UNIVERSIDADE TÉCNICA DE LISBOA

INSTITUTO SUPERIOR DE AGRONOMIA

NEW DECISION SUPPORT TOOLS FOR
FOREST TACTICAL AND OPERATIONAL PLANNING

TESE APRESENTADA PARA OBTENÇÃO DO GRAU DE DOUTOR

EM ENGENHARIA FLORESTAL E DOS RECURSOS NATURAIS

ORIENTADOR: Doutor José Guilherme Martins Dias Calvão Borges
CO-ORIENTADOR: Doutor Pedro Manuel Moreira Vaz Antunes de Sousa
JÚRI:
Presidente: Doutora Maria Margarida Branco de Brito Tavares Tomé

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Resumo

A importância económica dos recursos florestais e das indústrias florestais em Portugal motivou vários estudos nos últimos 15 anos particularmente sobre planeamento florestal estratégico.

Esta tese foca o planeamento florestal ao nível táctico e operacional (PPFTO). Aborda os problemas de corte, transporte, armazenamento e entrega dos recursos florestais nas fábricas. Foram desenvolvidos novos métodos de Investigação Operacional e Sistemas de Apoio à Decisão (SAD) para alguns destes problemas existentes em Portugal.

Em concreto, o Estudo I integrou decisões de médio-prazo sobre o escalonamento do corte, classificação e afectação da madeira. O método de solução baseou-se na decomposição do problema e combinou heurísticas com algoritmos de programação matemática.

O Estudo II apresentou uma solução baseada em *Revenue Management* para o Problema de Recepção de Matérias Primas. Este problema operacional evitou o congestionamento de camiões para descarga nas fábricas.

O Estudo III utilizou a metodologia de Arquitectura Empresarial para especificar o SAD que integra as operações realizadas ao longo da cadeia de abastecimento de madeira.

O Estudo IV testou a mesma metodologia numa *toolbox* capaz de abordar a complexidade das interacções entre os agentes envolvidos no planeamento florestal regional.

O Estudo V propôs uma *framework* tecnológica que combina o planeamento florestal com o controlo de operações.

Palavras-chave: Gestão florestal, Cadeia de Abastecimento florestal, Planeamento Operacional, Planeamento Táctico, Optimização, Heurísticas, Sistemas de Apoio à Decisão, Arquitectura Empresarial

New Decision Support Tools for Forest Tactical and Operational Planning

Abstract

The economic importance of the forest resources and the Portuguese forest-based industries motivated several studies over the last 15 years, particularly on strategic forest planning.

This thesis focuses on the forest planning processes at tactical and operational level (FTOP). These problems relate to harvesting, transportation, storing, and delivering the forest products to the mills. Innovative Operation Research methods and Decision Support Systems (DSS) were developed to address some of these problems that are prevalent in Portugal.

Specifically, Study I integrates harvest scheduling, pulpwood assortment, and assignment decisions at tactical level. The solution method was based in problem decomposition, combining heuristics and mathematical programming algorithms.

Study II presents a solution approach based on Revenue Management principles for the reception of Raw Materials. This operational problem avoids truck congestion during the operation of pulpwood delivery.

Study III uses Enterprise Architecture to design a DSS for integrating the operations performed over the pulpwood supply chain. Study IV tests this approach on a toolbox that handled the complexity of the interactions among the agents engaged on forest planning at regional level.

Study V proposes an innovative technological framework that combines forest planning with forest operations' control.

Keywords: Forest management, Forest supply chain, Tactical Planning, Operational Planning, Optimization, Heuristics, Decision Support Systems, Enterprise Architecture

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List of articles

I.   Marques AF, Borges JG, Sousa P, Gonçalves L, Diaz E. 2012. **Integrating harvest scheduling and timber assortment and assignment planning processes. An application to forest tactical planning by a pulpwood company in Portugal.** Manuscript to be submitted to Forest Science

II.   Marques AF, Ronnqvist M, D'Amours S, Weintraub, A. and Gonçalves J, Borges JG, Flisberg P. 2012. **Solving the Raw Materials Reception Problem using Revenue Management principles: an application to a Portuguese pulp mill.** Manuscript to be submitted to the European Journal of Operational Research

III.   Marques AF, Borges JG, Sousa P and Pinho A, 2010. **An enterprise architecture approach to forest management support systems design. An application to pulpwood supply management in Portugal**. European Journal of Forest Research130 (6): 935-948

IV.   Marques AF, Borges JG, Pina JP, Lucas B, Garcia J. 2012. **A participatory approach to design a regional forest management planning decision support toolbox.** Manuscript submitted to European Journal of Forest Research

V.   Marques AF, Borges JG, Sousa P, Fonseca M, Garcia R, Batista G. 2010. **Applying enterprise architecture to the design of the integrated forest products supply chain management system.** In: Varajão, Cunha M. (Eds.) ENTERprise Information Systems, Part II, International Conference CENTERIS 2010 Proceedings, CCIS 110, Springer-Verlag Berlin Heidelberg 2010, pp. 32-40

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1. Introduction

Forest resources are produced, exploited and progressively transformed across the forest-based supply chains that provide the finished products to the customers. The significant impact of the forest operations over the cost of the raw materials delivered at the mills gate is well acknowledged. Operational research methods (OR) and decision support systems (DSS) have been successfully developed in Portugal over the last 15 years, especially for strategic forest planning. Yet, little attention was given to the medium and short term forest planning processes.

This thesis focuses on the types of decisions addressed by the forest tactical and operational planning problems (FTOPP). These problems relate to harvesting, transportation, storing and delivering the forest resources to the mills for primary transformation. Yet, it also acknowledges their relation with strategic planning problems as well as the impact of these forest operations over the remaining supply chain activities conducted for producing, distributing and selling the products to the customers.

The thesis further analyses the computerized tools based on OR and DSS that have been developed to support these medium to short term forestry decisions.

This research was built upon a comprehensive literature review of the OR methods and DSS currently used to support FTOPP. The review encompassed 90 peer-reviewed articles on 30 scientific journals, books sections, extended abstracts on conference proceedings and working papers published mainly over the last 2 decades (1990-2012). Previous surveys on the contribution of OR to the forestry sector by Ronnqvist (2003), Epstein et al. (1999), Weintraub et al. (2000), Carlsson et al (2006), Weintraub and Romero (2006) and D'Amours et al. (2008) were also considered. It further relied on the results of the Portuguese Country report (Marques et al s/d) conducted on the framework of the FORSYS COST-Action. This report was produced from a series of workshops with stakeholders of the Portuguese forestry sector. It also acknowledged the 24 replies to a specific questionnaire on computerized-tools developed in Portugal.

Innovative research work was conducted to address some of the main open questions brought to light by the previous reviews. The forestry experts collaborating with this research were asked to rank the FTOPP reported on the literature in order to select those approached.

Accordingly, study I presented the integrated forest tactical planning problem (study I). The problem components include harvest scheduling and pulpwood assortment and assignment over a procurement network encompassing stands, intermediate storage yards and pulp and bio-energy plants. The proposed solution approach relies on problem decomposition and combines the use of heuristic and mathematical programming algorithms to solve its MIP formulation. The master harvest

scheduling problem is solved using simulated annealing. Each iteration of this meta-heuristic, encompasses a 2-Opt solution procedure for the integer harvest scheduling sub-problem and either a newly developed greedy Admissible Flow Solution Heuristic (AFSH) or a linear programming solution for the product assortment and assignment. Results from its application to a problem encompassing twelve 1-month temporal horizon, 4 pulp mills, 1 bio-energy plant, 3 intermediate storage yards, 6 product assortments and a forest area with 700 eucalypt stands extending over 4888 ha in South-Central Portugal were discussed.

Study II introduced the novel Raw Materials Reception Problem (RMRP) and presented an innovative solution approach anchored on Revenue Management principles. The solution builds on segmenting carriers/trucks and its real-time 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 warehouses, therefore leading to a reduction of the material handling cost. Results from its application to a case study case study encompassing 120 wood daily deliveries on 6 possible docking stations inside the mill were presented.

Studies III to V focused on the design of DSS that could cope with the complexity of the forest tactical and operational planning processes. Accordingly, Study III applied the Enterprise Architecture approach into the design of the DSS for integrating the operations performed over the pulpwood supply chain. This methodology further proved to be adequate to foster the involvement of end-users into the DSS development.

Study IV tested the same methodology into the design of a toolbox to approach the complexity of the network of interactions among the agents engaged on forest planning at regional level. Accordingly, the proposed regional toolbox addressed distinct stakeholders' interests and decision processes as well as supported communication, cooperation, negotiation and information sharing, facilitating the regional interactions network.

Study V reported the results of applying Enterprise Architecture approach to the design of the Forest Products Supply Chain Management System. Emphasis was also on the common procedures and automatic data exchange mechanisms that may foster collaboration among the agents of the supply chain. The proposed solution further included a technological framework aiming to combine forest planning and operations control.

These studies were conducted within the framework of consultancy projects (study III) or research projects (studies I, II, IV and V). Study I was the outcome of the SADPOF project (Sistemas de Apoio à Decisão em Planeamento Operacional Florestal) supported by the QREN national funds. Studies II and V resulted from the CAMTEC project (Novas tecnologias ao serviço da gestão da cadeia de abastecimento de produtos florestais), also with the financial support of national funds. Study II add

the additional support of the FORSYS COST-Action (Forest Management Decision Support Systems) and the ForAdapt project (Knowledge exchange between Europe and America on forest growth models and optimisation for adaptive forestry) under the Marie Curie International Research Staff Exchange Scheme Fellowship within the 7th European Community Framework Programme. Study IV reported partial results of the Motive project (Models for Adaptive Forest Management) also supported by the European Commission under the 7th Framework Programme for Research and Technological Development.

The thesis starts by framing the FTOPP under the context of the Portuguese forestry sector. Section 2 identifies the forest operations and places them into the pipeline of activities considered on the supply chains of the main Portuguese forest resources. Then, the scope of tactical and operational planning is defined, taking into account the hierarchical planning approach often used in forestry (Weintraub and Cholaky 1991, Church et al 1998). The main FTOPP are identified. A brief overview of computerized-tools is presented. The nature of the decisions and the computerized tools available to address them are deeply discussed. The results of the Portuguese country report bring light to the status of FTOPP in Portugal. Section 3 focuses on the synthesis of the OR models and methods developed on studies I and II. It also describes the Enterprise Architecture approach adapted for the specificities of the FTOPP. Section 4 reports the main findings of all the studies. Yet, the readers interested on the detailed results are directed to the full papers presented at the end of the thesis. The last section presents the main conclusions and outlines research challenges under this domain.

2. Review of computerized tools to address forest tactical and operational planning problems

2.1. Forest operations in the context of the Portuguese forest-based supply chains

The forest resources and the forestry industries are key economical elements of the Portuguese specialization pattern (Borges 1997). In recent years, the forest sector has contributed in average to 4% of the annual GNP – one of the largest relative contribution in the EU -, 10% of exports and 9% of the industrial employment (INE 2009). The forest area extends over 3.5 x 10^6 ha corresponding to over one third of the country's territory.

Forest resources are produced, exploited and progressively transformed across the forest-based supply chains that deliver intermediate or finished products to the customers (Figure 1). The forest operations relate to harvesting, transportation, storing and delivering these raw materials to the transformation centers. These activities constitute the procurement network that is commonly placed at the beginning of the supply chain.

There are similarities on the forest operations performed for exploiting the main Portuguese forest resources. The Portuguese forestry production relies mainly in timber and cork. Both account for 41% and 29% of the gross economic value of forest products (GEVFP). The Portuguese timber growing stock is mainly provided by the maritime pine (*Pinus pinaster* Ait.) and the eucalypt stands (*Eucalyptus globulus* Labill). Together, these plantations extend over 44% of the forest area, particularly at the northern region. Cork is provided by the cork and holm oak agro-forestry systems (*Quercus suber* and *Quercus ilex*) that extend over about 12% of the forest area, particularly at the southern region. The by-products of the timber exploitation are gaining economic importance due to the recent policies fostering the bio-energy production. Other non-wood marketable products (e.g. pine nuts), hunting and recreation account for 20% of GEVFP.

Yet, distinct production, distribution and sales networks were found on the country's most relevant forest-based industries. The Portuguese pulp and paper industry consumes both maritime pine and eucalypt. The pulp production network encompasses 7 operating units producing 2182x10^3ton of pulp from 6722x10^3m^3 of unbarked woodpulp per year (CELPA, 2008). Most pulp production targets the European market, although about 45% is internally consumed mainly in two vertically integrated paper mills. There are a few dozens of converting mills for paper-based products. Yet, the industry is

highly concentrated into two major economical groups, with self-owned forestland, thus controlling all the supply chain activities, including the products distribution and sales.

Both pine and eucalypt are consumed by the lumber industry. The primary transformation occurs in more than 250 small-scaled sawmills and in 12 panel mills distributed mainly in the center and northern regions. The lumber and panels are then transformed into engineered wood products on more than 4500 small-scaled carpentry and furniture units (AIMMP, 2008). These units typically conduct the products distribution and sale directly to customers.
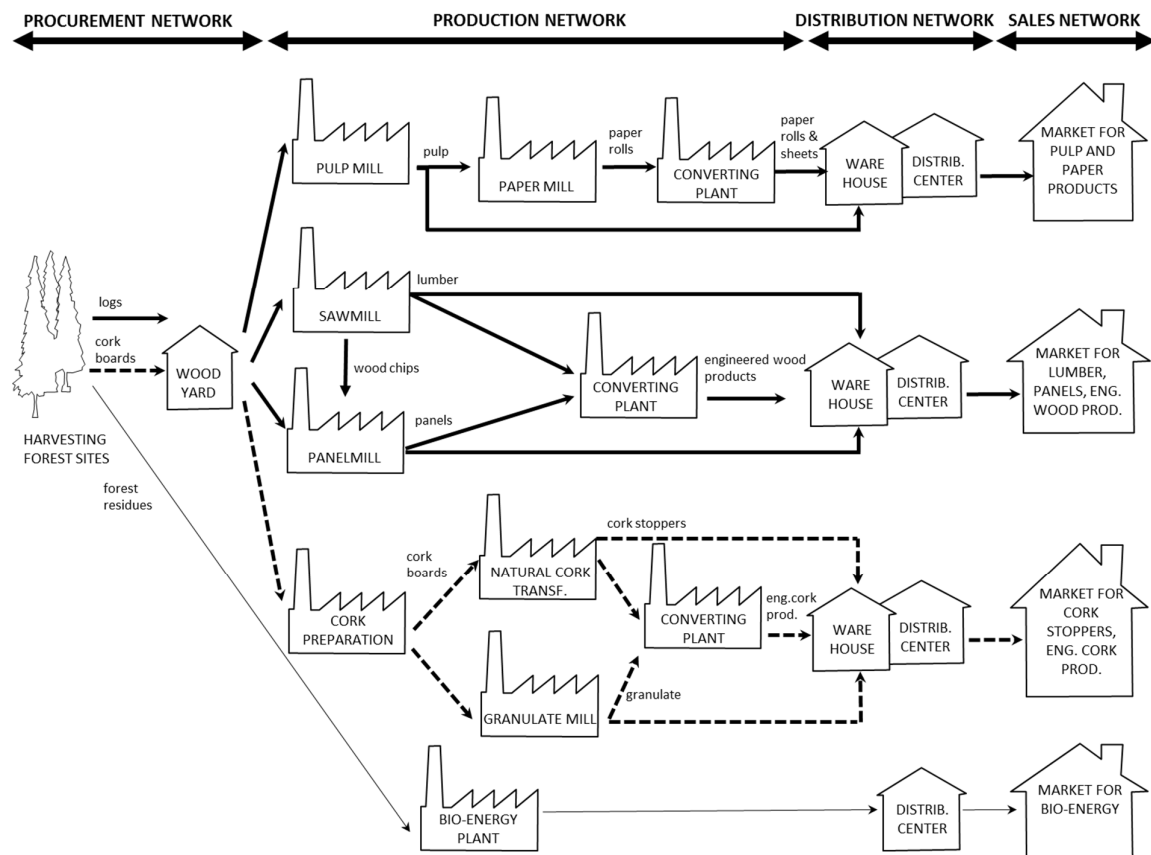
Figure 1 - Timber, cork and forest residues supply-chains

The forest residues resulting from harvest are consumed on the 10 bio-energy plants spread across the country. Together they produce about 133,6MW per year (CELPA, com. pess.). The electricity is currently sold to the national company that distributes and sells it to the final customer.

The natural cork is consumed by the national cork industry. The cork preparation and primary transformation is spread by many small-scaled units concentrated at the southern region. The cork boards are then used mainly for cork stoppers production (Marques 2002). The by-products are converted into granulates, that are used in many cork-based engineered products (e.g. construction materials, shoes, cork-based fabrics) (APCOR 2011). These products are sold in specialized markets directly by the converting units or other local distribution channels.

