\end{aligned}
$$

The first component of the cost function is the product of truck total waiting time (W_v) by the unit cost for each minute spend by the loaded truck at the queue (C^W). The W_v is time between the beginning of the unloading operations (U_{vsd}) and the truck arrival to the service gate (A_v), including the duration of the service stage (L^G) and the ride from the gate to the unloading dock (t_d) (8). C^W may be established as the average fixed cost for a loaded truck specialized on a given type of raw material ([2]). The second component of the cost function is only considered when unloading takes place at the storage cells in the stockyard. It is the product of the cost of handling one ton of materials at the stockyard (C^M) by the amount transported by the truck (l_v). The third component is the product of the cost for each minute of overtime work at the stockyard (C^O) by the number of minutes beyond closing hours when unloading took place. On equal values of these cost components, the truck with the highest priority index should come forward in the queue. C_{vsd} takes a very high value whenever the raw material assortment transported by truck v is not accepted at the unloading dock d.

The remaining equations of problem [P1] set the problem constraints. The daily delivery must be assigned to exactly one time slot (3). It is assumed that unloading operations start at the beginning of a time slot and the truck is empty at the end of the slot. This is consistent with the rule previously used that establishes the time slots length according to the maximum duration of the unloading operation. Reciprocally, the time slot must be assigned to one truck at the most (4). It is not mandatory to have the time slots at the docks all assigned during phase 1. In fact, these slots may be allocated further on to freights from the stockyard. Contrarily, the majority of the time slots at the stockyard are expected to remain unassigned due to the preferential unload directly on the production lines in order to reduce the materials handling cost. Furthermore, simultaneous unloading operations on the same location are not foreseen. The next equation limits the number of deliveries to the lines in order to keep π time slots available for unplanned trucks (5). Finally, equation (6) states the binary requirements.

The optimal solution of the assignment problem provides the trucks planned unloading time and location (U_{vsd}^{plan}) and consequentially its planned arrival time at the service gate (A_v^{plan}) for all the expected daily deliveries. The time slots assigned during this phase become reserved and will be kept available as long as possible for planed truck segment (or higher). The arrivals in compliance with the A_v^{plan} will use the reserved slots, therefore will complete the delivery process with minor waiting time.

Phase 1 ends with the computation of the truck's booking lists. The booking list of the truck BL_v groups all the time slots reserved to its segment and to lower segments that start after its planned arrival time. As an example, consider truck 1, high priority and truck 5, low priority, planed to arrive at 7:15 and 8:10, respectively (Figure 3, upper part). The booking list of truck 1 includes the time slots reserved for high, medium and low segments starting after 7:15, while the booking list of truck 5 only includes the time slots reserved for the low segment. Both can access the unreserved time slots.

The following phases of the solution method re-assigns the trucks to the time slots in real-time, in response to delays of the expected daily deliveries or the arrival of unplanned trucks. Phase 2 - **Time Slot Promising** - starts by computing the delay each time a truck arrives. The truck delay (L_v) is the difference between its planed arrival time and the index ϕ that signals on-time arrivals (delay equal to zero), normalized by the gate closing hours in order to get values between 0 and 1 (9). The computation of index ϕ is based on the tolerance parameter α that is established by the mill as a tolerance interval around the planned arrival time where the truck is still considered to arrive on-time(9).

The L_v is then used to update the truck priority index P_v^u (10). The P_v^u, together with the revised values of the threshold parameters (γ_n^u) (11), are used during the downgrade process to establish the new segment for the delayed trucks.

$$
\begin{aligned}
L_v &= \tfrac{A_v^{real}-\phi}{b^E}, if A_v^{real} > \phi; 0 \text{ otherwise} && (9)\\
& \quad \text{with } \phi = min\left\{\left(A_v^{plan}+\alpha\right);\left(U_{vsd}^{plan}-t_d-L^G\right)\right\} \\
P_v^u &= \delta_1 P_v^i + \delta_2\left(1-L_v\right); \delta_1+\delta_2=1; 0 \leq \delta_1, \delta_2 \leq 1 && (10)\\
\gamma_n^u &= \delta_1 \gamma_n + \delta_2\left(1-\tfrac{\Delta}{b^E}\right) && (11)
\end{aligned}
$$

The downgrade process is further ruled by the value of the downgrade parameter (Δ) set by the mill. It is the limit for the delay above which the truck at the bottom of its priority segment will be downgraded. All the delays equal or below Δ will keep its priority segment. For the delays above Δ, the trucks with higher P_v^i will also keep its priority segment, while the others will change to a lower priority segment. It is noteworthy that even high priority trucks can be downgraded to the lowest priority segment when very long delays occur. The low priority trucks can be downgraded to a very low priority segment only used for this process. The unplanned