2.2. Scope of forest tactical and operational planning

Forest planning focus on the decisions undertaken for projecting the forest operations of the procurement network. The impact of forest operations on the following activities of the supply chains is also of importance. The cost of these forest operations may represent 30-50% of the procurement cost related with acquiring the forest resources (Weintraub 1996).

Adequate forest planning can reduce the procurement cost trough the best use of the material and immaterial resources allocated to the forest operations. It may further enhance the ecological and social sustainability of the forest operations. The effect of the procurement cost reduction may spread across the supply-chain, ultimately leading to lower prices of the forest-based products consumed by the final customers. It also may lead to the increase of the price paid to the forest producers, fostering forestry production.

The forestry literature reports a large number of forest problems related with planning the procurement network world-wide. These problems have long been classified according to their temporal dimension. The strategic, tactical and operational categories are commonly accepted in forestry (e.g. D'Amours et al 2008, Church 2007). The strategic problems aim to address broad-scale planning decisions over a long period of time (Gunn 2007). The planning periods (PP) are often years or even decades while the time horizon (TH) used for planning can go up to several decades, depending on the revolution and the composition of the forest stands. The Portuguese pulp industry usually acknowledges yearly PP and TH of 36 years corresponding to 3 consecutive rotations of the eucalypt stands (e.g. Falcão and Borges 2002). The cork industry plans the forest operations conducted on cork agro-forestry systems using 5-years PP. Cork stripping starts at 45 years and may extend up to 145 years (Borges et al 2008).

The tactical planning problems approach mid-term decisions considering monthly to yearly PP and TH of 10 to 30 years. The operational problems relate to the short-term decisions that precede and determine the real-world operations (D'Amours et al 2008). The time frames can go from minutes to hourly PP spread across a TH that can go from few weeks to months.

Early studies used the terms annual or operational planning to refer to tactical (e.g. Murray and Church 1995, Epstein, Nieto et al. 1999, Clements et al. 1990). While operational plan is called project. These terms still persist on the Portuguese forestry industry today.

The hierarchical planning approach often used in forestry (Weintraub and Cholaky 1991, Church et al 1998) recognizes an increasing level of desegregation on the information used/produced from the strategic to the operational plans. Consequently, the strategic decisions become constraints to the shorter term plans (figure 2). Yet, bottom-up relations are also of importance. The execution updates provided by the forest operations control enhances the quantity and the quality of the information used for planning, therefore increases the robustness of the forest planning process.
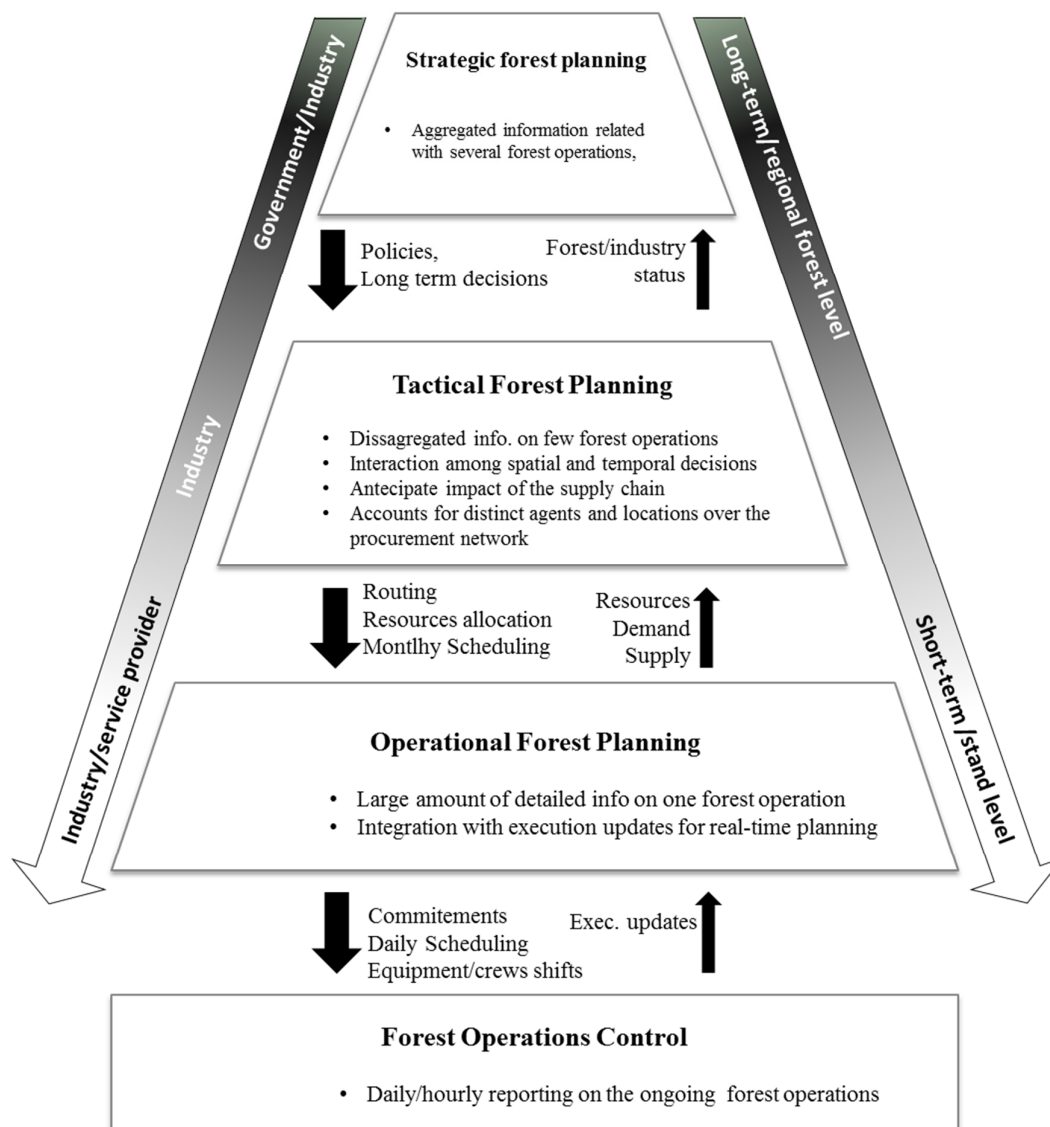

Figure 2 – Forest planning hierarchical approach

Specifically, the strategic plan is produced usually at the national or regional level using aggregated information about the forest resources availability and demand. It foresees the forest and industry policies as well as the long-term decisions on aggregated target forest-based productions and expected execution time frame for the forest operations. These decisions set for the first 1 to 5 years are the input for the tactical plans.

Tactical plans are built upon disaggregated spatial and aspatial information about the material resources available for the forest operations foreseen for each forest region. Tactical planning encompasses both spatial and temporal decisions concerning the scheduling and allocation of the resources to the forest operations. They may further provide adequate routes for transporting the forest resources from the harvesting sites to the storing and transformation facilities. The tactical plans are the input for detailed operational planning.

Operational plans are often conducted separately for each forest operation and/or agent engaged on the forest-based supply chain. Operational planning is highly data-dependent for both alphanumerical and spatial information. It provides the commitments, daily forest operations schedules per location as well as the equipment/crew schedules and shifts that will regulate the operations execution.

Forest Tactical and Operational Planning problems (FTOPP) relate to nuclear decisions undertaken during forest tactical and operational planning processes. These decisions may be clustered into the FTOPP framework (Table 1). This framework takes into account their temporal dimension and the stage of the procurement network where they occur (i.e. Forest Management and Harvesting, Forest resources transportation, Forest resources intermediate storing, Forest resources delivery at the mill). The framework was similarities with the Supply chain planning matrix for the pulp and paper industry presented in Carlsson et al 2006 and D'Amours et al. 2008.

Recently, the community of experts engaged on the FORSYS COST-Action proposed a complementary classification for the forest planning problems based on 6 main problem dimensions (Borges et al 2012). Including the spatial and temporal scales used for planning, the spatial context, number of parties involved, number of management objectives and target goods & services.

Both the literature review and the book by Borges et al. s/d reported that forest tactical and operational planning problems have been seldom addressed world-wide.

Complementary to the international literature review, the Portuguese country report developed under the FORSYS framework (Marques et al 2012) provided a valuable characterization of both the FTOPP prevalent in Portugal and the computerized-tools available to support decision-makers in this domain.

The report identified 18 problem types. Yet, only 6 of them were related with the tactical or operational scales. These problems were discussed based on questionnaires and workshops conducted with a large number of stakeholders. Yet, the large majority of the publications referenced to strategic problems. The only two publications reported for tactical and operational planning related to studies I and IV of the current thesis.

Table 1 – Classification framework for forest tactical and operational problems (adapted from Marques et al s/d)

	Forest Management and Harvesting	Forest resources transportation	Forest resources intermediate storing	Forest resources delivery at the mill
Tactical	[Mt1] Harvest scheduling [Mt2] Harvest service adjudication [Mt3] Equipment/crew allocation [Mt4] Roads network management	[Tt1] Harvest unit assignment/catchment area [Tt2] Wood assortment [Tt3] Transportation adjudication [Tt4] Trucks/drivers allocation [Tt5] Fleet management	[St1] Terminal layout [St2] Wood stock planning [St3] Yard equipment/crew allocation	[Rt1] National & internat. market deliveries planning [Rt2] Wood suppliers adjudication
Operational	[Mo1] Extraction of logs [Mo2] Harvest & transport. Synchronization [Mo3] Bucking & sorting strategies [Mo4] Equipment/crew scheduling	[To1] Truck routing/scheduling	[So2] Terminal reception daily planning [So1] Yard equipment/crew scheduling	[Ro1] Wood reception scheduling

2.3. Computerized tools to support forest tactical and operational planning

A full range of computerized tools have been proposed for forest planning. Generic computerized tools include simulation systems that run growth and yield models, operational research (OR) techniques, information systems and decision support systems (DSS) (e.g. D'Amours et al. 2008, Ronnqvist 2003). Yet, OR techniques and DSS are the most commonly used to support decision-making.

Previous surveys already documented the contribution of OR to the forestry Industry. The Handbook of Operations Research in Natural Resources edited by Weintraub et al (2007) emphasized that OR approaches have been used over the last 40 years to model the complex functioning of the systems

based upon natural resources, as well as improving their management efficiency. The literature reported the use of linear, integer, mixed-integer and nonlinear models. The solution methods used depend on the required solution time and may include for example dynamic programming, LP methods, branch & bound methods, heuristics, column generation and Multi-Criteria Decision Making approaches (Ronnqvist 2003).

The contribution of the DSS on the improvement of the quality and transparency of decision-making in natural resources management is well established (Reynolds et al. 2007). The wiki page of the FORSYS COST-Action reports 62 DSS for forest management developed over 23 countries. These DSS cover a broad range of forest ecosystems, management goals and organizational frameworks. Yet, only 18 of which addressed medium and/or short term decisions.

Most of the DSS for forest planning reported on the literature share similar architectures. Their architecture evolved to meet increasingly complex problems faced by forest owners and forest managers. Typically, they are multicomponent systems, structured on functional modules supported by a Database Management System and accessed by graphical user interfaces (Figure 3).

The core components of these DSS are the model builder and optimizer. They often are separate modules yet deeply related. The first generates the optimization model for the problem instance. It retrieves the information required for planning, that may be stored in external systems accessed by a middleware layer. Due to the complex nature of the forest planning problems, the DSS are highly data-dependent. They often rely on spatial representations of the stands, inventory of the forest resources, and base ground information about relevant economic, social and ecological indicators. The model builder may run growth and yield models for obtaining production estimates for the model. This module further establishes the values for the parameters used by the model and the solution method.

The second module runs the heuristic or exact solution method. The latter may be coded within the DSS or invoked from an external OR solver. Furthermore, these DSS often foresee spatial features for results display levered on commercial or Open Source Geographical Information Systems.

Despite the large number of DSS developed, some studies (e.g. Reynolds et al. 2007, Menzel et al 2011) emphasized the need for a clear focus on the target users, therefore acknowledging the human dimension in information systems. Stakeholders' participation may be instrumental to develop a DSS that might address effectively the business specificities (Sousa and Pereira 2005). This is a critical success factor for decision support systems (Arnott and Dodson 2008).
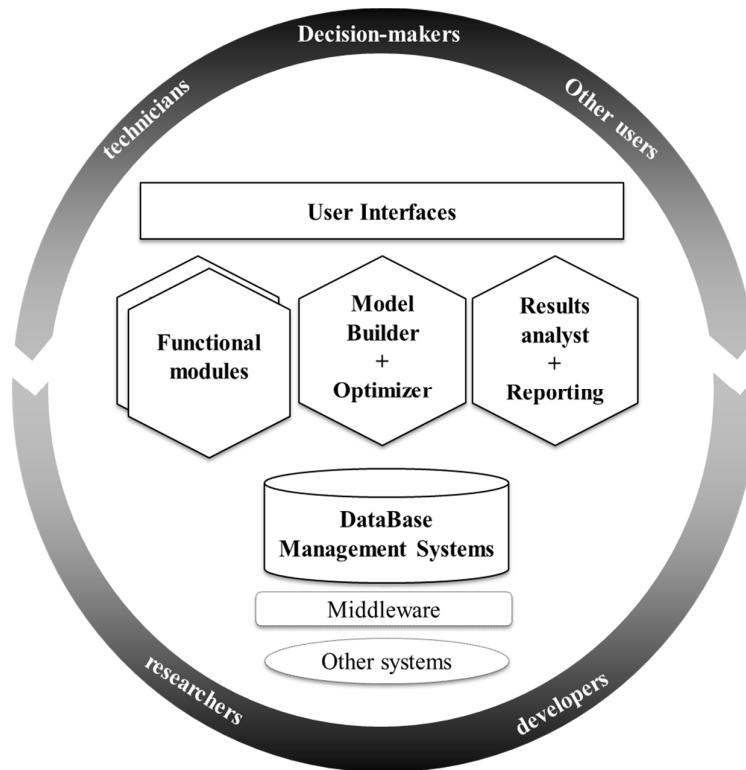
Figure 3 – Generic components of the Decision Support Systems for Forest Management

OR methods and DSS for forest planning have been developed in Portugal since the 90's. Typically, the complexity of the optimization models requires its implementation within a DSS that can easily generate the model instance. The DSS may approach more than one optimization model or model variants.

The first DSS research prototype was SADfLOR. It was developed by the university researchers with the cooperation of forest stakeholders (e.g Forest Service, Conservation Agency and Forest Industry) (Falcão and Borges 1999). This stand-alone system includes a Database that stores spatial and aspatial information. In this DSS, growth and yield models (DUNAS (Falcão 1999), GLOBULUS (Tomé et al 1998, Tomé et al 2001) and SUBER (Tomé at al. 1999)) are used within a prescription generator to simulate alternative management pathways, which then are fed into a optimization method (e.g. mathematical programming and heuristics such as Simulated Annealing, evolution programs, genetic algorithms) to help identify efficient strategies.

Since then, 7 other research prototypes (DinDUNAS, Agflor, Mflor, EfLOR, PfLOR, StandSIMOPT and SADPOF) and 3 new commercial products (Metafarms and 2 industry-owned DSS) were developed. Yet, only SADPOF from study I relates to tactical and operational planning (Marques et al s/d).

2.4. Survey of forest Tactical and Operational Planning problems and available tools

The characterization of the FTOPP during the literature review encompassed the analysis of the proposed decision variables in order to map the publications into the FTOPP framework (Table 1). The methods and DSS developed for FTOPP were further analysed.

The review results showed that the majority of the case studies approached in the literature refer to industry owners, particularly pulp industries. Few articles addressed the lumber-based supply chain. For example Carlgren et al. (2006) solved the log sorting problem on three Swedish forest-based companies holding both pulp mills and sawmills; Ronnqvist (2003) discussed the log bucking problem at sawmills. No references were found for case studies focused on the perspectives of the non-industrial forest owners or local communities.

The problems most commonly addressed support medium-term decisions on forest management and harvesting operations, particularly harvest scheduling. This problem consists on scheduling the best month for clearcut for the stands selected for harvesting on the planning horizon. It often aims regular wood flows distributed over the planning periods. It the case of vertically integrated industries, the latter can be replaced by monthly timber harvesting levels demanded at the mills.

The seasonality of the harvest operations is often acknowledged. The site conditions may delay the persecution of the harvesting operations. Also the conditions of road network may preclude the access to remote stands. Specifically, harvesting in Nordic countries prevails during the winter when the ground is frozen, thus reducing the risk of damage while moving the logs out of the forest (D'Amours et al. 2008). While in Mediterranean countries harvesting and transportation is forced to occur mainly during the summer. Budget constraints may also be considered. Early studies approached this problem with linear formulations. The decision variables stated the number of acres of the stand that should be harvested on each planning period (e.g. Weintraub and Navon 1976).