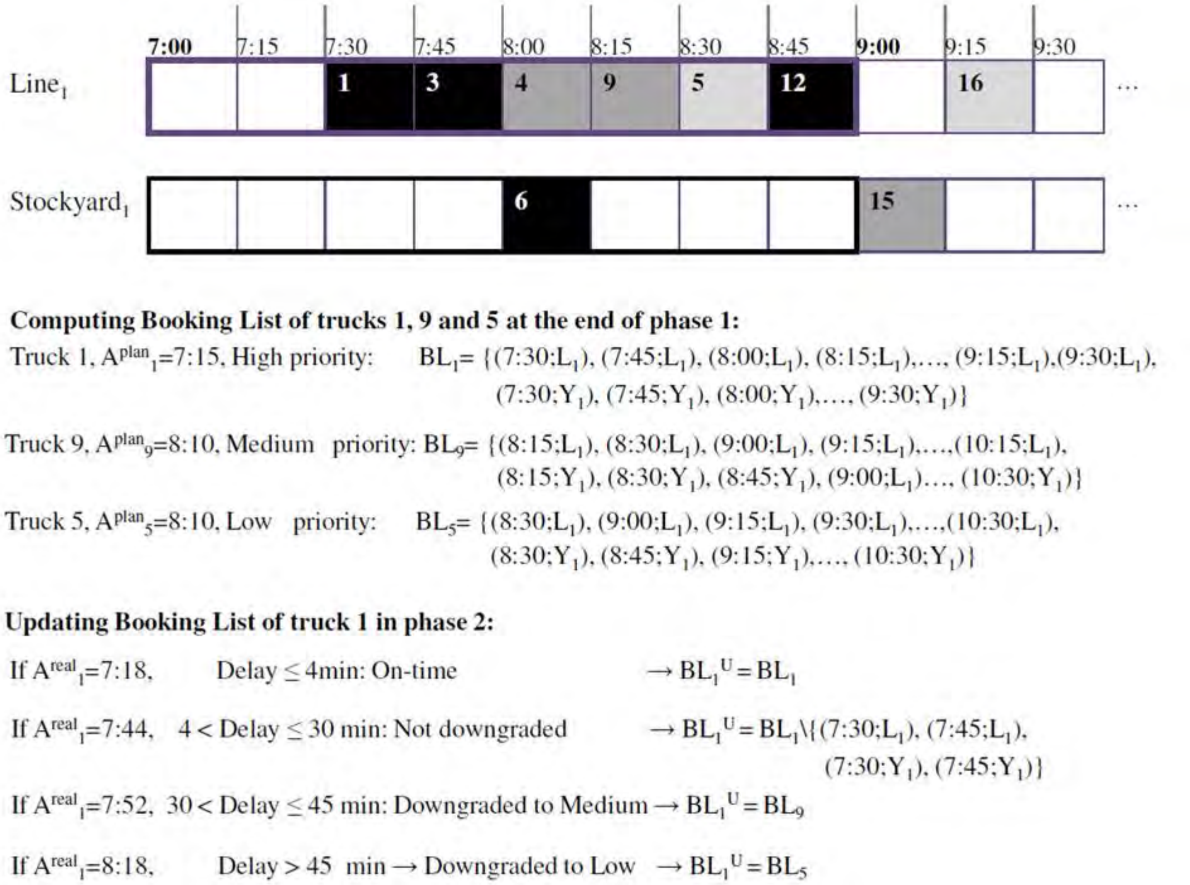

Figure 3: Example of computing the booking lists of trucks 1, 9 and 5 at the end of phase 1 and updating the booking list of truck 1 at the end of phase 2. The example shows the 15-min time slots at line 1 and stockyard 1 reserved to the trucks at the end of phase 1. Trucks 1, 3, 6 and 12 are high priority, trucks 4, 9 and 15 are medium priority and trucks 5 and 16 are low priority.

trucks have P_v^u equal to zero and are classified in the lowest priority segment.

At the end of phase 2, the truck booking list is updated to reflect the results on the downgrade process. It often lead to the reduction of the time slots available for the delayed trucks (Figure 3, lower part). Then, the truck is allocated to the best time slot available at its updated BL_v, based on the minimum assignment cost criteria (7), providing the truck expected unloading time and dock U_{vsd}^{esp}. At this stage, higher priority trucks arriving late may be assigned to time slots reserved to lower priority trucks, leading to the multiple-reservation situations that are addressed on the next phase. In the previous example, if truck 1 arrives at 7:52 it will be assigned to the slot reserved for truck 9, leading to one of these situations.

Phase 3 - **Time Slot Allocation** - focus on the line supply stage and starts by counting the number of trucks promised to each unloading dock at the line, β minutes before the beginning of each time slot. When there is only one promised truck, the truck-slot allocation becomes final ($U_{vsd}^{real} = U_{vsd}^{esp}$).

When there are multiple-reservation situations, the time slot is finally assigned to the truck arriving on-time or to the truck that minimizes the truck-slot daily reception cost (7). The remaining trucks are re-assigned to the best time slot on its updated BL_v, according to the same minimum cost criteria. When this situation occurs in the time slots at the gate, the postponement of the service stage may impact on the feasibility of the expected unloading time. If so, the truck is further re-assigned to a new time slot at an unloading lock. Consequently, new multiple-reservation situations may occur that will be handled equally.

When there is no truck promised for that time slot at the line, the upgrading process anticipates the delivery phase for the best compatible truck waiting in the queue, which is selected using the same minimum cost criteria (7), and then vacant the slot that is initially reserved to that truck. The truck is considered compatible if its freight assortment matches the assortment accepted at the line and the new delivery time can be met, considering the truck entrance time summed to the duration of the ride between the service gate and the dock. Finally, when no truck is available at the service queue, the procedure triggers a freight request of stocked materials from the stockyard.

4 Case study: Pulpwood reception at a Portuguese pulp mill

The proposed solution approach was tested on the particular case of RMRP related with pulpwood reception at a pulp mill. The case study was based on data from the pulp and paper mill Europac Kraft Viana at Viana do Castelo from the EuroPac Group, located at the northern region of Portugal. The Europac Group is the 4^{th} main European producer of Kraftliner for paper and board products. It has 30 mills operating in Portugal, Spain and France. The mill Europac Kraft Viana produces since the 80's Kaftliner paper for packaging, using *Pinus pinaster* and *Eucalyptus globulus* pulpwood as well as recovered paper. Its annual production rounds up 350 thousand metric tons of paper, consuming about 700 thousand metric tons of maritime pine and 180 thousand metric tons of eucalyptus pulpwood. The majority of the pulpwood comes from the national market. Only a small fraction is produced on self-managed forests.

The pulpwood reception follows harvesting and transportation as the last step of the wood procurement processes. The pulpwood is transported mainly by road from the harvest sites and wood yards to the mill. The specialized wood truck carries one lumber product assortment, consisting in barked or unbarked logs of different volume and density. Their maximum tonnage is limited by national regulation to 40ton or 60ton (about 28 or 48ton of loading capacity). The company outsources the transportation services to few local cooperatives, each with 20 to 40 carriers. The market wood is supplied usually by small-scaled entrepreneurs that conduct harvesting operations and hire the transportation services on-demand.

The wood reception at the mill is often conducted without planning in advance. Yet, an average sized pulp mill can receive more than 120 trucks per day. The wood reception process unfolds as previously described. The truck arriving at the mill is placed at the service queue, where it may stay for several minutes or even hours, if it arrives during rush hours.

The operations at the service gate take less than 10 minutes. The load is weighted and the receptionist decides its unloading unloading dock d, taking into account freight/truck characteristics. The intermediate wood yard is the frequent destination. There is an active storage cell ($d \in D^Y$) for each product assortment accepted at the mill (p_d). Exceptionally, the truck transporting the adequate assortment may unload at one of the unloading docks that feed the woodpulp production lines ($d \in D^L$).