When even-aged forests extend over vast areas, the impact of clearcut operations is acknowledged. Spatial constraints are added to the problem in order to limit the maximum size of the clearcut opening areas. Therefore, mitigating the risk of soil erosion and reducing the impact on the landscape scenic value. In general, constraints on the maximum clearcut size preclude the clearcutting of adjacent stands (adjacency constraints) (Martins et al 2005).

Furthermore, spatial constraints are also considered for addressing specific ecological and environmental goals, such as reducing the fragmentation of old forest assuring a minimum size of old growth patches, maintaining uncut borders around key habitats, creating corridors between valuable

habitats, preserving stream-side riparian zones or scenic road corridors (e.g. Martins et al 2005, Baskent and Kelles 2005, Weintraub and Murray 2006).

The harvest scheduling problems that include adjacency constraints typically have IP or MIP formulations. The binary decision variables are set to 1 if the stand is harvested on a certain planning period; 0 otherwise. It is frequent to distinguish between the Area Restricted Models and the Unit Restricted Models proposed in Murray 1999. The Unit Restricted Models formulations prevail in the forestry literature. The complexity of these NP-Hard problems often precludes the use of exact solutions. The literature reports use of exact approaches to solve harvest scheduling problems that involve both temporal and spatial constraints (e.g. Kirby, Wong et al. 1980, Covington, Wood et al. 1988, Torres Rojo and Brodie 1990, Jones, Weintraub et al. 1991, Hof and Joyce 1993, Yoshimoto and Brodie 1994, Murray and Church 1995b, Snyder and Revelle 1997, Guignard, Ryu et al. 1998, Borges, Hoganson et al. 1999, Murray 1999, McDill, Rebain et al. 2002, Crowe, Nelson et al. 2003, Andalaft, Andalaft et al. 2003, Goycoolea, Murray et al. 2005, Martins, Constantino et al. 2005, Weintraub and Murray 2006, Constantino, Martins et al. 2008). It further highlights the use of heuristics within tactical/operational decision support systems since they may provide near optimal or near feasible solutions within reasonable computing time (e.g. Nelson and Brodie 1990, Richards and Gunn 2000, Falcão and Borges 2001, Caro, Constantino et al. 2003). In particular, simulated annealing (SA) has been widely used in forest management planning (e.g. Dahlin and Sallnas 1993, Lookwood and Moore 1993, Murray and Church 1995b, Tarp and Helles 1997, Boston and Bettinger 1999, Falcão and Borges 2002, Heinonen and Pukkala 2004, Falcão and Borges 2005).

Some authors proposed MIP and IP formulations for combining monthly harvest schedules with other types of decisions, like road network design and maintenance (e.g. Clark et al. 2000, Richards and Gunn 2000). The aim is to match in time the felling operations with the execution of the investment on the road network that accesses the harvest sites. The decisions related with road management are often modeled with binary variables that are set to 1 if a pre-determined road link is built/upgraded to another road class on a given planning period and 0 otherwise. Flow variables are often used to establish the relations between the harvesting and the road building decision variables. These flow variables represent the amount of product transported from a harvest site to a mill on a given period. The typical size of the tactical harvesting problems includes 12 time periods (monthly decisions in annual planning), 5–10crews, 5–20 industries and 100–1,000 areas (Ronnqvist 2003).

Other authors (e.g. Ronnqvist 2003, Karlsson et al 2004, Broman et al 2009) proposed MIP formulations for the tactical harvesting problem that further includes decisions on transportation to industries and which equipment/crews to use/assign. The flow variables are here used to address transportation decisions as well as linking the binary decision variables. The solutions for these MIP problems include branch-and-bound algorithms that run on commercial solvers like CPLEX (e.g.

Karlsson et al 2004) as well as heuristics such as Simulated Annealing and Tabu search (e.g. Murray and Church 1995). The OPTIMED system was been used for tactical forest planning in the Chilean pulp and paper companies (Epstein et al 1999).

Andaleft et al. (2003) further combined harvest scheduling and road network maintenance with product assortment and assignment decisions. The authors proposed several solution strategies involving strengthening of the model, lifting of constraints and applying Lagrangean relaxation to the MIP formulation. Forsberg et al. (2005) presented the FLOWOPT system that addresses both forest management and transportation decisions.

Despite the larger scope of decisions addressed by these combined problems, the focus often remains on harvest scheduling. These are the decisions that will be presented on the plan for future implementation. The anticipation of decisions approached by other FTOPP related with harvest scheduling aims to provide robustness to the planning process. Yet, when focusing on these other problems separately, the inclusion of new objectives and more detailed resources availability constraints may lead to reviewed decisions. Specifically, the harvest scheduling problem may consider whether a certain equipment type is assigned to a certain harvest unit. However, the equipment/crew allocation problem will determine which equipment will be used taking into account the set of equipment that can perform each operation, their performance, maintenance status, the operators' skills and availability.

When the harvesting operations are contracted to third-party service providers, the harvest service adjudication problem is of importance. It consists on clustering the harvesting stands into larger work orders and their assignment to service providers, taking into account their performance over previous contracts. Yet, not reference was found on the literature about this problem.

The short-term planning of forest management and harvesting operations focus on log bucking and extraction of the logs from the felling locations on the proximity of the forest roads. The first problem aims to establish how to fell the tree into products (or assortments) of specific length, diameter and quality (the bucking pattern), suitable for the different utilizations (Epstein et al. 1999b). Log bucking often occur at the harvest sites and it is performed manually by experienced log makers or at sawmills where more sophisticated equipment can be used. Yet, Ronnqvist (2003) reported the development of the Swedish system Aptan used for optimizing the value of a tree as well as the use of solution methods based on dynamic programming. Epstein et al (1999b) reported the use of OPTICORT for forest operational planning in Chilean pulp and paper companies.

The second problem consists on establishing the harvesting and forwarding routes as well as the logpile number, locations and capacity that enable the minimum duration of the forwarding operations (Carlsson and Ronnqvist 1998). Spatial data on the location of the road network and characteristics of

the forest site (slope, type of terrain) are key inputs for this problem. A complicating factor of this problem is that the forwarder can load several assortments in different loading patterns. The decisions on the loading patterns will result in limitations at the unloading process (Carlsson and Ronnqvist 1998).

Other problems that fall into this category are the daily scheduling of the equipment/crews and the synchronization between the harvesting equipment and the truck loading operations. The first intents to establish target values for key performance indicators used for evaluating the work persecution for the equipment/crew according to its characteristics and the harvest site conditions. It ultimately leads to an estimative of the expected duration of the harvesting operations. The second intents to synchronize in time the movements of the forwarder that places the logs at the logpiles and the trucks loading operations that carry the logs out of the forest sites. No reference was found on the literature about these problems.

The tactical wood transportation problems took the second place on the ranking of problems addressed on the literature on forest tactical and operational planning. The main decisions undertaken at tactical level related to product assortment and assignment (also called wood-flow problems (Carlsson and Ronnqvist 1998)). These decisions are often combined into IP or MIP formulations (e.g. Carlgren, Carlsson et al. 2006). The former addresses the selection of the combination of species and/or log sizes from a harvest site that may meet demand requirements at a minimum operational cost. The latter, also referred to as raw material distribution or medium-term transportation planning problem, aims at identifying the stands (or catchment area) that may provide the raw material needed by individual transformation units at a minimum transportation cost (e.g. Forsberg 2005, Ronnqovist 2003). The wood-flow decision variables have been used to address these problems. These variables represent the flow of an assortment type transported from a source location to a destination on a given planning period. The problem may be formulated and solved as an LP transportation. The assignment problem of the harvest units to the possible destinations over the procurement network may also support decisions related with the volume of wood that may be stored in intermediate storage yards. In this case, maximum storage capacity and storage duration are included on the problem formulation.

The use backhaulage tours can dramatically decrease the cost related with the wood assignment problem (Ronnqvist 2003). Backhaulage tours sequence the pick-up and delivery points in a way that reduces the distance travelled without load, when compared to making the same haulage tasks by direct tours (Carlsson and Ronnqvist 2006). The transportation problems with backhauling may be approached with LP formulations (Carlsson and Ronnqvist 2006). The model encompasses two types of continuous decision variables, representing the flow transported on direct trips (haulage) and on the backhaulage trips. The size of this model grows rapidly with the number of supply and demand points included on the model. Consequently, the same authors proposed the use of a column generation

procedure that generates dynamically the columns of the LP model. The readers are directed to (Carlsson and Ronnqvist 2006) for a complete description of this solution method. A typical case has about 500–1500 supply points and 20–100 demand points. Not all combinations of supply and demand points are possible and the number of direct flow is therefore typically 1,000–10,000. The number of potential backhaulage tours is many millions.

At the operational level, the main decisions relate to the establishment of the routes for a fleet of trucks (i.e. the sequence of the wood supply and demand points visited by the trucks during one day). The truck routing problem is also called truck scheduling problem as the sequence of visits performed will dictate the schedules for the fleet of trucks. This problem is a variant of the vehicle routing problem with time windows. Here, each node can be visited several times and the supply/demand is much more than one truckload. This problem can be handled in real time - dispatching problem (Ronnqvist, et al 1998) or solved some time in advance, for example one day ahead - Log Truck Scheduling Problem (Palmgren 2005) or Timber Transport Vehicle Routing Problem (Gronalt and Hirsch 2005). The general IP formulations for this problem rely on binary decision variables set to 1 if a trip is done and 0 otherwise. Yet other mixed integer programming formulations and heuristics approaches have been developed for these problems (e.g. Palmgren 2005, Gronalt and Hirsch 2005, Flisberg et al 2007, Palmgren et al 2002, Gronalt and Hirsch 2007). Weintraub et al 1995 reported the use of ASICAM for transportation planning in use at several forest companies in Chile and Brazil. The typical size of these problems have 20–150 trucks, 100–500 supply points and 20–100 demand points. The number of constraints is (given the numbers) 140–750. The number of variables is many billions (Ronnqvist et al 2003).

The bibliography on wood forest resources intermediate storing and forest resources delivery at the mill is scarce. These problems relate with managing the yard layout, controlling the wood stock levels for each product assortment and assigning the equipment/crews to the unloading operations. The operational problem related with wood reception scheduling both at the storage yard and at the mill was considered a priority by the forestry experts collaborating in this research. The congestion and queuing of trucks at the mill gate often occur, increasing the duration and costs of the transportation services.

This review on forest tactical and operational problems further highlighted the need for innovative planning approaches for some of the FTOPP previously discussed. It further discussed the main research challenges in this domain. The first challenge is the integration of the different planning problems related with procurement, production, distribution and sales. It includes both the relations among FTOPP and the need for synchronizing the planning processes throughout a set of independent business units (e.g., entrepreneurs, carriers, sawmills, pulp and paper mills), their suppliers and their customers (D'Amours et al 2008).

The second challenge is developing computerized-tools for supporting the complex network of interactions among the several agents engaged on the forest-based supply chains. These tools must promote communication, cooperation and negotiation between the agents. Similar tools may also be instrumental for addressing forest planning processes with multiple decision-makers/stakeholders.

The last challenge relies on integrating forest operational planning and forest operations control. It is well acknowledged that forest operational plans are instrumental for anticipating the operations execution (e.g. Ronnqvist et al 1998).Yet, there is often a lack of specific control operations aiming to monitor the gap between the plan and the operations execution. Therefore, triggering re-planning events whenever the gaps recorded exceed the accepted threshold.

2.4.1. FTOPP in Portugal

According to Portuguese Country Report (Marques et al. s/d), the FTOPP range from regional to forest and stand level problems. Regional problems often rely on the geographical location of the agents engaged on the procurement network. While forest level problems acknowledge the spatial representation of the forest units, yet without considering neighborhood relations. All of these problems focus on multiple objectives, targeting mainly market wood products.

This report also highlights that the nature of the management objectives and decision variables set for the FTOPP emerge from the organizational framework where the planning process takes place. Particularly in Portugal the sophistication of the planning process is related with the land tenure pattern. About 86% of forestland is hold by non-industrial private landowners (NIPF), while about 7% is industry-owned. Local communities own about 6% of forestland, while only 1% is national forest managed by the state. Most of the NIPF have small-scaled properties, ranging from less than 10 ha, at the northern and central Portugal, to 100ha at the southern regions where the oak agro-forestry systems prevail.

The main medium-term decision undertaken by NIPF and local communities relates with performing or postponing the forest operations suggested by the generic prescription models available for the main forest species. Their planning process is often immaterialized and dictated by the local juncture. Clearcut may be delayed if no buyer was found for the wood on the forest in advance. The wood is often sold at the forest, therefore short-term planning is conducted by the third-party entrepreneurs. When the wood is sold on the logpile near the road network, the short-term planning is conducted by the forestland owner often with the technical support of the forest owners associations or within the

context of the newly created forest intervention areas (ZIF). Nowadays, there are 132 organizations and 134 ZIFs spread across the country (AFN 2012).

Similarly, the main decisions related with tactical planning of public forestlands concern the selection of the buyers for the wood sold in the forest. The process is regulated by standard auctioning procedures. Short-term planning is also conducted by the buyer. The wood-trade entrepreneurs are typically small-scaled local companies with limited planning capacities.

Contrarily, the Portuguese industry owners, with large scale holdings (more than 500ha) typically conduct sophisticated forest planning processes. The tactical planning process schedules the forest operations to be conducted each month at the forest region, in order to maximize the net present value of the forestry production while assuring the accomplishment of the target wood levels demanded by the mills. The tactical plan supports the annual forestry budget and the contracts with service providers (for harvesting and transportation) and wood suppliers. This plan conditions the decisions on the allocation of the resources and the operation schedules done by the service providers. It further provides input for the industry operational plans (commonly called projects) produced at the stand/ harvest unit level. The latter presents the equipment/crew schedule at the weekly or daily basis as well as provides detail on the characteristics of the forest operations, their spatial representation, the harvesting routes and location of the logpiles.

The report identified 34 computerized tools available in Portugal with research and commercial purposes. It included growth and yield models, optimization models, information systems and DSS. The results showed that most of the computerized tools aim to support problems related with long-term forest planning, performed by a single decision-maker aiming multiple-objectives and wood/non-wood products. Forest tactical and operational planning problems were addressed only by 2 of the computerized-tools. The SADOF was developed for research purposes in the context of Study I. The architecture of this DSS encompasses the user interfaces, the spatial database and an application layer that manages the creation and edition of forest tactical planning scenarios. The core application modules are the model builder and optimizer. The latter uses Simulated Annealing and a case-specific heuristic to solve the MIP formulation for the integrated forest tactical problem. This DSS provides alphanumerical and geographical representation of the monthly harvest plans, monthly wood delivery plans and detailed forest operations schedules.

The second tool reported was the commercial information system Wise Forms (Makewise 2011). This solution encompasses mobile devices for collecting data on the harvest sites during the forest operations. The information is synchronized centrally enabling the computation of operational indicators.

3. Material and methods

3.1. Case studies

Three of the case studies approached the forest planning decisions under the perspective of the vertically integrated pulp and paper companies operating in Portugal. Specifically, Study I was inspired on the tactical problem characterized with the forestry experts from Portucel-Soporcel. The problem components included harvest scheduling, pulpwood assortment and assignment over the procurement network. It encompassed 700 eucalypt stands extending over 4888 ha in south-central Portugal, 3 intermediate storage yards, 4 pulp mills and 1 bio-energy plant. 6 product assortments were considered, corresponding to eucalypt logs of different length and barking status as well as different forest residues chipping status. The product flows were planned over a twelve 1-month temporal horizon.

Study II addressed the operational problem of delivering the pulpwood to the pulp mill, under the perspective of the EuroPac mill at Viana do Castelo. The case study encompassed 120 daily deliveries (72 planned and 48 unplanned) of 3 distinct pulpwood assortments that could be assigned to 496 time slots available on 6 possible docking stations inside the mill, corresponding to the raw materials warehouses and the wood chips production lines.

Study III was retrieved from the case of pulpwood supply to the Celbi mill located at Figueira da Foz. The study focused on processes and business information required to support forest management and wood inbound logistics under an integrated wood supply chain management approach. Specifically, the project aimed at specifying a computerized system to support pulpwood supply business processes (e.g. strategic to operational forest management planning, forest operations follow-up and accounting, forestland classification and forest inventory) as well as acquisitions of wood on the national market. Logistic activities associated with transportation planning and follow-up, wood yard management and wood reception in the mills facilities were also addressed. Information flows and interdependencies with the remaining supply chain activities related with pulp and paper production, distribution and sales were also considered.