The delivery stage may take several minutes due to the congestion at the unloading docks. Yet, unloading operations often take only take 10-15 minutes using an stationary electric crane. When empty, the truck exits on the same gate where a new weighting estimate is recorded. Both measurements will be used to compute the pulpwood weight that will dictate the pulpwood value. The supply stage assures the continuum operation of the production lines during 10-14 hours per day. The line includes an unloading table connected to a rolling runway that forward the pulpwood to the log feeders. There, the wood will be mechanically barked and chipped. The lines are continuously powered by pulpwood mainly from the intermediate wood yard. The internal transport is carried by trailers that compete with the trucks for the service of the stationary loading/unloading equipment. The maintenance and operation of the internal fleet increases the pulpwood handling cost (C^M). The resulting wood chips are stacked and stored under open air conditions. They usually represent a safety stock for the pulp mill to operate in continuum during one to two weeks.

Both service and delivery queues are currently handled using a First-In-First-Out approach based exclusively on the truck arrival time. The increased traffic in certain rush hours (specially close to lunch time and at the end of the day) often lead to congestion at the service gate and at the unloading docks. The trucks can use up to 4 hours to complete the unloading operation, when it should take about 40-50 min. The prolonged waiting time represent a cost for the carrier that can be estimate a fraction of the fixed costs related with the truck maintenance and the drivers costs (C^W). It further impacts negatively the capacity use of the fleet and causes disruption on the planned transportation schedules. Consequently, the carriers may be forced to retard the next planned trips, incurring in additional costs of the drivers working extra-hours. It can even lead to the cancellation of some planed trips, implying the expansion in time of the transportation services or the increase of the number of trucks/trips required.

Case Simulation

The data set used in this study relates to one delivery day at the mill, when the service gate works from 06hr to 21hr (Table 2). The 2hr time windows are split into 17 time slots (L^G) of 7min duration. The mill accepted three product assortments: eucalypt with and without bark (A, B) and maritime pine without bark (C). The unloading docks were one active storage cell at the stockyard for each assortment, as well as 2 production lines for product A and one for product B. The working shift at the lines started 1hr after the gate and it is split into 15min time slots (L^L and L^Y). The length of the time slots corresponded to the maximum duration on the truck unloading operation using the electric crane. The ride between the gate and the unloading docks (t_d) took about 10min.

The data set included the preferred arrival time, load and product assortment transported by each of the 72 expected daily deliveries (v) simulated based on real-life information. There were no records of expected daily deliveries that could be used in this study, although they may become available when new transportation planning activities are embraced (e.g. [5]). 40% of the deliveries were marked as coming from market wood suppliers. The data set further included the number of additional deliveries planned for each truck during that day. There may be less trucks than the number of deliveries since the same truck can perform more than one trip during the day. Both the number of truck per time window at the gate and their distribution among its time slots were randomly generated. The simulation forced 40% of the deliveries to arrive in rush hours (9hr-11hr, 11hr-13hr and 19hr-21hr). Consequently, the average number of 17 trucks per time window could rise up to 20 during these periods.

For phase 2 and FIFO, the data set included 48 other unplanned trucks coming from market wood suppliers and randomly generates the delays in the arrival time of all the deliveries. It assumed that the trucks could arrive before the gate opening hours (W_v^{bef}).

Solution approaches

The case study was solved using the 3-phase method for the RMRP. The phase 1 segmented the expected daily deliveries into 3 priority segments (high, medium and low) according to the value of the truck's priority index and the threshold parameters γ_1, γ_2 (0.6 and 0.3 respectively). The truck v was high priority if $\gamma_1 \leq P_v^i \leq 1$; medium priority if $\gamma_2 \leq P_v^i < \gamma_1$ and low priority if $0 \leq P_v^i < \gamma_2$.

The priority index of the truck was computed as a pondered sum of five sequencing criteria (1). σ_1 addressed the historical behavior of the truck over the last 15 deliveries; σ_2 considered the number of trips still planned for the truck; σ_3 matched the product transported with the assortments needed at the unloading docks; σ_4 privileged the trucks from priority origins (e.g. the maritime ports) and σ_5 privileged higher capacity trucks arriving fully loaded. Both the priority index and the criteria took values between 0 and 1. σ_1 and σ_2 were considered the most important criteria, thus having the higher weights values (λ_1 = 0.5, λ_2 = 0.2). The remaining

Table 2: Characteristics of the case study and values of the parameters of the 3-Phase method for the baseline scenario

Constant		Value
Input data:		
V	=	$\{1, 2, ..., 120\}$, with$V^F = \{1, ..., 57\}$, $V^M = \{58, ..., 72\}$, $V^U = \{73, ..., 120\}$
D	=	$\{1, 2, ..., 6\}$, with$D^L = \{1, 2, 3\}$, $D^Y = \{4, 5, 6\}$
L^G	=	7min
L^L, L^Y	=	15min
b^S, g^S	=	420, 364
b^E, g^E	=	1260
t_d	=	10min
p_d	:	$p_1 = p_2 = p_4 = \{A\}$; $p_3 = p_5 = \{B\}$; $p_6 = \{C\}$
C^W	=	0.51ϵ/min
C^M	=	0.35ϵ/ton
Parameters used in the solution method:		
n	=	3 $\{high, medium, low\}$
π	=	10%
λ_1	=	$0.5; \lambda_2 = 0.2; \lambda_3 = \lambda_4 = \lambda_5 = 0.1$
γ_1	=	$0.6; \gamma_2 = 0.3$
α	=	4min
Δ	=	30min
δ_1	=	0.5
β	=	10min

criteria were weighted with 0.1.

Phase 1 proceeded with the computation of the daily reception extra-cost, assuming that C_W and C_M were set to 0.51Euro/min and 0.35Euro/ton. The ratio between these values impacted on the optimal solution of the assignment problem. As an example, given one truck arriving at the gate carrying 28ton of product A, it was preferably assigned to the production lines if its total waiting time was below 19.2min (19.2*0.51 = 28*0.35); and to the stockyard otherwise.

The trucks booking lists computed at the end of phase 1, included the time slots up to 240min after the truck planned arrival time which remained unassigned as well as those assigned to trucks from its priority segment or lower.

Phase 2 computed the truck delay and new priority index, using the α tolerance parameter of 4 min. The delay of the truck was considered equality important as the initial value of the priority index, therefore δ_1 and δ_2 are set to 0.5. The downgrade process for the delayed trucks relied on a parameter Δ set to 30 min.

Phase 3 run 10min before starting each time slot at the gate or unloading dock.