Study IV approached the decision-making processes of multiple stakeholders engaged at regional forest planning at the Chamusca county. This county is a rural and low population density municipality where forestlands extend over 51% of the county territory. Eucalypt and maritime pine plantations extend over 62% of the county forest area while cork and holm oak multi-functional forests occupy 35% of this area. The remaining 3% corresponds to protection areas. The set of stakeholders engaged on this research included 22 entities, divided among 13 stakeholders groups, representing more than 900 people with direct interests in the region. The key-stakeholders were the

forestland owners. The forestland is predominantly private. Pulp and paper companies and a few large-scale non-industrial private forestland owners (NIPF) are responsible for managing 73% of the area while the remaining area is held by more than 2,200 NIPF, some with holdings with less than 1ha. These stakeholders can act individually or grouped into forest associations and federations. Typically, NIPF sell stumpage and cork to local trade entrepreneurs. Often, the latter own the harvesting equipment and rely on local workers hired for the harvest season. The transportation of forest products is typically outsourced to logistic operators or individual haulers. Forest operations are regulated by the regional office of the forest authority according to regional plans and forestry policies. The regional office is also responsible for managing the public forests in the county. Recently and as a response to the 2003 wildfires that burned $20x10^3$ha of the county's territory (Marques et al. 2011), the local municipality also plays a key role in developing and supervising forest wildfires prevention plans as well as in coordinating the forest wildfires suppression efforts. Other stakeholders include forest investment funds, non-governmental organizations, local communities and forest research agencies.

Study V focused on the computerized tools that could be used to support forest planning and forest operations control across the procurement network. It addressed the main forest-based supply chains in Portugal. Consequently, the board of experts engaged on this study included experienced forestry experts from Celpa working on the pulp and paper supply industry and from Centro Pinus intervening on the lumber industry. The private and publics forestland owners were also represented.

3.2. Data for forest tactical and operational planning

Most of the information used was collected in the course of workshop sessions with the different skilled experts involved on the projects that provided results for this thesis. Specifically, studies I and II required a large amount of spatial and aspatial information related with the description of the components of the procurement network. The description of the wood supply point - harvesting units - included the area and geographical location of the stands, inventory estimates of total eucalypt commercial volume and weight as well as estimates of forest residues weight in each planning period. The chipping costs and the log bucking costs for producing the different assortments were considered. The description of the demand point - pulpwood and biomass transformation facilities - included the geographical location, the monthly demand levels of the different assortments and their unit price, assumed constant over the planning period. It was assumed that their storage capacity was unlimited.

The Intermediate storage yards were simultaneously supply and demand points. They were demand points as they stored the wood products delivered from the harvest units. They were supply points as they provided the supply to the transformation facilities. They may play an important role in the company strategy as they contribute to avoid uneven seasonal supply of raw material from the

harvesting units. They may further contribute to a reduction of the transportation costs as logs drying under open air conditions leads to lower weights and as railway transportation from these yards to the mills is possible. Each storage yard was characterized by its location, maximum storage capacity, storage costs and maximum allowable storage duration. The latter was key to avoid decay and devaluation of product assortments. These storage yards were considered empty at the beginning of the planning horizon.

Study I further acknowledged the road and railway network spatial representations to compute the distances among all the components of the procurement network. The network was represented as a complete and oriented graph. The transportation cost on the arcs was the product of the distances between the each pair of locations by the unit cost related with the type of product carried.

The data set used in Study II related to one working day from 06hr to 21hr at the service gate that accesses the pulp mill. The 2hr time windows were split into 17 time slots of 7min duration. The mill accepted three product assortments, generically named product A, B and C. The unloading locations included one active cell at the intermediate wood yard for each assortment, as well as 2 unloading docking stations for product A and one for product B. The working shift started 1hr after the gate and it was split into 15min time slots. The length of the time slots corresponded to the maximum duration on the truck unloading operation using the electric crane stationary in each location. The ride between the gate and the unloading destinations took about 10min.

Two separate data sets of daily trucks schedules were simulated. The first - planned deliveries - corresponded to the deliveries requests planned in advance to arrive on that day. The delivery request was characterized by the truck planned arrival time, the assortment carried, the number of trips planned for that day and the estimate of the weight of the truckload.72 planned deliveries were considered, 40% of these coming from market wood suppliers. The remaining deliveries came from self-managed forests. For the latter harvest site was identified. Both the delivery key-identifier and the truck key-identifier were also acknowledged. There may be less trucks than the number of deliveries since the same truck can perform more than one trip during the day. This data set may be the outcome of the transportation planning activities (e.g. Marques et al. 2010) or may be randomly generated. This study applied random functions to set the number of deliveries in each time window, using higher probabilities for arrivals on the rush hours. About 40% of the deliveries occurred on 7hr-9hr, 11hr-13hr and 19hr-21hr. The average number of 17 trucks per time window could rise up to 20 in the rush hours. In each time window the deliveries were regularly spread across the time slots at the entrance gate. Then, random values were obtained for the remaining attributes.

The second data set - real deliveries – also used on Study II encompassed all the deliveries that actually arrive at the service gate during that day. It included the same planned trucks as the first data

set plus 48 unplanned trucks of market wood suppliers. These unplanned trucks may arrive before the gate opening hours or during the working shift. Arrivals after the gate closing hours were received on the next day. The delivery was characterized as before yet considering their real arrival time, and including the waiting time for the truck arriving before the gate opening hours. Random functions were further used to generate the real arrival time for all the deliveries as well as the remaining information related with the unplanned trucks.

Studies III to V were built upon detailed information about the business processes, their activities, information flows, and roles of the agents involved in its execution. It further required the inventory of the existing information systems and the IT infra-structure (Table 2). The future policies regarding forest management and mill supply were also addressed. The primary information sources were documentation already produced by the company. For example, the companies that adhered to quality certification schemas may already have their processes and information flows fully documented. All the data repositories of the company were further analyzed. They may include paper forms, templates and key excel sheets. These repositories provided the basis for describing the attributes that compose the information flows consumed and produced by the business activities.

When addressing future business processes or undocumented processes, the information was retrieved from workshops with the agents directly involved on the processes or visits of the project team to the locations where the processes took place. This survey was later validated by the agents.

3.3. Enterprise Architecture methodology adapted for FTOP

The Enterprise Architecture (EA) methodology presented in (Spewak and Hill 1992) was adapted and applied in all studies. This methodology has been used to identify system requirements to support business processes, ensuring the alignment between the business requirements and the Information Technology (IT) function (Sousa and Pereira 2005, Schekkerman 2007, Schekkerman 2009). The EA framework was developed within the IT domain to promote an integrated and global view of the entire IT function, namely of its relationship with business processes. Nevertheless, EA captures and represents knowledge about the organization decision-making dynamics. Accordingly, this approach has been applied to support Information Systems design in several organizations worldwide, e.g. governmental organizations (e.g. Martin et al. 2004, Hjort-Madsen 2006), retail industry (Stecher 1993; Vasconcelos et al. 2003), furniture manufacturing (Xu et al. 2007). (Shunk et al. 2003) further uses an EA approach to analyze the process interactions and to establish the supply-chain process integration in the defense electronics industry. (Ribeiro et al. 2005) demonstrated its potential for

specifying the Integrated Forest Management System strategic module for a major pulp and paper industry in Portugal.

This thesis adapted the EA methodology to cope with the complexity of the FTOPP. The emphasis was on participatory techniques that foster the incorporation of the experts into the systems design, enhancing the human dimension of information systems. Such techniques may effectively assure the alignment between the business needs and the systems functionalities. They may further enhance knowledge transfer and foster the utilization of the computerized-tools by the forestry technicians and decision-makers to support real-world planning processes (e.g. Menzel et al 2012). This methodology was also extended to include the Problem Definition stage (Figure 4).
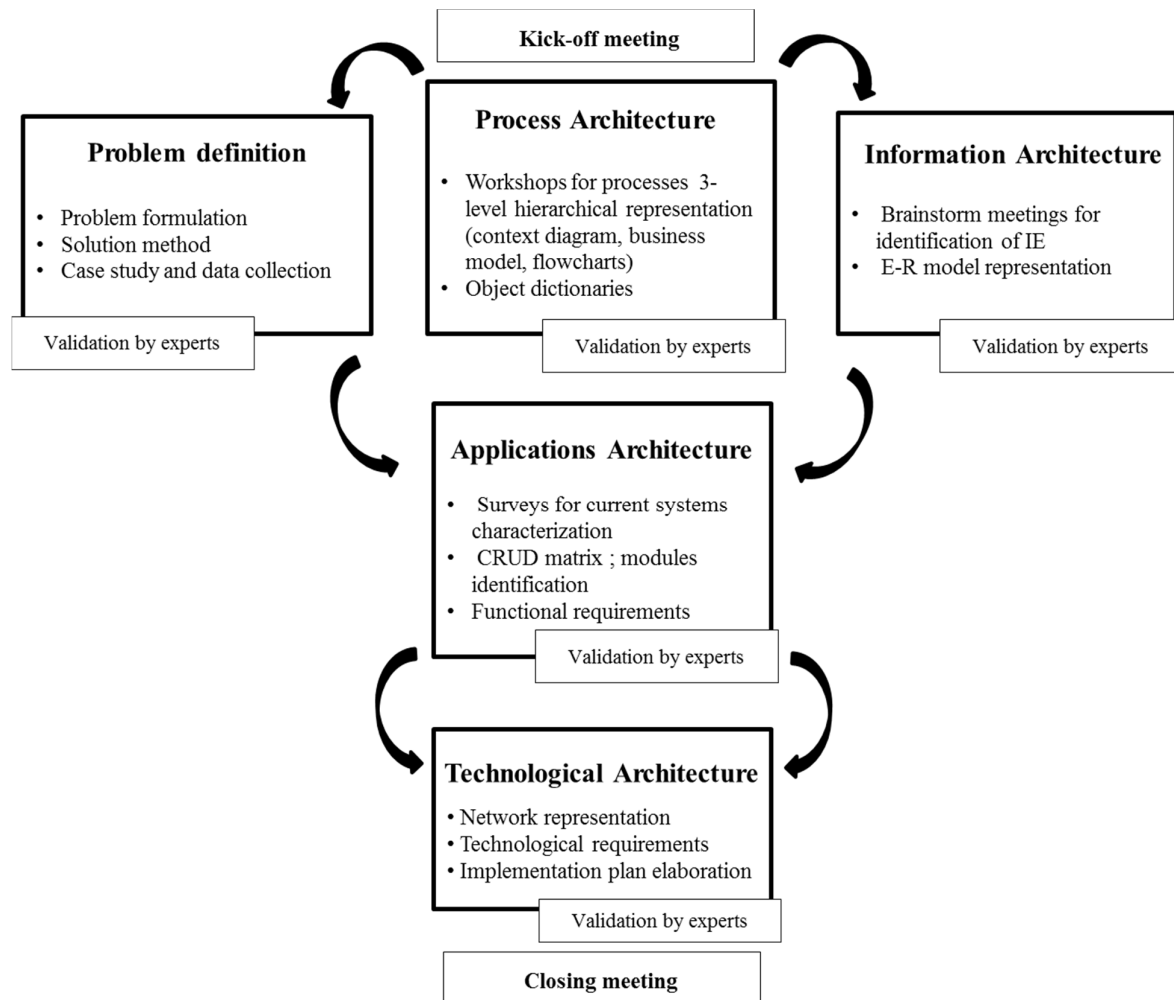
Figure 4 – Enterprise Architecture methodology extended for FTOPP

The first stage of the proposed approach - Process Architecture - focused on current and future business processes. A three-level hierarchical top-down structure was often used for processes representation. It encompasses the context diagram, the business model and the business processes. The readers are directed to the article referring to Study III for a complete description of the three-level process hierarchical representation. The business processes are a sequence of interrelated activities and information flows performed to produce products & services or support key business functions on the organization (Table 2). The identification of the profiles responsible for conducting the activities is also of importance. The business processes provided the basis for the forthcoming stages of Information Architecture and Problem Definition.

The Information Architecture aimed to identify the core information entities, based on the information flows produced/consumed by the activities. Each Information Entity (IE) had a business responsible for its management that ruled the IE life cycle (i.e. acquisition, classification, quality control, presentation, distribution, and assessment). It was characterized by one unique identifier defined from a business perspective, the description, and a set of attributes. The IEs were further E-R model. This model emphasized the relations among the IEs. It was instrumental for the development of the DataBase Management System.

The problem description stage encompassed the establishment of the model and solution method for the forest planning problem that fits the objectives and constraints imposed by the experts. It encompassed a series of workshops with the forestry experts who were asked to analyses and rank a list of problems (e.g. Table 1) according to their business impact. The case study description and the data collection were then conducted, preferably by the experts.

The participatory techniques were instrumental for the conducting these stages. Specifically, the Post-It method was used within the workshop meetings and brainstorm sessions. This technique aimed to foster discussion among the participants as well as explicit and document the stakeholders' knowledge, concerns and requirements (e.g. Kangas et al. 2008). The readers are directed to the article on Study III for a complete description of this method. Additionally, the experts were asked to comment and validate the reports produced after each stage.

The next stage - Application Architecture - was built from previous EA artifacts. It used the CRUD matrix to identify the future functional modules needed to support core business processes and the information entities. This stage further provided detailed descriptions of the modules functional requirements, the content of the data repositories, types of graphical user interfaces and interfaces with other existing or foreseen systems. The gap analysis between the proposed modules and the existing systems identified future developments as well as systems to be discontinued. The last stage -

Technological Architecture – addressed the technological requirements and implementation guidelines.

The kick-off and closing meetings involved all the members of the team, forestry experts and all the other stakeholders interested on the project results.

Table 2 - Characterization of the Enterprise Architecture artifacts

EA artifact	Properties
Role	Identifier, Name and Description Organization Physical location
Process	Identifier, Name and Description Category (business or support) Objectives Physical location Frequency (daily, monthly, triggered by client, other) [Activities] [Responsible Role and Participant Roles] [Input and output information] [Relationship with other processes]
Activity **(and Activity Dictionary)**	Identifier, Name, Description [Associated Processes]
Information flow **(and Information Dictionary)**	Identifier, Name, Description Support type (paper, electronic flow, oral communication…) [Associated Processes]
Information entity	Identifier, Name, Description Objective [Associated Information flows] Key-Identifier [Associated Attributes] [Relationship with other information entities] [Relationship with the processes, based on CRUD matrix]
Attribute	Abbreviator, Name Units Source Optional (yes/no) Data type: Check box, value list, text (char number), date, integer, decimal, logic (V, F) Table name and field name on the data model
Information system	Identifier, Name, Description Objective [Supported processes, based on CRUD matrix] [Supported information entities, based on CRUD matrix] [Supported activities] Interfaces (GUI, with external systems and with other internal modules) Migration and integration requirements Technological requirements
Application Module	Identifier, Name, Description Interfaces Functional requirements

Studies III to V implemented slight variations of the proposed EA methodology, justified by their specific problem scope. In particular, study IV extended the process architecture methodology to a multiple stakeholder's context. According to the stakeholders' engagement plan, the process architecture stated by selecting the representative stakeholders that should take part on the design of the DSS. Then, the individual decision processes of the stakeholders were addressed as described above. The next stage merged the individual processes into the integrated stakeholders' analysis. This analysis provided the background for the identification of the regional toolbox components (Figure 5). The readers are directed to the articles referring to these studies for a complete description of these variations.

Stakeholders selection	Individual decision processes	Integrated stakeholders analysis	Regional Toolbox components
1st workshop: id. groups	Select modeling tool	1st workshop: integrated context diagram	Required decision-support tools
Clustering stakeholders	1st workshop: context diagram	2nd workshop: overall RFMP framework	Data elements
Contacts	2nd worshop: decision process	Matrix with questionnaire consolidation	Data ownership matrix
Kick-off meeting	Questionnaire		Validation by stakeholders
	Fill repository & report		Final meeting
	Validation by stakeholders		

Figure 5 – Forest stakeholders' engagement plan for designing the regional forest management toolbox

Studies I and II further encompassed the development of a decision support system according to the specifications of the Enterprise Architecture reports (SADPOF). The SADPOF is composed by web-based graphical user interfaces, a spatial database and the model builder and optimizer modules. It currently provides the tactical plan for case study I, including monthly harvest plan and the monthly pulpwood delivery plan. The ongoing improvements will develop the interfaces for the daily reception schedules produced on study II. The geographical maps related to each optimal planning scenario are displayed on a stand-alone application. This DSS further enables tradeoff analysis to assess the impact of variations on the model parameters over the results of the baseline scenario. The SADPOF has coded on VB.NET and C#.NET using the Visual Studio environment. The GIS application was developed in MapWindow GIS Open Source software (Ames P. 2011).