The results of the 3-Phase method were compared against the currently used First-In-First-Out (FIFO) procedure in terms of the final daily reception extra-cost and other key temporal indicators retrieved from the daily delivery schedules. The FIFO procedure sequenced the trucks according to their real arrival time at the service gate. This procedure did not acknowledge

Table 3: Description of the scenarios "what-if"

	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7
N. docks at the lines	3	3	3	3	**4**	3	3	**0**
N. Time Slots at the gate	119	**168**	119	119	119	119	119	119
N. Time Slots at the lines	168	168	168	**252**	224	168	168	**0**
N. Time Slots at the stockyard	221	221	**327**	221	221	221	221	221
Total N. deliveries	120	168	120	120	120	240	120	120
% unplanned deliveries	40	40	40	40	40	**70**	40	40
% arrivals at rush hours	40	40	40	40	40	40	**65**	40

the planning phase that tackled the expected daily deliveries, therefore all the arrivals were unplanned. The truck segmentation was not performed nor the direct unload at the production lines. Moreover, the FIFO procedure did not used time slot discretization at the gate nor at the unloading docks. Both the real entrance time (E_v^{real}) and the real unloading time for the truck (U_v^{real}) were computed as the maximum between its arrival time and the time when the operation ended on the previous truck (12 and 13).

$$E_v^{real} = max\left\{A_v^{real};(E_{v-1}^{real}+L^G)\right\} \qquad (12)$$
$$U_v^{real} = max\left\{(E_v^{real}+t_d);(U_{v-1}^{real}+L^Y)\right\} \qquad (13)$$

Finally, a trade-off analysis assessed the adequacy of the 3-phase method to support decision-making in respect to the design of the reception processes. For this purpose, the 3-phase method was applied to solve 7 "what-if" scenarios, generated under the same conditions of the main problem instance (called the baseline scenario (C_0)) but with alternative values for one of the key problem parameters (table 3). C_1 reduced the time slots at the gates from 7 to 5 min and increased the number of trucks arriving at the gate from 120 to 168. C_2 and C_3 decreased time slots at the stockyard and at the lines from 15 to 10 min, respectively. C_4 considered one additional production line processing the assortment type B, increasing the number of time slots at the production lines to 252. C_5 changed the proportion of unplanned arrivals from 40% to 70% and increased the total number of deliveries from 120 to 240. C_6 only affected the proportion of the trucks arriving at the rush hours, that rose to 65%. C_7 ignored the possibility of direct unloading at the lines, therefore only acknowledging the time slots at the 3 active storage cells at the stockyard.

WDS: Wood Delivery System

Both solution approaches were implemented in the Wood Delivery System. This prototype of a decision support system was built with a modular architecture, including the data management module that accesses the data files built during case simulation and enables the scenario parametrization; the optimization module that runs the selected solution method, and the reporting module that presents the results into text files and graphical user interfaces. The interface with the daily reception schedules was designed to fit the needs of the receptionist at the service gate. It displays the sequence of trucks entering the gate as well as their expected unloading time and dock resultant from phase 3. Yet, the same interface may display the schedules for the planned deliveries that is the outcome of after phase 1 (Figure 4). All the modules were coded in VB.NET using a Visual Studio 2008 environment.

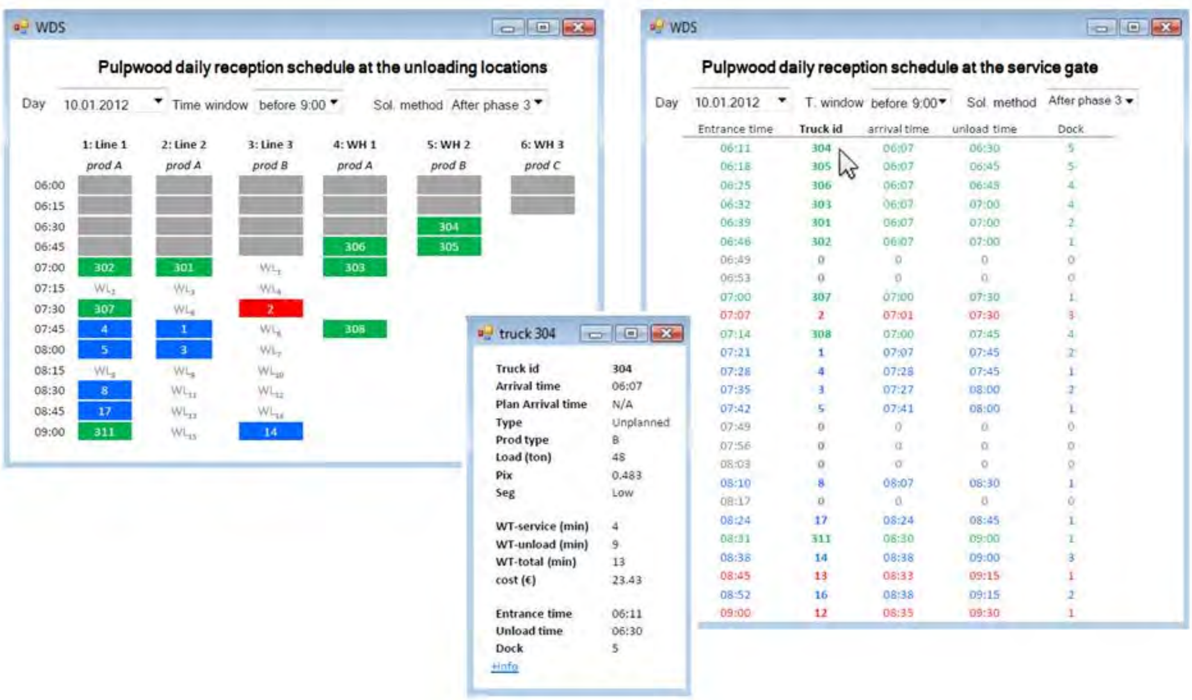

Figure 4: Pulpwood reception schedules for the first time window of the day at the service gate and at the unloading locations. Results obtained for the baseline scenario at the end of the 3-phase method

5 Results

All runs were conducted within a Microsoft Windows operating system in a 2.8 GHz and 2 Gb Pentium D desktop PC. The average performance of the 3-phase method was 12 sec, while the FIFO procedure displayed results in less than 1 sec. The higher running time for the 3-phase method was due to the optimal solution of the assignment problem during phase 1. This problem was solved with the COIN-OR CBC solver [4], using as input the mps file format with the problem instance, generated with GNU GLPK v4.34 for windows [3]. For the baseline scenario, this problem encompasses 28008 decision variables and 462 constraints. The number of decision variables was reduced by considering only the feasible combinations of deliveries and time slots at the unloading docks. This pair is feasible if the product assortment transported by the truck matches the product accepted at the line and if the truck unloading operation can start at the beginning of the time slot (i.e. $A_v^{plan} + L^s + t_d \leq S^s, \forall s \in S$).

Table 4: Results of the baseline scenario after phase 1 and phase 3 with the 3-Phase solution method and FIFO

	Phase 1	**Phase 3**	**FIFO**
Cost indicators in Euro			
Total daily reception extra-cost	413.2	2670.5	6023.4
Cost of the trucks waiting inside the mill	335.9	2409.4	4706.0
Cost of materials handling at the stockyard	77.4	261.1	1317.4
Temporal indicators in minutes			
Sum waiting time during service stage	0.0	2986.9	2694.9
Sum waiting time during delivery stage	588.0	1206.0	6084.9
Maximum waiting time for any delivery	28.0	162.0	190.1
Average waiting time for any delivery	8.2	34.9	73.2
Time slot occupation indicators			
N. deliveries after hours	1	12	10
% of Occupation of the slots at the gate	60.5	90.8	–
% of Occupation of the slots at the lines	36.3	47.6	–
% of Occupation of the slots at the stockyard	4.8	12.7	–

The results of applying the 3-phase solution to the baseline scenario (C_0) showed that the daily reception extra-cost for the universe of the 120 deliveries summed 2670.5Euro at the end of phase 3 (Table 4). 90.2% of this value related to the extra-cost of having the trucks stationary inside the mill, waiting to complete the delivery process. While the remaining 9.8% related to the material handling extra-cost of the 40 deliveries unloaded at the storage cells in the stockyard.

As expected, the daily reception extra-cost after phase 1 was significantly lower than in phase 3 (413.2Euro against 2670.5Euro), as it only took into account the sub-set of the 72 expected daily deliveries. The low value of the material handling cost in phase 1 (77.4Euro) was also a consequence of the optimal solution of the assignment problem [P1] that foresee the preferential assignment of 61 deliveries directly to the production lines (18 for line 1, 19 for line 2 and 24 for line 3).

The 3-phase method led to a 55% reduction of the daily reception extra-cost, when compared with the FIFO procedure used today (2670.5Euro against 6023.4Euro). This was a direct consequence of both the reduction of the waiting time during the delivery stage (from 6084.9min to 1206.0min) and the reduction of the materials handling cost associated to the possibility of having the trucks unloading directly at the production lines.

The analysis of the key temporal indicators was instrumental for assessing the quality of the resulting raw materials delivery schedules. The total waiting time correspondent to the planned schedules (after phase 1) summed 588.0min. The wait was exclusively related with the delivery stage, since the procedure spread the arrivals across the time slots at the gate in order to avoid congestion and queuing.

The delivery schedules obtained at the end of phase 3 had a total waiting time 52% lower than FIFO (Table 4). As expected, 3-phase method led to significant reductions on the total waiting time during the delivery stage (1206.0min against 6084.9min). Yet, FIFO performed better during the service stage (2694.9min against 2986.9min). This was due to the fact that FIFO did not rely on time slot discretization, therefore the arrival truck could be directly received if no other truck was first in line, without having to wait for the beginning of a time slot.

Consequently, the number of trucks received after the gate normal closing hours (21hr) with the FIFO procedure is also slightly inferior than with the 3-Phase method (12 against 10 respectively). The trucks arriving after hours or waiting in the queue after the lines closing hours were unloaded at the stockyard where all the cells could work overtime. The last reception scheduled with the 3-Phase method took place at 22hr38min, and unloading occurred 17min afterwards. The impact of the overtime work at the gate and stockyard represented an extra cost of 39.8Euro.

The biggest positive effect of the 3-Phase method was reducing the average waiting time for any delivery. In fact, after running phase 3, the trucks waited in average 34.9 min to complete the reception process. While in the FIFO procedure used today, the same trucks would wait an average of 73.2 min. The proposed method increased the number of trucks with total waiting inferior to 20 min from 17.5% to 53% (Figure 5).

The reduction of the waiting time to complete the delivery process was more pronounced when considering the on-time and the higher priority deliveries. With the 3-Phase method, the planned deliveries arriving on-time waited in average 9 minutes independently from their priority segment (Figure 7); while trucks in high as medium segments arriving with delay waited in average less than 20min. In these cases the waiting time ranged from 8 to 38 min and 0 to 54min, respectively. This range of variation was strongly affected by the small proportion of trucks classified as high priority (3.3% against 42.5% classified as medium), as well as the fact that all of them happen to arrive later than their planned arrival time.

Moreover, the goal of completing the entire reception process in less than 45min was achieved with the 3-Phase method for all the on-time arrivals, the high segments and some of the medium priority deliveries. These trucks had the total waiting time inferior to 13min. The minimum duration for the delivery process until unloading was 32min, corresponding to 7min for the service stage, 10min on transit inside the min, 15min to unload.

Still with the proposed method, the delayed low and very low segments waited in average 63min, but the wait could go up to 162 min. Yet, the maximum waiting time stood close to the the threshold of 160 min aimed by the mill and was lower that the maximum of 190.1 min recorded with the FIFO procedure.

The results further showed the level of time slots occupation during the delivery day. After phase 3, 90.8% of the total number of time slots at the service gate were assigned to one truck. Therefore, the gate was working almost at its full capacity for the given slot length of 7 min. The level of occupation of the time slots at the lines was 36.3% after phase 1 and 47.6% after phase 3. These were significantly lower than the equivalent indicators at the stockyard (4.8% and 12.7% respectively). As expected, the level of occupation of the slots at the lines after phase 1 stood below the minimum limit of 10% previously set by the constraint D in problem