The solution method used on study II may perform a system call to the GNU mixed-integer programming solver LP SOLVE v.5.5.2.0 for optimal solution of the assortment and assignment sub-problem. While in study II a new system call executes both the GNU GLPK v4.34 solver for windows (Margot F, 2008) and the COIN-OR CBC (Margot F, 2011) solver in order to get optimal results for the assignment problem.

3.4. Optimization models and methods

Studies I and II proposed innovative models and solution methods to address two of the main FTOPP prevalent in Portugal. Study I aimed to maximize the net present value related with the decisions of when to harvest each stand, the type of assortment produced and the product flows to the demand points located across the procurement network (Figure 10). Subjected to the fulfilling the minimum target monthly demand levels of product assortments at the pulp mills and at the bio-energy plant. It further acknowledged spatial constraints that set the minimum and maximum size of the clear cut openings.

MIP formulation (Study I)

The proposed mixed-integer formulation to the **integrate harvest scheduling, product assortment and assignment problem** (IFTPP) can be described as:

$$\max Z = \sum_{j \in J} \frac{\sum_{i \in I} \sum_{f \in F} \sum_{p \in P} (PR_{pf} - CT_{ip}^f - CP_p) q_{ijp}^f}{(1+tj)^{j-1}} + \sum_{j \in J} \frac{\sum_{f \in F_T} \sum_{f \in F_M} \sum_{p \in P} (PR_{pf} - CF_{pf}^f) t_{fjp}^f}{(1+tj)^{j-1}} - \sum_{j \in J} \frac{\sum_{i \in I} CH_i x_{ij}}{(1+tj)^{j-1}}$$

(1)

$$\textit{Subject to: } \sum_{j \in J} x_{ij} = 1 \qquad\qquad \forall i \in I \qquad\qquad (2)$$

$$\sum_{j-PE < j' < j+PE} \sum_{i' \in adj_i} A_{i'} x_{i'j'} + A_i x_{ij} \le A \max_{PE} \qquad \forall i \in I, \forall j \in J \qquad (3)$$

$$\sum_{i' \in adj_i} A_{i'} x_{i'j} + A_i x_{ij} \ge A \min_j \qquad\qquad \forall i \in I, \forall j \in J \qquad (4)$$

$$\sum_{p \in P^L} \sum_{f \in F} q_{ijp}^f \le AV_i^L x_{ij} \qquad\qquad \forall i \in I, \forall j \in J \qquad (5.1)$$

$$\sum_{p \in P^{FR}} \sum_{f \in F} q_{ijp}^f \le AV_i^{FR} x_{ij} \qquad\qquad \forall i \in I, \forall j \in J \qquad (5.2)$$

$$\sum_{i \in I} \sum_{f \in F} \sum_{p \in P_B^L} q_{ijp}^f = B_j \qquad\qquad \forall j \in J \qquad (6)$$

$$\sum_{i \in I} q_{ijp}^f + \sum_{f \in F_T} t_{fjp}^f \ge TG_{pj}^f \qquad\qquad \forall j \in J, \forall p \in P, \forall f \in F_M \qquad (7)$$

$$\sum_{j'=1}^{j'=j-1} (\sum_{i \in I} \sum_{p \in P} q_{ij'p}^f - \sum_{p \in P} \sum_{f \in F_M} t_{fj'p}^f) = \sum_{p \in P} E_{fp}^{j'} \qquad \forall f \in F_T, \forall j \in J : j \ge 2 \qquad (8.1a)$$

$$\sum_{p \in P} E_{fp}^j = 0 \qquad\qquad \forall f \in F_T, j = 1 \qquad (8.1b)$$

$$\sum_{p \in P} E_{fp}^j + \sum_{i \in I} \sum_{p \in P} q_{ijp}^{f'} - \sum_{p \in P} \sum_{f \in F_M} t_{fjp}^f \le CMax_f \qquad \forall j \in J, \forall f \in F_T \qquad (8.2)$$

$$\sum_{i\in I} DP_{ip}^{f} \le D\max_{pf} \qquad\qquad \forall\, p \in P,\ \forall f \in F_T, \qquad\qquad (9)$$

$$\sum_{j'=1}^{j}\sum_{i\in I} q_{ij'p}^{f} - \sum_{j'=1}^{j-1}\sum_{f\in F_M} t_{fj'p}^{f} \ge \sum_{f\in F_M} t_{fjp}^{f} \qquad\qquad \forall\, j \in J,\ \forall\, p \in P,\ \forall f \in F_T \qquad\qquad (10)$$

$$q_{ijp}^{f} \ge 0 \qquad\qquad \forall\, i \in I,\ \forall\, j \in J,\ \forall\, p \in P,\ \forall f \in F \qquad (11.1)$$

$$t_{fjp}^{f} \ge 0 \qquad\qquad \forall\, j \in J,\ \forall\, p \in P,\ \forall f \in F_T,\ \forall f \in F_M, \qquad (11.2)$$

$$x_{ij} \in \{0,1\} \qquad\qquad \forall\, i \in I,\ \forall\, j \in J \qquad\qquad (11.3)$$

Where:

J	Set of months of the planning horizon, j=1,…, 12
Tj	interest rate
I	Set of stands to be harvested over the planning horizon, i=1,…, 700
A_i	Area of the stand i (m^2)
adj_i	Set of stands adjacent to stand i (within a distance from i less than DISTMIN)
P	Set of assortments, p=1,…, 6 includes the subset of forest residues (P^{FR}), divided into chipped (P^{FR}_C:p=1) and non-chipped (P^{FR}_{NC}:p=2) and the subset of logs (P^L), divided into barked (P^L_B: p=3,4) and unbarked (P^L_{UB}: p=5,6)
AV^L_i	Total quantity of pulpwood produced at stand i (ton)
AV^{FR}_i	Total quantity of forest residues produced at stand i (ton)
F	Set of product destinations, f= 1, 2,…, 8; it includes the subset of storage yards (F_T:f=1,2,3) and the subset of mills and bio-energy plants (F_M:f=4, 5,…, 8),
Y_{pf}	Binary parameter set equal to 1 if assortment p is accepted at the storage yard f $\in$ F_T and to 0 otherwise
CT_{ip}^{f}	Total transportation cost (by road) of assortment p from stand i to transformation facility f (€/ton)
$CF_{p,f\in F_T}^{f\in F_M}$	Total transportation cost (by railway) of assortment p from the storage yard f $\in F_T$ to the mill f $\in F_M$ (€/ton)
CH_i	Total harvest cost of stand i (€) (includes, harvesting, forwarding, and planting if it occurs at the final coppice cycle within the rotation)
CP_p	Total product processing cost for assortment p
PR_{pf}	Price of assortment p on the mill f $\in$ F_M (€/ton)
$Amax_{PE}$	Maximum clearcut opening area over the exclusion period (ha)
DISTMIN	Minimum distance between adjacent stands
$Amin_j$	Minimum clearcut opening area in each period j
PE	Exclusion period (months)
TG_{pj}^{f}	Target flows from assortment p in period j to the mill f $\in$ F_M (ton)
B_j	Supply of barked logs in period j (m^3)
$CMax_f$	Maximum capacity of the storage yard f $\in$ F_T (ton)
$Dmax_{pf}$	Maximum allowable storage duration for assortment p in storage yard, f $\in$ F_T (months)
DP_{ip}^{f}	Storage duration of assortment p from stand i, in storage yard f $\in$ F_T (months)

The decision variables are:

x_{ij} Binary variable set equal to 1 if stand i is harvested in period j and to 0 otherwise

q_{ijp}^{J} Quantity of assortment p, produced in stand i, transported to destination f in period j, $\forall i \in I$, $\forall j \in J$, $\forall p \in P$, $\forall f \in F$ (ton)

$t_{f \in F_T, jp}^{J \in r_M}$ Quantity of assortment p, transported from storage yard $f \in F_T$ to final destination $f \in F_M$ in period j, $\forall j \in J$, $\forall p \in P$ (ton)

The auxiliary variables are:

E_{fp}^{j} Quantity of product p, stocked at storage yard f, at the beginning of period j, $\forall j \in J$, $\forall p \in P$, $\forall f \in F_T$ (ton)

The model aims at maximizing the IFTPP net present value (Equation 1). All stands must be harvested exactly once over the planning horizon (Equation 2). Each clearcut opening areas must meet both a maximum size constraint over the exclusion period and a minimum operational size constraint (Equations 3 and 4, respectively). The total flow from each stand is constrained by the availability of both pulpwood and residues at the stand (Equation 5). A bookkeeping condition (Equations 6) was included to help keep track of the monthly supply of barked pulpwood logs. The solution must meet the target monthly demand of each product assortment by each pulp mill and bio-energy plant (Equation 7). Each storage yard was assumed empty at the beginning of the planning horizon (Equation 8.1b). The stock in each storage yard at the beginning of remaining 11 months was computed by adding the incoming flows and subtracting the outgoing flows (Equation 8.1a).This bookkeeping variable was used to ensure that the storage yard maximum capacity is not exceeded (Equation 8.2). The storage duration of each product in a yard was computed with a specific procedure described below in order to ensure that the maximum allowable storage duration is not exceeded (Equation 9). The outgoing flow of an assortment from each yard at the end of each period cannot exceed the current stock level computed as the difference between the assortment incoming and the outgoing flows up to the end of the period (Equation 10). Finally, equations (11) set the nature of the decision variables.

Solution method (Study I)

The solution method developed in Study I was built upon a problem decomposition approach that addressed sequentially the harvest scheduling and the product assortment and distribution sub-problems by a combination of heuristic and mathematical programming algorithms (Figure 6). The master problem was solved using simulated annealing (SA) (Kirkpatrick, Gelatt et al. 1983).

Specifically, the solution process started with the generation of a random solution to the harvest scheduling sub-problem encompassing the third term in equation (1), equations (2) to (4) and (11.3). Each stand was assigned a harvesting period. Afterwards, a solution was found to the product

assortment and assignment sub-problem. Here the timber harvested according to the timing and location in the solution to the first sub-problem was assorted into products and these products were assigned to destinations within the considered timber procurement network. This sub-problem was defined by the two first terms in Equation (1) and by Equations (5) to (10) and Equations (11.1) and (11.2). This is a variant of the linear programming transshipment problem with the particularity of including decisions on the type and amount of the assortments of timber harvested in each stand (supply points). The assortments aim to be transshipped over a network of supply and demand points and intermediate storage yards. This solution was provided by either a newly developed heuristic procedure or a linear programming algorithm (e.g. LP SOLVE).
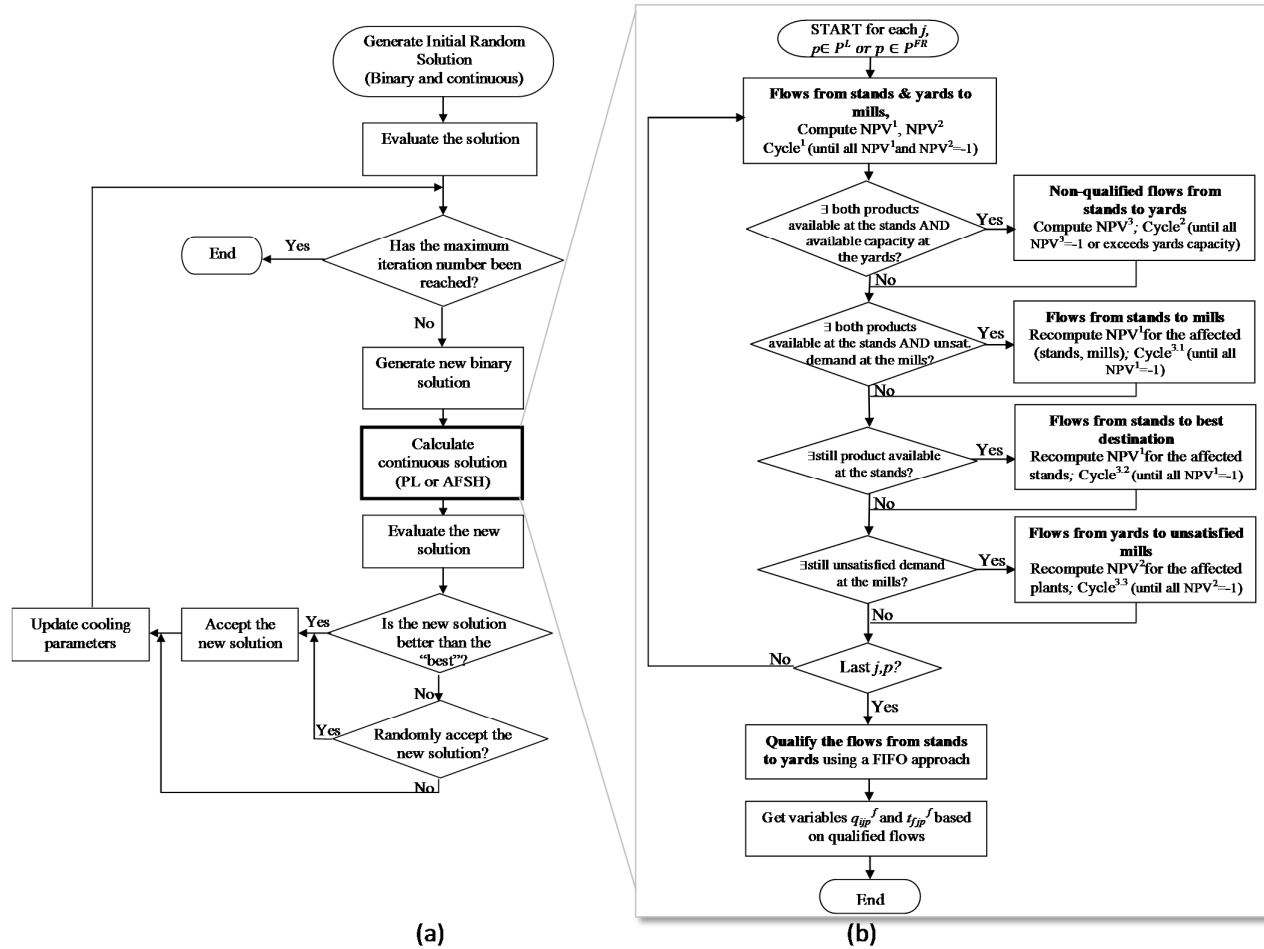

Figure 6 – The solution method for the IFTPP, including Simulated Annealing (a) and the Admissible Flow Solution Heuristic (AFSH) flowchart (b)

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The greedy **Admissible Flow Solution Heuristic (AFSH) procedure** was based on empirical transportation rules applied nowadays during the wood logistics planning process. In summary, these rules promote the distribution of all available supply at the harvest units to the most profitable destinations while ensuring that demands are met at all final transformation centers. Additionally, the procedure ensured that the outgoing flow of any assortment from each yard at the end of each period did not exceeded its current stock level. The readers are directed to the article referring to Study I for a full description of the solution method.

The candidate solution for the entire problem was evaluated by a **fitness evaluation function** that includes two terms (Equation (12)). The first term was the objective function (Equation (1)). The second was a penalty function ϕ that assessed whether constraints in Constant sets (2) to (9) were met and that assigned penalties to the deviations d_2, d_3, d_4, $d_{5.1}$, $d_{5.2}$, d_6, d_7, $d_{8.2}$ and d_9 between the current value cv and the target values (left-hand side term value pv in Constant sets (2), (3), (4), (5.1), (5.2), (6), (7), (8.2) and (9)). Thus, higher constraint deviations were penalized although unfeasible solutions can be selected (Falcão and Borges 2001). The penalty weights w_2, w_3, w_4, $w_{5.1}$, $w_{5.2}$, w_6, w_7, $w_{8.2}$ and w_9 can be parameterized according to the forestry expert's perception of the constraints relative importance. Constant sets (8.2) and (10) were always met due to the structure of the AFSH procedure.

$$Z' = Z - \phi(w_2, w_3, w_4, w_{5.1}, w_{5.2}, w_6, w_7, w_{8.2}, w_9, \quad d_2, d_3, d_4, d_{5.1}, d_{5.2}, d_6, d_7, d_{8.2}, d_9), w_c \in [0,1] \quad (12)$$

$$d_c = \begin{cases} 0 & , if \ (cv < pv \ and \ constra\text{int} "\geq") \ or \ (cv > pv \ and \ constra\text{int} "\leq") \\ |cv - pv| & , otherwise \end{cases} \quad (13)$$

Deviations d_2, $d_{5.1}$, $d_{5.2}$, d_6 and d_7 were easily computed after getting the values of the decision variables in the current candidate solution. The computation of deviations d_3 and d_4 further required the use of GIS in order to estimate the size of openings in every month and to check whether the exclusion period was met. Finally, the AFSH FIFO procedure was used to compute d_9.