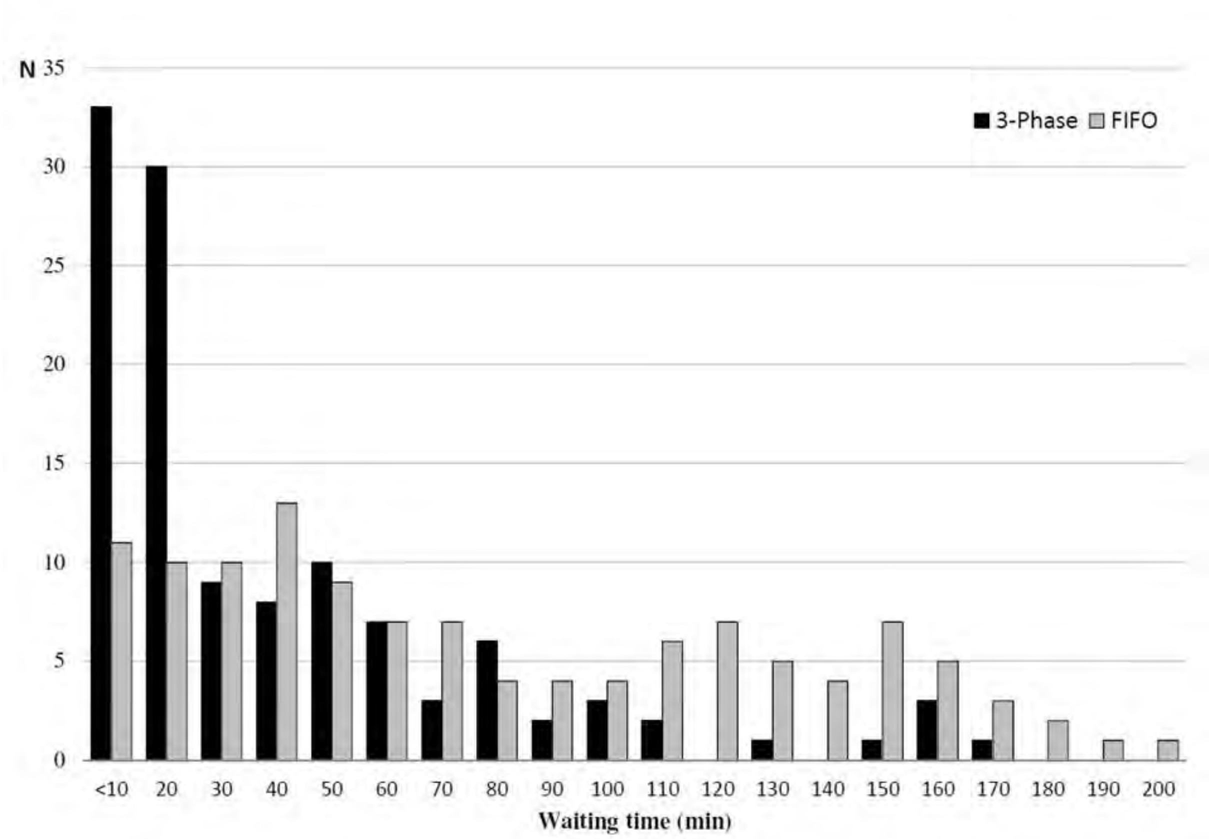

Figure 5: Histogram of the waiting time to complete the reception process for the 120 deliveries, obtained at the end of the 3-Phase method and FIFO

[P]. The low level of occupation of the time slots at the lines obtained after phase 3 led to the need of about 83 requests for internal freights from the stockyard to the lines. These requests corresponded to a minimum of 2318ton of pulpwood consumption. It represented the minimum level of stock reposition to be considered in phase 1 for the next delivery days.

Another important positive effect of the 3-Phase method was the stabilization of the queue particularly at the delivery stage (Figure 6). There was an average of 1 truck waiting in the queue to unload. Contrarily, the FIFO procedure led to large fluctuations in the average queue size at the stockyard. The large number of trucks waiting to unload were recorded after lunch time ([9,11[, [11,13[), and at the end of the day ([19,21[, 8.6 trucks).

The evolution of the service queue resembled this previous behavior. Yet, the number of trucks is queue with FIFO was slightly better than with the 3-Phase method (maximum of 6.9 and 6.4, recorded for the period [19,21[).

Consequently, these rush hours recorded also the highest values for the maximum waiting time for any truck both with the 3-Phase method and with FIFO ([11,13hr[, 162min and 141min, respectively; [19, 21hr[, 82.8min and 190.1min, respectively).

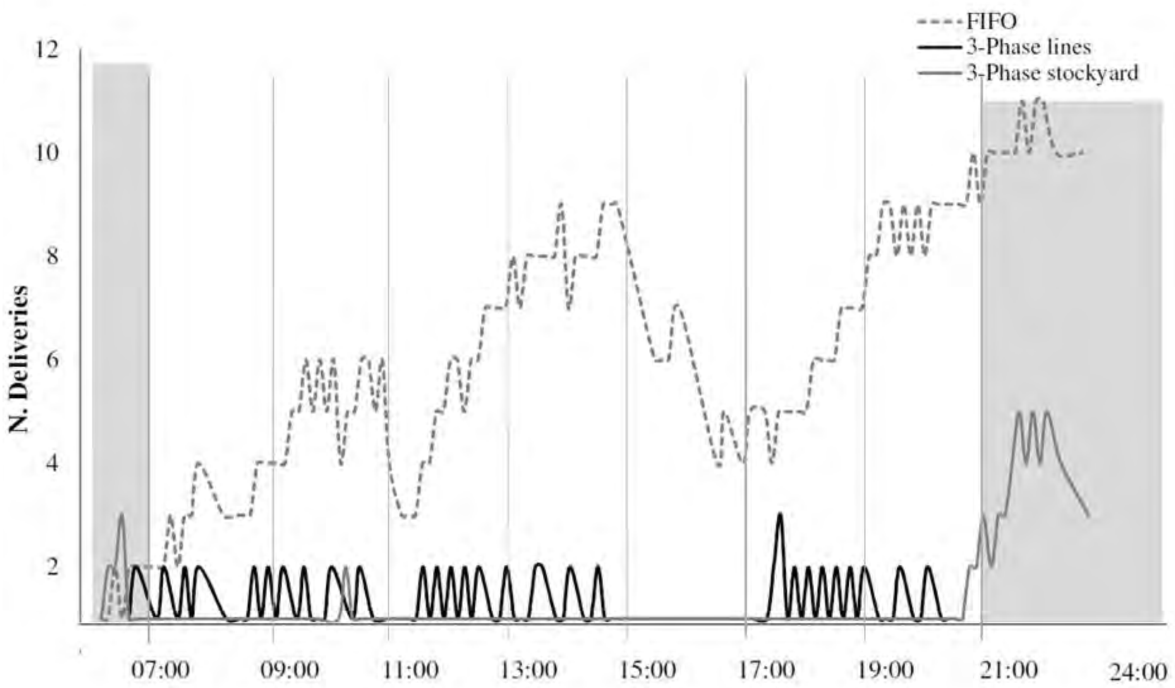

Figure 6: Evolution of the queue size at the delivery stage during the delivery day, with the 3-Phase method and with FIFO