Afterwards, the process unfolded according to the standard SA algorithm. If the iteration provided an IFTPP solution associated to a fitness evaluation function (Z') value that was higher than its best known value (BZ') than this current solution (CZ') was accepted and stored. If the iteration provided a solution CZ' inferior to BZ', the current IFTPP solution acceptance was determined by a probability function $P(CZ', BZ', T_k)$. This function took as input the difference between the CZ', BZ' and the value of the temperature parameter T_k. A random number $random \in [0,1]$ was generated and the current solution was accepted if this number was inferior to the current $P(CZ', BZ', T_k)$ value. The T_k started with an initial pre-defined value (T_0) and decreased at the end of each iteration according to an exponential cooling scheme (Equation (15)) (e.g. Kirkpatrick, Gelatt et al. 1983, Nourani, 1998).

Thus, the probability of accepting inferior solutions increased with the temperature and it decreased with the difference between CZ' and BZ'.

$$P(CZ',BZ',T_k) = e^{\frac{CZ'-BZ'}{T_k}} \qquad (14)$$

$$T_{k+1} = \alpha T_k, \qquad \alpha \in [0,1] \qquad (15)$$

The SA algorithm iterated until the maximum number of iterations (Nit) was reached or T_k equals its pre-defined final temperature minimum value (T_f).

Problem formulation (Study II)

Study II addressed the three main stages of the reception of raw materials at the transformation mills. Including the reception of the trucks at the service gate (service stage); the truck unload at the unloading location inside the mill (delivery stage); and the continuous supply of raw materials to the production lines, either by direct freights or internal movement of the stocked material from the intermediate warehouses (line supply stage) (Figure 7).
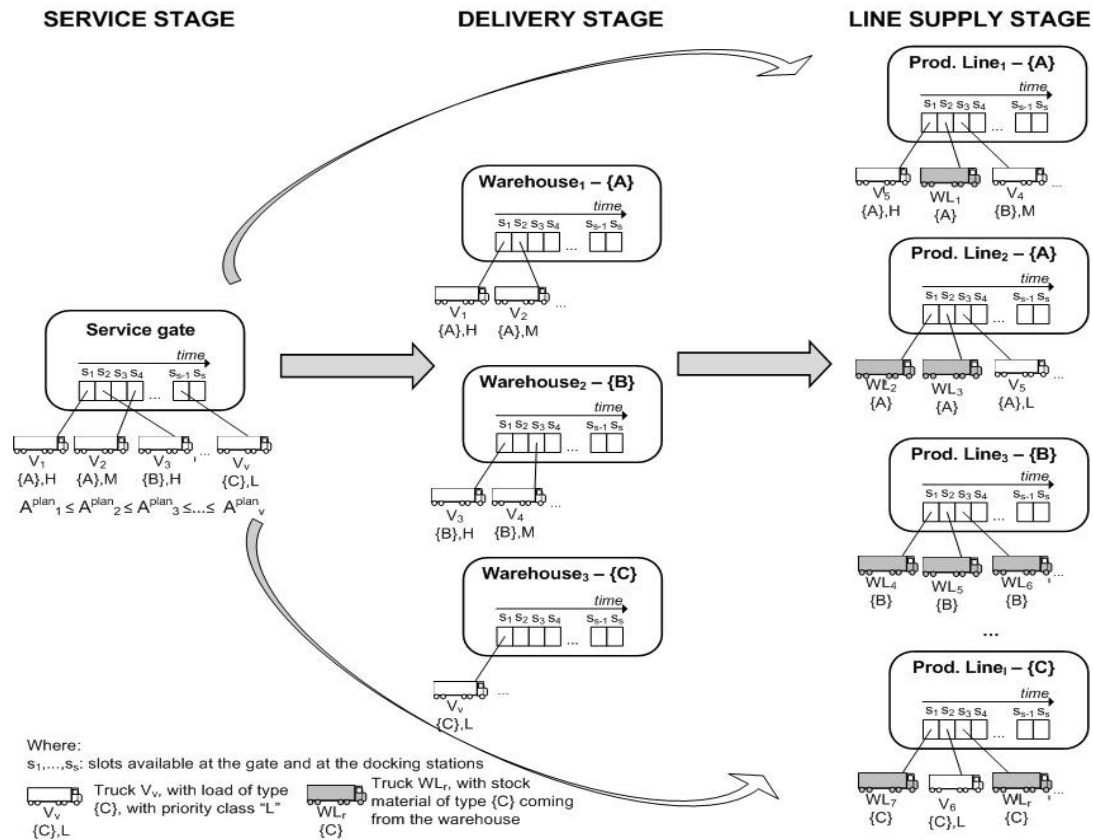

Figure 7 - Graphical representation of the raw materials reception problem

The Raw Materials Reception Problem (RMRP) consisted on sequencing the trucks at the service gate and conducting its optimal assignment to the time slots at the gate and at the unloading locations in order to minimize the raw materials reception costs. It acknowledged both the cost of materials handling at the warehouse and from there to the unloading dock, and the cost of having the trucks stationary inside the mill waiting for unload. The problem further acknowledged the arrival time for the expected deliveries and awarded with direct entrance the on-time arrivals. Consequently, the trucks were compelled to arrive within the reserved service slots and were preferentially assigned directly to the production lines. The outcome of the RMRP problem further impacted on the raw materials transportation planning and on the management of the intermediate warehouses. In fact, it fostered the compliance with the hauliers routing and scheduling plans. It also may improve the efficiency of the stock handling processes by enhancing the synchronization among the schedules of the warehouse stationary equipment with the trucks arrival at the unloading locations.

The RMRP had similarities with other airline and hotel booking problems where Revenue management (RM) techniques have been successfully applied. Revenue gains of 4-5% were reported in some airline industries (Philips 2005). The readers are directed to Quante et al. 2008, Philips 2005 and Tallury and Ryzing 2005 for a complete overview of RM principles.

Solution method (Study II)

The solution method proposed on Study II was the 3-phase procedure, anchored on the RM principles. It was built on segmenting the expected trucks and progressively managing their assignment to the available time slots at the unloading locations (Figure 8).

The first phase of the solution method - **Time Slot Allocation Planning** - run before a given delivery day. It received the planned deliveries that were the outcome of daily routing processes, and provided their optimal assignment to the slots available at unloading locations, according to their priority class.

This phase started by computing the time slots at the gate and at the unloading locations. It proceeded with the carriers/trucks segmentation into a closed-set of previously established priority classes (or segments), based on the value of its priority index (P_v^i). This index was 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, set during the transportation planning activities (Equation 16). It took values between 0 and 1. The weights of the criteria (λ_i) were set by the user as they express his policy for evaluating the hauliers transportation services. Furthermore, threshold parameters γ_{n-1}

were used to set the minimum value of the priority index above which the truck is classified into a priority class.
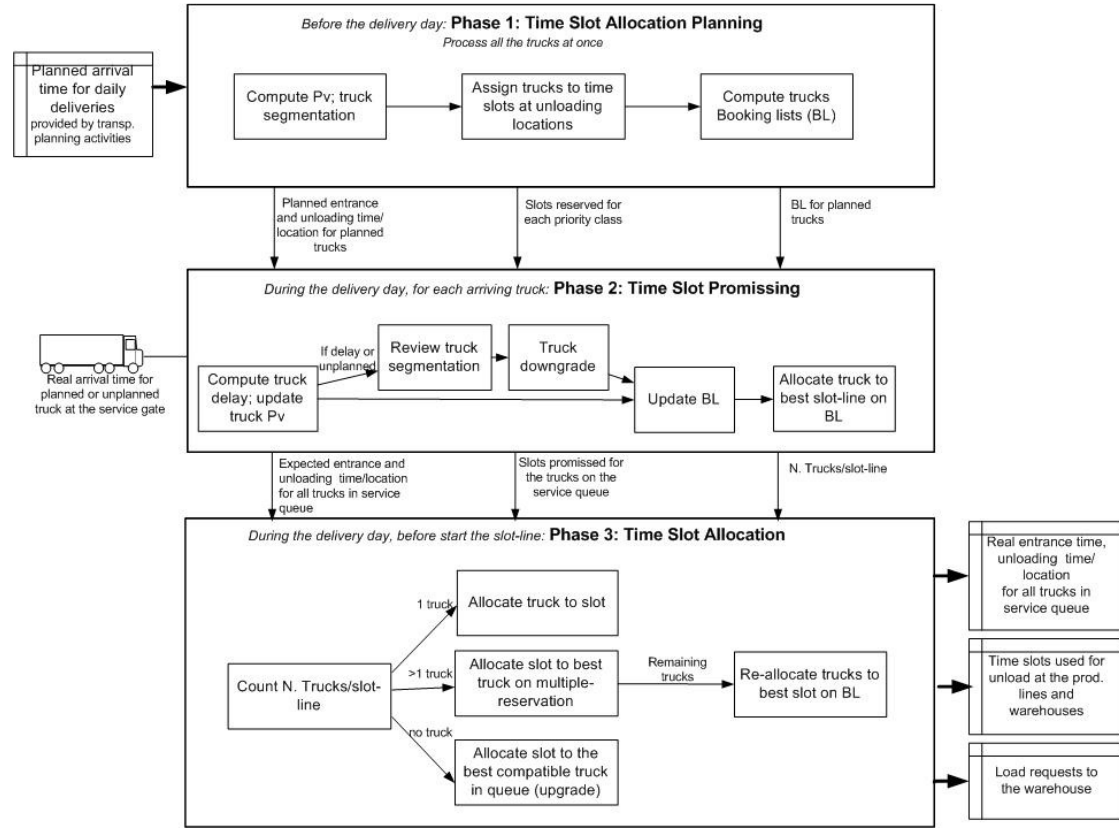
Figure 8 – Structure of the proposed 3-phase solution method for the RMRP

The priority index was further used to compute the raw materials reception cost (C_{vsd}). On equal values for the remaining cost components, the truck with the highest priority index should come forward on the queue. The remaining cost components were the cost of having the trucks stationary inside the mill waiting for unload, the cost of the materials handling when unloading occured at the intermediate warehouses and the cost of keeping the unloading resources available overtime (Equation 17). The first was the product of truck total waiting time (W_v^{plan}) by the unit cost for each minute spent by the loaded truck at the queue (C^W). The W_v^{plan} may be computed as the time difference between the beginning of unloading operations (U_{vsd}^{plan}) and arriving at the service gate (A_v^{plan}), including the duration of the service stage (L^G) and the ride from the gate to the unloading location (t_d) (Equation 18). The second component of the cost function was only considered when the unloading occurred at the intermediate warehouse. It was the product of the unit cost materials

handling (C^M) by the amount of material transported by the truck (l_v). While the third component was the product of the unit cost for overtime work (C^O) by the number of minutes beyond the line closing time when unloading should take place, either because the truck arrived after hours or its overall waiting time for unloading was prolonged. Whenever the transported raw material assortment is not accepted at a unloading location, C_{vsd} took a very high value "M"'.

$$P_v^i = \sum_i \lambda_i \, \sigma_{i,} \quad \sum_i \lambda_i = 1, \quad 0 \le \lambda_i \le 1 \qquad (16)$$

$$C_{vsd} = \frac{C^W W_v^{plan} + C^M l_v + C^O (U_{vsd}^{plan} - b^E)}{P_v^i}, \forall v : p_v = p_d, s \in S \qquad (17)$$

$$W_v^{plan} = (U_{vsd}^{plan} - (A_v^{plan} + L^G + t_d)) \qquad (18)$$

Phase 1 proceeded with the solution of the minimum cost assignment of the v expected deliveries to the s time slots available at each unloading location d. It was formulated as an Integer Programming problem. The decision variables X_{vsd} were set to 1 if truck $v \in V$ was assigned to slot $s \in S$, at the unloading location $d \in D$ and 0. It was describe as:

$$\min Z = \sum_{v \in V} \sum_{d \in D} \sum_{s \in S} c_{vsd} x_{vsd} \qquad (19)$$

Subject to:

$$\sum_{d \in D} \sum_{s \in S} x_{vsd} = 1. \quad \forall v \in V \qquad (20)$$

$$\sum_{v \in V} x_{vsd} \le 1, \quad \forall s \in S, d \in D \qquad (21)$$

$$\sum_{v \in V^M} \sum_{d \in D^L} \sum_{s \in S} x_{vsd} + \sum_{v \in V^F} \sum_{d \in D^L} \sum_{s \in S} x_{vsd} \le \pi' \qquad (22)$$

$$x_{vsd} \in \{0,1\} \qquad \forall v \in V, s \in S, d \in D \qquad (23)$$

The objective function aimed at minimizing the raw materials reception cost through the optimal assignment of the trucks with the daily deliveries to the available time slots at the unloading locations (equation 19). The remaining equations set the problem constraints. The daily delivery was assigned to exactly one time slot (Equation 20). It was assumed that unloading operations started at the beginning of a time slot and the truck was empty at the end of the slot. This was consistent with the rule previously used that sets the time slots length according to the maximum duration of the unloading operations. Reciprocally, it was imposed the assignment of the time slot to one truck at the most

(Equation 21). It was not mandatory to have the time slots at the docks all assigned during this phase. In fact, some slots may be allocated afterwards, to freights coming from the intermediate warehouse. Contrarily, the majority of the slots at the warehouses were expected to remain unassigned due to the preferential unload directly on the wood chips production lines in order to reduce the materials handling cost. Furthermore, simultaneous unloading operations on the same location were not foreseen. The next equation limited the total number of deliveries to the lines in order to keep ($\pi' = \sum_{s \in S^L}(1 - \pi)$) slots available for unplanned trucks (Equation 22). Finally, equation (23) stated the binary requirements.

The optimal solution of the assignment problem provided the planned unloading time and location (U_{vsd}^{plan}) and consequentially, the planned arrival time at the service gate (A_v^{plan}) for all the delivery requests. The compliance with A_v^{plan} during the delivery day was considered maximum priority. These trucks took the lead on the service queue, therefore their waiting time to service and delivery was minimized.

The solution further provided the sets of time slots reserved for each segment that were used on the truck booking list (BL$_v$). The BL$_v$ grouped all the feasible slots reserved to that truck, including the slots reserved for its segment and to lower segments, available since its planned arrival time. During phase 2, the reserved slots were kept available for the planned truck segment as long as possible.

The following phases of the solution method were designed for real-time slots re-assignment, triggered by delays of the expected deliveries or the arrival of unplanned trucks.

The second phase - **Time Slot Order Promising** - runs after each truck arrival. It relied on re-segmenting the trucks and re-assigning to a slot at its updated booking list. The latter excluded the slots no longer available due to the real arrival time and the possibility of downgrade to lower segments as a consequence of the truck delay. It started by computing the delay of each truck arriving at the service gate (L_v) and updating its priority index (P_v^u). The parameter σ signal on-time arrivals, corresponding to null delays. It relied on a tolerance parameter (α) set by the mill as a tolerance interval around the planned arrival time where the truck was still considered to arrive on-time. Positive delays corresponded to the time difference between the real arrival time and σ, normalized by the shift ending time in order to get values between 0 and 1 (Equation 24). The P_v^u reflected the impact of the trucks delay on its given priority classification (Equation 25). Consequently, on-time arrivals kept their priority class; yet, late arrivals could lead to the downgrading process.

$$L_v = \frac{A_v^{real} - \sigma}{b^E}, if\ A_v^{real} > \sigma;\ 0\ otherwise$$

$$\sigma = \min\{(A_v^{real} + \alpha); (U_{vsd}^{plan} - t_d - L^G)\} \tag{24}$$

$$P_v^u = \delta_1 P_v^i + \delta_2(1 - L_v); \quad \delta_1 + \delta_2 = 1; \quad 0 \le \delta_1, \delta_2 \le 1 \tag{25}$$

$$\gamma_n^u = \delta_1 \gamma_n + \delta_2\left(1 - \frac{\Delta}{b^E}\right) \tag{26}$$

The downgrading process consisted in re-classifying the truck into a lower priority class, according to its updated priority index and the revised values of the threshold parameters γ_n^u (Equation 26). It led to the reduction of the slots available at its BL_v. This process was ruled by the value of the downgrade parameter (Δ) set by the mill. It was the limit for the delay above which the truck at the bottom of its priority class will be downgraded. This parameter was further used to identify the new priority class for the late arrivals. Accordingly, all the delays equal or below Δ kept its priority class. While delays above Δ depended on the value of P_v^u. The trucks with higher P_v^u kept their priority class even for higher delays. Yet, even the high priority trucks may be downgraded to the lowest priority class when very long delays occurred. Even low priority trucks may be downgraded to a very low priority class only used for this process. The unplanned trucks had null P_v^u corresponding to the lowest priority class.