Table 5: Results for the scenarios obtained with the 3-Phase solution method

	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Daily reception extra-cost (Euro)	2670.5	3425.8	2406.1	2542.4	2615.2	13139.6	4566.5	6805.4
N. deliveries after hours	12	14	11	11	12	140	19	17
Sum waiting time-service (min)	2986.9	3474.3	2986.9	2986.9	2986.9	22825.4	6454.0	2976.3
Sum waiting time-delivery (min)	1206.0	1500.0	521.0	851.0	1206.0	2191.0	1607.0	7414.0
Max waiting time for any truck (min)	162.0	209.0	199.4	161.0	162.0	636.0	317.0	1153.0
Avg waiting time for any truck (min)	34.9	31.9	29.2	24.9	34.9	169.1	67.7	96.2
% Occup. slots at gate	90.8	91.7	91.6	91.6	90.8	84.0	84.9	86.6
% Occup. slots at lines	47.6	70.8	28.6	34.5	37.9	42.9	45.2	0.0
% Occup. slots at stockyard	12.7	15.8	18.7	10.0	10.4	12.7	11.3	46.6

Trade-off analysis

The 3-Phase method was successfully applied to solve several "what-if" scenarios, proving valuable information to support decision-making in respect to the design of the reception process. The scenario that led to worse results in terms of the daily reception extra-cost was related with increasing the total number of daily deliveries to 240 (C_5). In this case, the extra-cost increased up to 400%, due to the increase of the waiting time, particularly at the service queue. In fact, the total waiting time summed 25016.4 min, more than 80% of the time is spent on the service queue.

The scenarios where the direct unloading at the lines was abolished (C_7) and the number trucks arriving at rush hours was increased (C_6) also led to higher extra-costs (Table 5).

Conversely, the reduction of the length of the time slots at the unloading docks (C_2 and C_3) as well as one additional production line processing product type B (C_4)led to improvements of less than 10% in the reception extra-costs. In particular, C_2 recorded the best value of the objective function as a consequence of reducing the waiting time at the delivery stage (from 1206min to 521min). Yet, the reduction from 80 to 48 in the number of freights directly unloaded at the lines, impacting negatively on the level of occupation of the time slots at the lines (37.9%) ultimatly leading to an increase of the raw materials handling cost.

Both C_3 and C_4 increased the total number of time slots at the lines, therefore increasing the number of trucks unloading directly at the production lines. Yet, these scenarios also required additional freights from the stockyard to assure the complete supply of the new time slots. It ultimately may led to a bigger fleet of trucks devoted to moving the raw materials from the stockyard to the lines. The cost of maintaining these fleet was not acknowledged.

The analysis of the scenarios C_5 and C_6 revealed that the maximum reception capacity at the baseline conditions was 100 to 140 daily deliveries. Above this threshold, some of the trucks were received after the gate normal opening hours, therefore with additional costs for overtime work. Furthermore, when the number of deliveries rose above 150, the reception of the last arriving trucks was delayed to the next working day.

The comparison among what-if scenarios further confirmed the best performance of the 3-Phase method for the priority trucks (Figure 7). In fact, the range of variation of the truck waiting time had slight variations across the scenarios in case of high and the medium priority trucks had slight variations across the scenarios; and were always below the values obtained with the FIFO procedure. These indicators had larger fluctuations in the case of the low and very low priority trucks. Yet, even in some scenarios (S_1, S_2, S_3, S_4, S_6) stood below the values obtained with FIFO. The maximum waiting time could rose above 420min in very low segments, particularly in the scenarios with an higher number of daily deliveries, where the congestion at the delivery stage delayed unloading for non-priority segments.

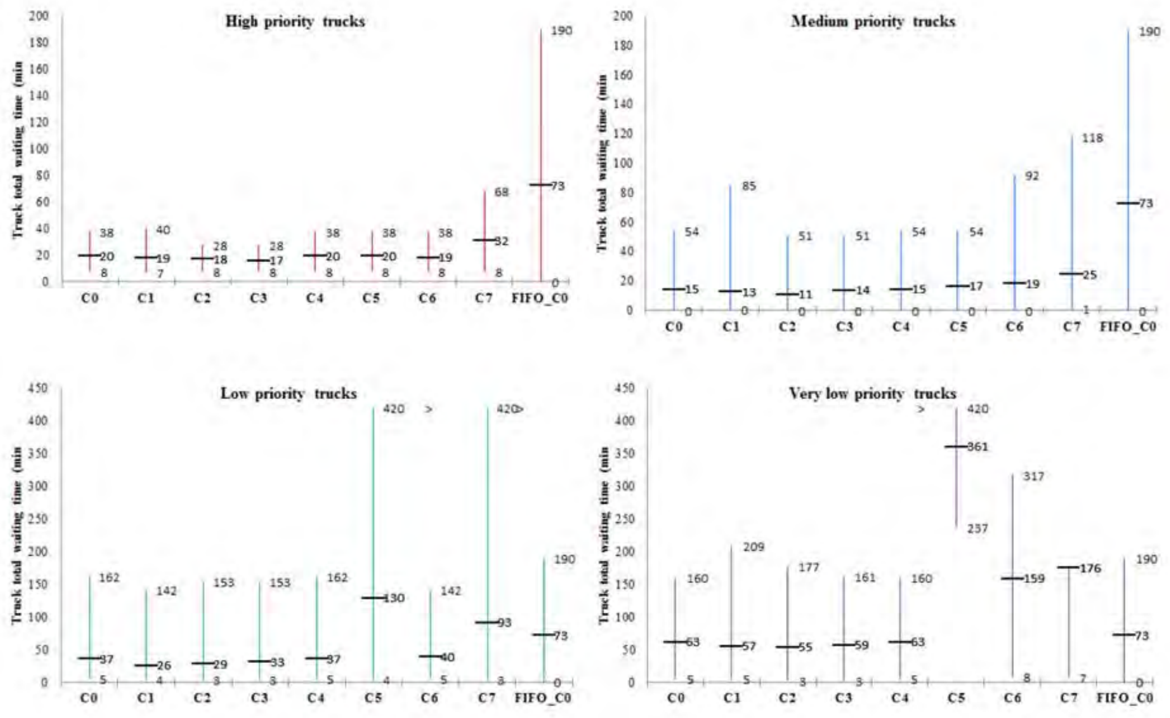

Figure 7: Comparison among the what-if scenarios of the maximum, minimum and average waiting time for a truck to complete the wood reception process, using the 3-Phase method

6 Discussion

The proposed solution approach was applied to a Portuguese pulp mill but the raw material reception problem is general. It may be applied to the reception process of other agricultural products like milk, fruit and livestock that other need to be delivered at the agro-industrial mill as soon as possible. It may further be applied to other business areas outside the management of natural resources, wherever the minimization of the waiting time before unloading is of interest and there are multiple unloading docks for the freight inside the mill.