At the end of phase 2, the allocation of the arriving truck to the best slot available at its updated BL_v was based on a minimum assignment cost criteria (Equation 17). It provided the truck expected unloading time/location (U_{vsd}^{exp}) and consequently, the best entrance time at the service gate. At this stage, delayed trucks high priority may be assigned to slots previously reserved to lower priority trucks, leading to the multiple-reservation situations that were addressed on the next phase.

The third phase - **Time Slot Order Allocation** - runs just before starting each slot at the production lines, assuring that there was one truck ready for unloading. It handled the multiple-reservation situations. When these situations occurred, the slot was finally used by the truck arriving on-time or by the truck with the minimum assignment cost (equation 18). The remaining trucks were re-assigned to the best slot on its BL_v, also considering a minimum cost criteria. The double-reservation on the slots at the gate led to the postponement of the service stage that may impact on the feasibility of the expected unloading time. In this case, the truck was further re-assigned to a new slot at an unloading location. This stage often led to new multiple-reservation situations for later slots that were handled afterwards using the same approach.

When there was no truck promised for that slot, the method proceeded with the upgrading process. It anticipated the delivery phase of the best compatible truck waiting in the queue, selected based on the minimum assignment cost criteria. In the case of a slot at the unloading location, the truck was compatible when the assortment required at the production line matched the assortment carried by the truck and the anticipation of the delivery time was feasible considering the truck entrance time. When upgrading occurred, the slot initially reserved to upgraded truck became vacant.

Finally, if no truck was available at the service queue, the procedure triggered a freight request of stocked materials from the warehouses. It ultimately provided the real unloading time for the truck. The readers are directed to the article referring to Study I for a full description of the solution method.

4. Results and discussion

4.1. Computational results for the integrated harvest scheduling and timber assortment and assignment problem (study I)

The proposed MIP formulation for the integrated forest tactical planning problem (IFTPP) effectively addressed the requirements stated by the forest practitioners of the Portuguese integrated pulpwood industry engaged in this research. The problem decomposition approach proved to be adequate to address the complexity of the IFTPP. The main IP sub-problem related with harvest scheduling, included maximum opening size constraints within a typical area restriction framework (e.g. Murray 1999; Borges and Hoganson 1999; Richards and Gunn 2000; McDill et al. 2002, Caro, Constantino et al. 2003; Baskent and Keles 2005; Weintraub and Murray 2006). The second LP sub-problem established the quantities produced of each assortment and its assignment to the transformation centers. It has similarities with the problems addressed by (Andalaft, Andalaft et al. 2003) and (Karlsson, Ronnqvist et al. 2003). Yet these authors targeted assortments of logs of distinct species while our research focused on one species (*Eucaliptus globulus* Labill*)*. The log size classes and forest residues products were assorted to better fit the operations requirements of the mills owned by the pulpwood company. The IFTPP further presented similarities with the bucking problem. Yet, the former addresses forest level planning, while the latter focuses on the optimization of bucking operations of individual trees (Epstein, Morales et al. 1999; Epstein, Nieto et al. 1999). The IFTPP introduced by this research further aimed to address the role of intermediate storage yards in reducing timber transportation costs. Finally, no road building and maintenance decisions were considered as this was not required by the pulpwood company.

All the runs reported unfeasible solutions. The unfeasibility of the current IFTPP problem instance was further confirmed with the commercial CPLEX MIP solver. The impossibility of reaching feasible solutions for this problem with an exact method may be related with the size of the problem and the nature of the adjacency constraints. This precluded the use of an exact method to evaluate the solution provided by the heuristic. Yet, difference between the best value of the fitness evaluation function and the best value of the objective function was less than 1%, thus suggesting solutions near feasibility.

The solution method including Simulated Annealing and AFSH led to better performances when compared with Simulated Annealing and LP Solve. The best solution of the objective function for this problem instance with 8400 integer variables, 235536 continuous variables and 85204 constraints, was obtained after 3h14min and almost 1000 SA iterations (about 12 sec per SA iteration). While the alternative method using LP Solve took 2 hr per SA iteration. The computational times could be decreased about two orders of magnitude with SA+CPLEX. Nevertheless, the difficulty of finding admissible solutions for this IFTPP and the fact that it does not support the computation of the maximum storage duration, made it inadequate to use during this research.

The fitness evaluation function used to evaluate the solution generated in each SA iteration performed successfully on the current problem instance. It aimed at providing results even for unfeasible parameter combinations.

The tactical plan for the selected run of the baseline scenario reported a global net present value of 324.70×10^4€ correspondent to the integration of harvesting with products assortment and assignment processes. Yet, this value was computed under the assumption of distinct assortment prices paid by the mills and the storage yards. It may not be the case of real-world situations on vertically integrated industries. Practical aspects related with the ownership and confidentiality of the information prevented the quantification of the earnings in respect to the current situation where these processes are conducted independently. The plan further reported that 64% of the revenue resulted from the delivery of pulpwood and forest residues that were transported directly from the harvest units to the mills. The delivery of assortments transshipped over the wood yards led to about 36% of the revenue.

The harvest schedules for the baseline scenario displayed an asymmetric distribution of the harvests over the 12 monthly planning periods (from August 2010 to July 2011) (Figure 9). Over $\frac{1}{3}$ of the stands were scheduled to be harvested in the first 3 months. Consequently, 59% of the total supply of pulpwood and forest residues was schedule to occur in this period.

The overall production of pulpwood and forest residues exceeded the demand at the mills. The surplus was predominantly converted into barked and chipped assortments. The clear predominance of these assortments (L4B, FRC and L2B) in all the runs suggested the profitability of barking and chipping operations at the forest site. Nevertheless, these results reflected the tradeoff between the harvest costs structure and the prices for the different assortments at the mills. This information is scarce and often incomplete. Improving the quality of the information used for planning is instrumental for increasing the robustness of the results, thus enhancing the use the proposed solution method on real-world planning processes.

The tactical plan further assigned product assortments to the demand points over the procurement network (Figure 10). It highlighted the role of the intermediate storage yards for this particular case

study. The importance of the storage yards to the pulpwood supply strategy already had been suggested in other studies (Karlsson, Ronnqvist et al 2003). In Study I, there was a predominance of direct transportation from the forest to the yards during the first planning months until they reached the maximum capacity. Two of these yards were almost permanently at its full storage capacity. They were the preferential suppliers for the mills, taking advantage of the decrease of the logs weight as a result of dying under open air conditions and the lower unit transportation costs associated to the railway transportation between the yards and the mills.

Yet, these results may be confined to the context of this case study. Changing the geographical location of the mills, the storage yards and the stands will impact on the transportation costs and may lead to different conclusions. Likewise, variations of the pulpwood price, the pulp wood storage cost, the transportation costs or the proportion among all may also impact on the results. Furthermore, acknowledging the stands growth across the planning period, addressing the relation between the stand volume estimates and the sum of the volume of the logs forwarded to the logpiles ready for transport and also improving the wood drying equations will provide robustness to the results.
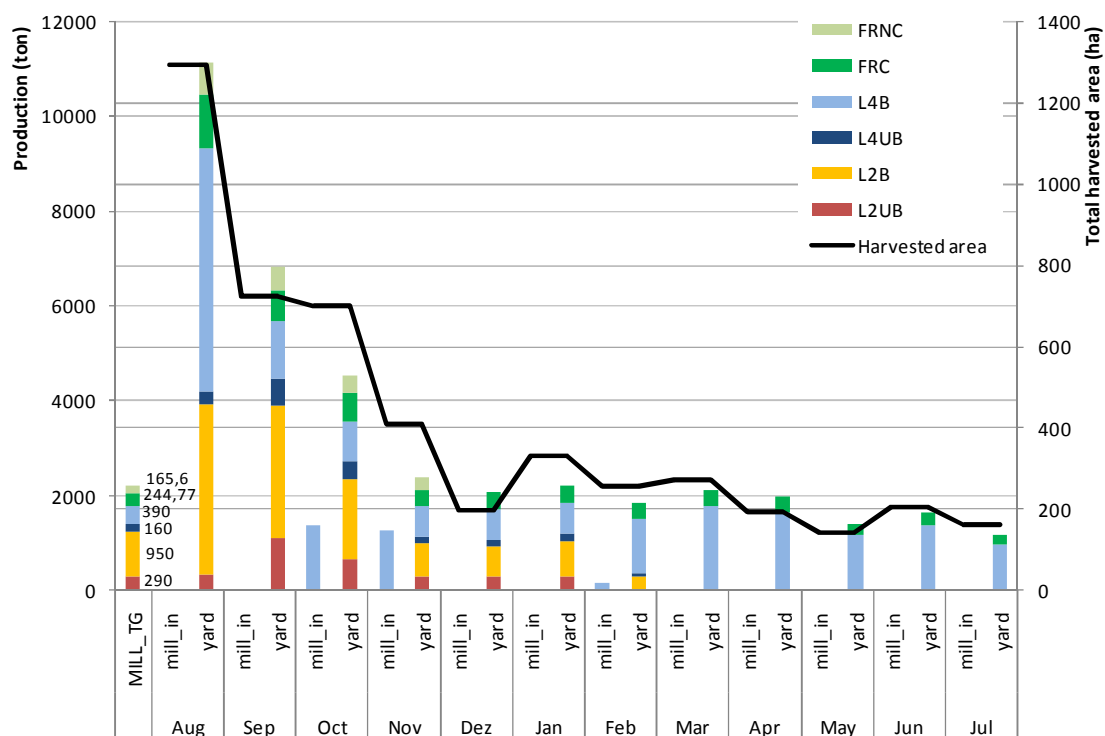
Figure 9 – Total monthly target levels of the assortments in all the mills (MILL_TG) and destination of the assortments produced each month at the harvest areas (to the mills – mill_in – or yard) (primary axis). Includes the total harvesting area per month (secondary axis). The assortments considered were 2m logs barked and unbarked (L2B, L2UB), 4m logs barked and unbarked (L4B, L4UB), Forest residues chipped and not-chipped (FRC, FRNC)

Figure 10 – Timber assortment plan for the IFTPP baseline scenario. Presents the assortments of pulpwood and forest residues produced on the forest units and its assignment to mills and yards over the procurement network. The considered assortments were 2m logs barked and unbarked (L2B, L2UB), 4m logs barked and unbarked (L4B, L4UB), forest residues chipped and not-chipped (FRC, FRNC)

The proposed solution method further provided good results for the trade-off analysis based on the generation and comparison among what-if scenarios. Scenario A_1 reduced the demand in all the mills to 80% of the values acknowledged in the baseline; Scenario A_2 considered null demand levels in all the mills; Scenario B_1 increased the capacity of all storage yards by 20%; Scenario B_2 assumed that all the yards were closed; Scenario C_1 maximum allowable clearcut opening area from 65ha to 30ha while C_2 increased it to 80ha.

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The results of the trade-off analysis showed that the best value of the fitness evaluation function was not very sensitive to the variations on the demand levels, storage capacities of the yards and maximum size of the clearcut opening area, induced by the different what-if scenarios. Yet, scenarios A_1, A_2, B_1 and C_2 reported a maximum of 1%improvement on the value of the fitness evaluation function, when compared with the baseline. Scenarios C_1 and B_2 led to a reduction of 1% and 9.4% on the value of the fitness evaluation function, respectively. The improvements on the objective function were generally associated with higher pulpwood flows to and from the yards as well as higher stock levels at the yards at the end of the planning horizon.

In general terms, all the scenarios suggested the concentration of harvesting and transportation operations on the first trimester of the planning period. The pulpwood flows to and from the yards prevailed over the direct transport from the harvest sites to the mills. The transport to the mills often matched the demand levels. Consequently, most of the scenarios presented high stock levels at the yards at the end of the planning horizon, mostly with pulpwood barked assortments and chipped forest residues. The production surplus was usually converted into the most profitable assortment-destination (L4B to Badajoz).

Furthermore, the generation of what-if scenarios was considered key to support decision making. The forestry experts acknowledged the benefits evaluating the impact of alternative values for the parameters used on the model. They further valued the possibility of using the weights on the penalty function to accommodate their preferences in respect to the constraints relative importance. The performance of the solution method was a key concern. The results should be produced within a few hours in order support real-world planning processes. The experts were even willing to use sub-optimal solutions whenever optimality could not be achieved within reasonable computational times.

4.2. Computational results for the raw materials reception problem (study II)

The proposed solution method was successfully applied for scheduling the daily deliveries at the mill for the current problem instance, encompassing 28008 decision variables (72 deliveries and 389 time slots) and 462 constraints.

The daily reception schedule at the service gate, obtained after running phase 3 - Time SlotAllocation, provided the entrance time for all the planned deliveries. As an example, 20 trucks were planned to arrive at the service gate until 9 a.m. (Figure 11). In this time window, 11 of the trucks were unplanned (301 to 311), therefore included on the low priority segment. Only 2 of the deliveries were classified high priority. 21% of the time slots at the gate were not used which suggested that the

service gate could accept more deliveries in this period, especially if the trucks would arrive before the opening hours.
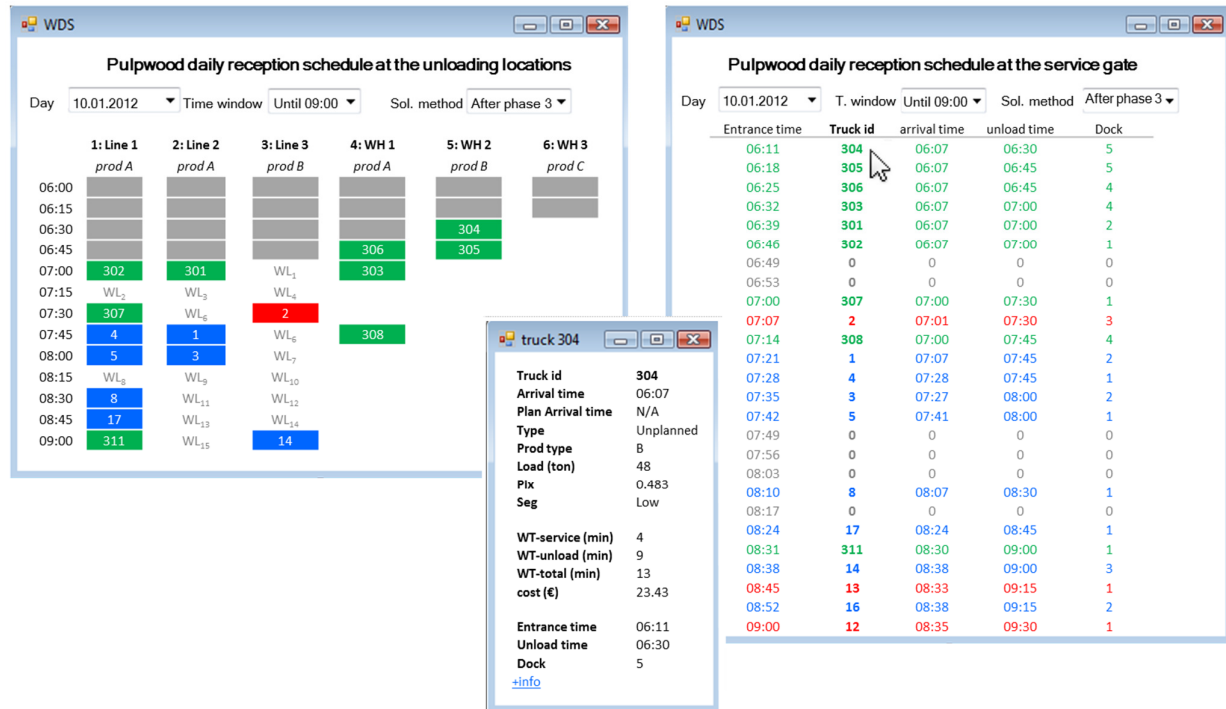
Figure 11 - Pulpwood reception schedule for the first time window of the day at the service gate and at the unloading locations for the baseline scenario obtained at the end of 3-phase method

The complementary view on the daily reception schedules at the unloading locations revealed that 60% of deliveries were unloaded at the docking stations at the wood chips production lines (locations 1 to 3, Figure 11) without passing through the warehouse. In this time window, only the unplanned arrivals were directed to the warehouse (locations 4 to 6, Figure 11), particularly those trucks arriving before the lines opening hours. Additionally, from the 27 time slots to be completed at the lines during the line supply stage, only 15 (55.6%) corresponded to internal freights coming from the warehouse.

Integrated daily results were further obtained for the baseline scenario after phase 3. The total waiting time summed 4192.9min. 80 of the 120 deliveries were unloaded directly at the lines during the 6 time windows that comprise the daily shift, corresponding to a total reception cost of 2670.5€. Only 52.4% of the time slots at the production lines were supplied by freights from the warehouse. 78.4% of the time slots at the gates were used for receiving deliveries in the course of the service stage.