In general terms, proposed approach for the RMRP may improve the efficiency of the raw materials supply chains, benefiting both the carriers and the mills. In particular, the expected benefits for the carriers relate with the possibility of reducing the fleet size, avoiding the drivers overtime work and increasing the drivers satisfaction. Another positive effect is encouraging the drivers to follow plans enabling optimization planning approaches. The carrier may plan in advance the fleet daily routes, assuring the compliance with the reserved time slots provided by phase 1 - Time Slot Planning, with the possibility to include delivery requests from other clients for the same day.

The expected benefits for the mill are directly related with the possibility of unloading the direct trucks directly at the production lines. This possibility decreases the material handling cost, reduces the staff and equipment required for the delivery process and avoids overtime work at the service gate. This may further lead to improvements of the mill layout as a consequence of less space needed for parking the trucks and smaller stockyards. Moreover, the WDS prototype will enhance the design of the reception process and further benefit the scheduling of the stockyard equipment.

When applying the proposed solution approach, special attention should be given to the length of the time slots at the service gate and at the unloading docks. Equally sized slots, with the length of the average duration of service/unloading operations, may not be adequate due to variations in the freight weight and in the efficiency of the unloading equipment. Smaller time slots may be preferred and the input data should state the number of time slots to be used for each delivery. Yet, managing the overlap among deliveries increases significantly the complexity of the solution method. Alternatively, larger time slots may be used, supplanting the rule of "1 truck/15min" by for instance "3 trucks/15 min". This increases the flexibility of the assignment process and may enable a certain level of over-booking enabled during phase 1, yet it also increases the complexity of the following phases of the 3-Phase method.

The main problem parameters should be adequate to the problem in-hand and deeply discussed with the business experts. In particular, α, Δ, β and the number of Number of segments considered for trucks classification should be set by the user. The companies often have on-going suppliers classification processes. Therefore efforts should be done in order to make them compatible with the carriers/trucks segmentation strategy used in the solution method. For this purpose, alternative carriers/trucks evaluation criteria and segmentation strategies may be used, like ABC analysis (e.g. [8]) based on the frequency of deliveries and service quality indicators of the carriers. Moreover, there may be some business rules that impact of the cost function used in the solution method. There may be some deliveries that are obliged to go to certain unloading docks, therefore should have very high costs for the remaining locations. This is the case of pulpwood needing to dry under open air conditions at the stockyard before going to the production lines.

It is noteworthy that the communication issues may be key to the success application of the proposed solution approach in real-world situations. The planned delivery schedules, the priority index and the report of the waiting time in each delivery service should be provided to the carriers in a credible and transparent way. Consequently, leading to IT investments in new on-line communication platforms. The advantages of minimum waiting time for on-time arrivals and the consequences of the delays may lead to new transportation contracts. Therefore, the number and selection of the carriers involved in phase 1 - Time Slot Reservation are key decisions undertaken by the mill.

7 Conclusion remarks

This paper introduces the novel Raw Materials Reception Problem (RMRP). The problem consists in sequencing the trucks arriving at the transformation mill and establishing its best unloading dock in order to avoid queuing, while assuring the continuous supply of the production lines. The problem statement on the real-world process of delivering pulpwood at a Portuguese pulp mill, but the problem is general. Other application areas may include the delivery of agricultural and livestock products to agro-industries.

The characteristics of the problem foster the development of a solution method based on application of Revenue Management (RM) principles. The proposed 3-Phase method is one of the first applications of RM to support natural resources management planning, extending the recent work of [1] in the lumber industry. The 3-Phase method relies in carriers/trucks segmentation and booking list computation for dynamically assigning the arriving deliveries to the time slots available at the unloading docks. Alternative techniques inspired on Queuing Theory were not considered for the RMRP, because the emphasis is on managing and controlling the raw materials inflows across the reception process, therefore the aspects related with designing and sizing the trucks queues are not of importance.

The proposed approach reduced the queuing effects and led to a 55% reduction on the daily reception extra-cost for one delivery day at the Portuguese pulp mill, when compared with the FIFO procedure used today. Both the total waiting time to complete the reception process and the materials handling cost were reduced. This method further accomplished the reduction of the waiting time for both the planned deliveries arriving on-time and the trucks on higher segments.

Finally, the implementation of this solution approach in the Wood Delivery System prototype enabled the generation of several "what-if" scenarios, those comparative analysis provided valuable information to design ad plan the reception process under both the carrier's and the mill's perspectives.

Acknowledgments

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References

[1] RC. Azevedo, S. D'Amours, and M. Ronnqvist. Profit-diven order promising âĂŞ an application with a canadian softwood lumber manufacturer. Technical report, FORAC, 2011.

[2] J. Goncalves. Custeio de camiÃţes de transporte de madeira. Technical report, 2003.

[3] F. Margot. Gnu linear programming kit, reference manual, version 4.34, http://www.gnu.org/software/glpk/. Technical report, GNU, 2008.

[4] F. Margot. First steps with coin-or, http://www.coin-or.org/cbc. Technical report, Coin-or, 2012.

[5] AF. Marques, M. Ronnqvist, and JG. Borges. Wood trucks operational transportation planning. Technical report, Forest Research Center, 2011.

[6] RL. Philips. *Pricing and Revenue Management*. Stanford University Press, 2005.

[7] R. Quante, H. Meyr, and H. Fleischmann. Revenue management and demand fulfillment: Matching applications, models, and software. *OR Spectrum*, page to be pusblished, 2008.

[8] R. Ramanathan. Abc inventory classification with multiple-criteria using weighted linear optimization. *Computers & Operations Research*, 33 (2006):695âĂŞ700, 2006.

[9] KT. Talluri and G. van Ryzing. *The theory and practice of Revenue Management*. Springer. New York, 2005.

[10] A. Weintraub, R. Epstein, R. Marales, J. Seron, and P. Traverso. A truck scheduling system improves efficiency in the forest industries. *Interfaces*, 26(4):1–12, 1996.