The maximum waiting time for any truck was 162 min, therefore close to the threshold of 160 min aimed by the mill. The average waiting time to complete the reception process increase for 34.94min, mainly due to the high values recorded on the rush hours (average of 36.3min and 36.06min in time windows [11hr, 13hr[and [19hr, 21hr[, respectively).

The 3-Phase method further accomplished the reduction of the waiting times for the planned deliveries arriving on-time. For these 33 trucks, their average waiting time was 10.22min, independently from their priority class. For the delayed and unplanned, the average waiting time for high and medium segments was less than 20min, while for low and very low segments could go up to 63min.

The consequence of the increased traffic at the rush hour at the end of the day was an high percentage of operations performed after hours. In fact, 9.2% of the trucks were received after the gate closing hours and 12.5% were unloaded after the lines closing hours.

The daily reception schedules provided by phases 1 and 2 led to similar conclusions. Yet, the sum of the waiting time for all the deliveries after phase 2 was 16% higher than in phase 3 (4192.9min for phase 2), resulting on a higher cost for the entire reception process (3034.9€). As expected, the outcome of Phase 1 - Time Slot Allocation Planning was significantly better than the following phases. The total reception cost was a small fraction of the cost obtained during phase 3 (413.2€ for phase 1), as it only took into account the sub-set of the planned trucks.

The 3-phase method led to substantially better results than the FIFO procedure used today. Specifically, the cost of the entire daily reception process was reduced from 6023.4€ to 2670.5€. The 55% cost reduction was a direct consequence of the 80 freights unloading directly at the lines. The higher number of possible unloading locations led to a drastic reduction of the sum of the waiting time for all the trucks at the delivery stage from 6084.9min to 1206.0min. Likewise, the maximum and the average waiting time for any truck to complete the reception process was reduced in about 28 min and 38 min, respectively. Direct unloading at the production lines further enabled 887.25of savings related with the abolished materials handling operations.

Yet, the FIFO procedure conducted to better results on the sum of the waiting time at the service stage (2694.9min against 2896.9min). This procedure did not rely on time slot discretization; the arrival truck could be directly received if no other truck was first in line, without waiting for the beginning of a time slot. Consequently, the number of trucks received after closing with the FIFO procedure is also slightly inferior than with the 3-Phase method (12, 10, 17 respectively).

Additional positive results of the 3-phase method was the stabilization of the queue size at the delivery stage. As expected, both methods presented large fluctuations on the size of the service queue across the delivery day.

The comparison among "what-if" scenarios proved to be adequate to address the impact of key parameter values used both on the case simulation and on the solution method, over the solution results. Scenarios 1 to 3 accessed the impact of reducing the length of the time slots at the gate and the unloading locations. SCN_1 reduced the L^G to 5 min, while SCN_2 and $SCEN_3$ reduced L^Y and L^L to 10min, respectively. SCN_4 considered one additional production line processing the assortment type B. SCN_5 changed the proportion of unplanned arrivals from 40% to 70%. The new data set for the real deliveries used in this scenario included 168 unplanned arrivals and a total of 240 deliveries per day. SCN_6 increased the proportion of the trucks arriving at the rush hours to 65%. SCN_7 removed the direct unloading at the lines, therefore considering only the 3 active cells at the warehouse.

Both methods showed that the total number of daily deliveries and its distribution across the delivery day had the greater impact on the total raw material reception cost. In fact, SCN_6 concentrated 65% of the 120 daily deliveries within the rush hours increased the value of the objective function to 4566.5€.

When the percentage of trucks arriving at the rush hours remained the same but the number of trucks rose to 168 trucks (SCN_1), a 22% increase of the objective function was reported with the 3-phase method (3425.8€). The same method presented up to 400% increase when the maximum number of 240 daily deliveries was considered (SCN_5). In the latter scenarios, the FIFO procedure recorded even higher upraise of the reception costs. The total reception costs of SCN_1 were almost two orders of magnitude higher than the 3-Phase method. It was of the same magnitude than the total cost obtained for SCN_5, although in this case 89 trucks were excluded from the cost computation as they could not be received before mid-night.

These results suggested that the adequate reception capacity at the baseline conditions was 100-140 daily deliveries. Above this threshold, some of the trucks were received after the gate normal opening period, therefore with additional costs for the employees working extra-hours. Furthermore, when the number of deliveries rose above 150, the reception of the last arriving trucks was delayed to the next working day.

The remaining parameter values tested related with the length of the time slots at the unloading locations led to variations of less than 10% of the receptions costs obtained for the baseline scenario.

This comparative analysis further showed that the possibility of direct unloading at the production lines considered only for the 3-Phase method was instrumental for improving the total pulpwood reception costs. In fact, scenario SCN_7 excluded the lines from the delivery stage resulting on a 154.8% increase on the value of the objective function, thus, surpassing the value reported with the FIFO procedure.

This analysis further reveled slight variations for the three indicators in the case of the high and the medium priority trucks (e.g. the truck average waiting time varied between 19-32 min and 11-25min

respectively) (Figure 12). Contrarily, larger fluctuations were reported for these indicators in the case of the low and very low priority trucks. The maximum waiting time for the later could rise above 420min in some scenarios.
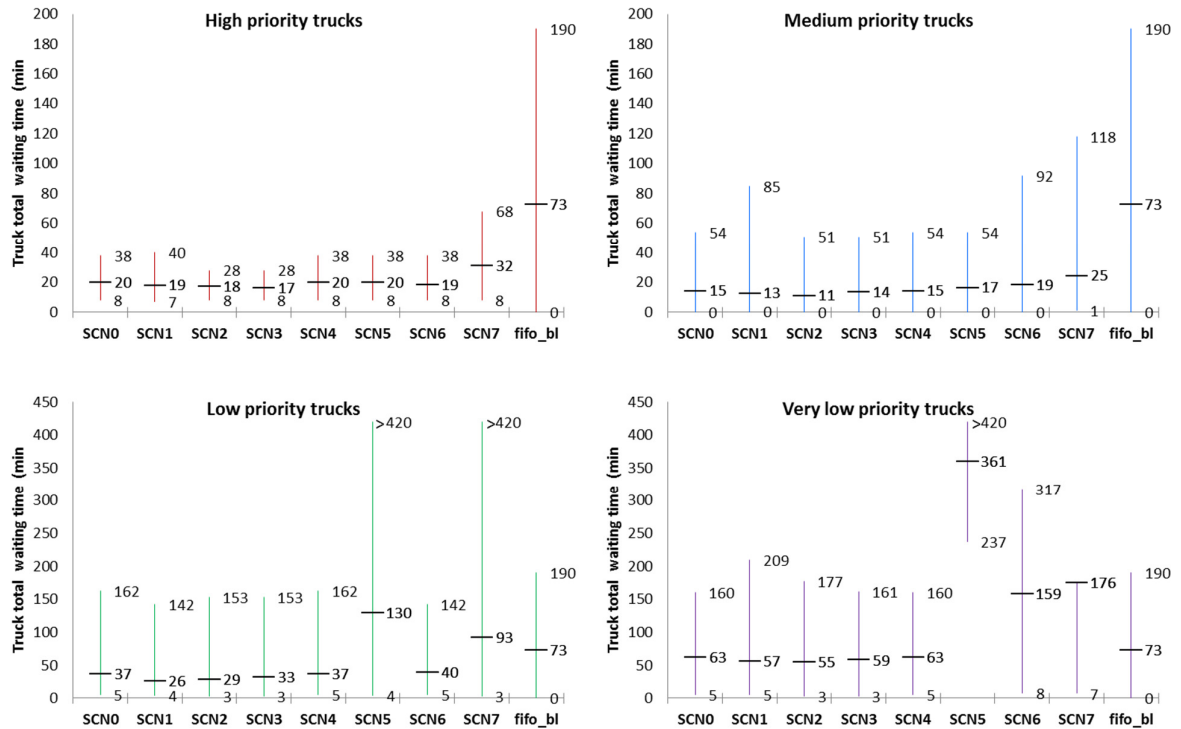
Figure 12 - Comparison among the what-if scenarios of the maximum, minimum and average waiting time for a truck to complete the wood reception process, using the 3-Phase method

Yet, on-time arrivals were awarded with reduced waiting periods, despite the truck segment. The correspondent minimum waiting time varied between 0-8min in all cases, with the exception of the very low priority trucks on SCN_5. The increased traffic of trucks from higher segments caused profound delays on the reception of the very low trucks that wait in this case an average of 361min.

4.3. Architecture of the Pulpwood supply information system (study III)

The Enterprise Architecture methodology provided a valuable representation of the complex interaction of activities performed on the pulpwood supply chain related with this Portuguese Pulp and

Paper Company. It successfully integrated business processes related with integrate forest production and wood logistics.

The Process Architecture presented the three-level process structure for the pulpwood supply management activities performed by the industry's Forest Management Department (FMD). The top level centric context diagram identified four other departments involved on forest planning as well as thirteen external entities. It further identified the nature of the information flows exchanged (Figure 13). The paper flows were still prevalent.

Figure 13 - Context diagram for the Forest Management Department (top level representation obtained at the Process Architecture stage), identifying the internal and external players involved in pulpwood supply as well as the information flows among them.

The intermediate process representation – the Celbi's Forest Production and Wood Logistics Future Business Model -, displayed both the processes and the information flows exchanged with the external entities identified previously. This business model was instrumental for developing the Pulp-Paper Supply Chain Processes Framework (Figure 14). The framework has similarities with other high-level process standards, such as the Supply-Chain Operations Reference-model (SCOR 2006) and the Process Classification Framework (APQC 2006). The proposed framework classified business

processes according to its supply scope and temporal scale. Thus, processes were classified according to forest production, wood logistics, pulp and paper (P&P) production, P&P logistics and P&P sales scopes and strategic, tactical, operational planning or operational and subsequent financial follow-up decision focus. It further addressed the transversal support processes, such as Human Resources Management, Environmental impact management, Working Hygiene and Security Management, Financial Management and IT management.


BUSINESS PROCESSES

	FOREST PRODUCTION	WOOD LOGISTICS	P&P PRODUCTION	P&P LOGISTICS	P&P SALES
STRAT. PLANNING	▪ Strategic forest planning ▪ Forest areas registration ▪ Land and wood acquisitions and rentals	▪ Wood yard location, layout and capability ▪ Routes and Transportation planning	▪ Plant location, layout and production capability ▪ Pulp and paper demand and offer estimates	▪ Warehouses location, layout and capability ▪ P&P distribution network design	▪ P&P market strategy (market selection, clients segmentation...) ▪ New products and services ▪ P&P pricing ▪ Sales network design ▪ P&P sales volumes estimates
TACT. PLANNING	▪ Tactical forest planning ▪ Forest inventory planning ▪ Forest roads management (maintenance, new roads) ▪ Work-orders characterization	▪ Self-owned wood assortment and assignment ▪ Wood deliveries agreements ▪ Suppliers qualification ▪ Equip. Management (trucks, harvesters...)	▪ Monthly qualified wood supply levels ▪ Plant equipment management (maintenance, acquisitions) ▪ Production factors supply management	▪ P&P plant stock management ▪ Equip. Management ▪ Transportation fleet management	▪ Client management (contracts) ▪ Client assignment to sales points ▪ P&P sales points stock management
OPERAT. PLANNING	▪ Harvest scheduling ▪ Forest sanity management ▪ Forestry projects elaboration ▪ Work orders adjudication ▪ Logging routes definition	▪ Transp. scheduling ▪ Crews scheduling ▪ Wood reception at pulp plant ▪ Trucks queue management	▪ Daily qualified wood supply levels ▪ Daily plant equipment management ▪ Production factors stock management ▪ Working-shifts scheduling	▪ Internal warehouse management (Picking and packing)	▪ P&P marketing campains ▪ Client management (P&P requests)
OPS&FIN. L FOLLOW-UP	▪ On-site forest operations follow-up ▪ Financial follow-up; Wood production costs estimates ▪ Self-supply wood valorisat. ▪ Inventory follow-up	▪ Transportation follow-up ▪ Wood yard availlability follow-up ▪ Wood quality evaluation ▪ Suppliers evaluation	▪ Plant equip. functioning follow-up; Workers management (absences, alocation to equipements...) ▪ P&P production levels and quality evaluation ▪ P&P prod. costs estimates	▪ Transport. follow-up ▪ P&P stock availlability follow-up ▪ Suppliers evaluation	▪ Client requests reception and follow-up ▪ P&P sales points stock availability follow-up ▪ Clients satisf. Evaluation ▪ Sales points evaluation

SUPPORT PROCESSES

▪ Human Resources management	▪ Environmental impact management	▪ Working Hygiene and Security Management	▪ Financial management	▪ IT management

Figure 14 - Preliminary version of the Pulp-Paper Supply Chain Process Framework, based on the business model for forest production and wood logistics developed for the case study

The business process related with forest production and wood logistics were further represented using the Business Process Modeling and Notation (e.g. OMG 2010). The readers are directed to the article referring to Study III for a complete description of the Celbi's Forest Production and Wood Logistics Future Business Model and the detailed description of the business processes.

The information architecture provided a description of the 25 nuclear Information Entities related with forest production and wood logistics. The Information Entities-Relationship model identified its main

attributes as well as the type of relationship among them (Figure 15). For example, the "management unit" information entity included the biometric data collected in inventory plots, type of ownership and the historic of forest operations. Each unit had at least one species and could produce several product assortments. It was annually audited in the course of the tactical and forest tactical and operational planning processes.
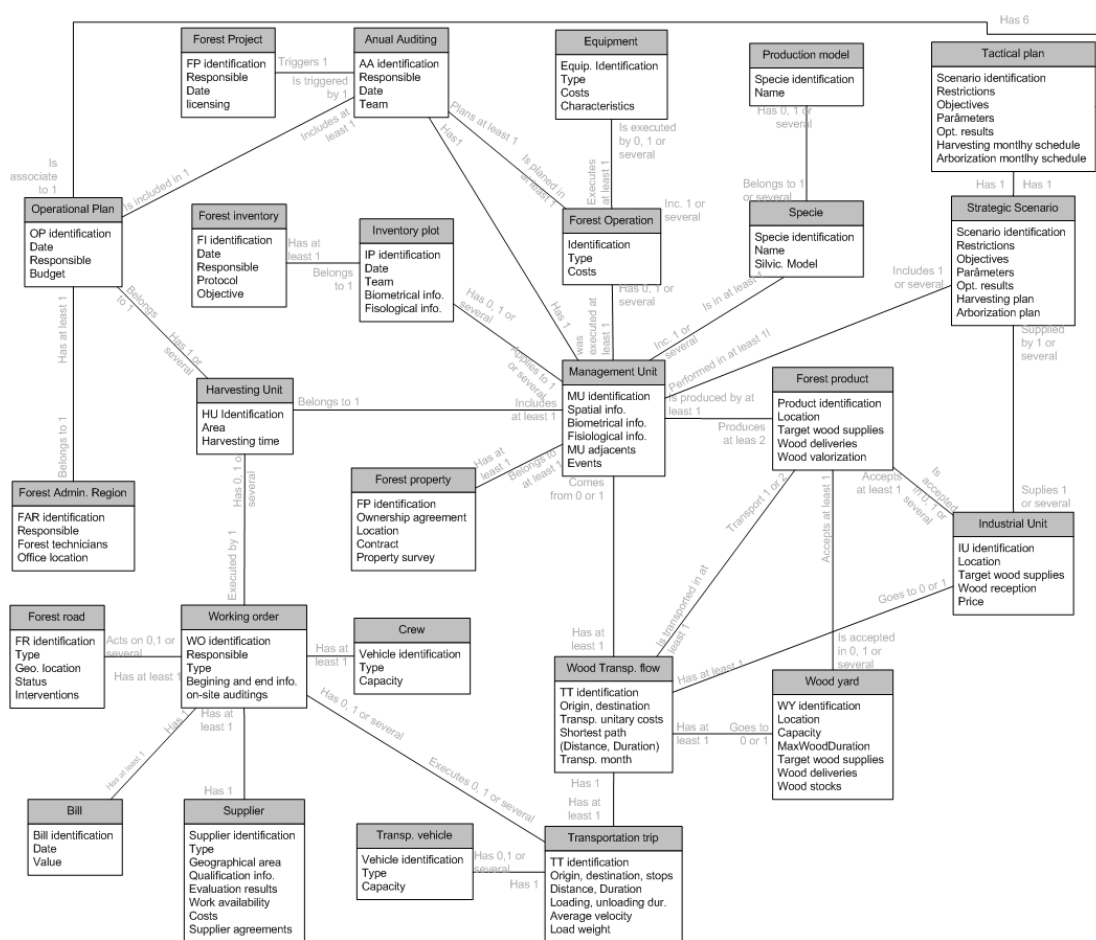
Figure 15 – Information Entities-Relationship model obtained at the Information Architecture stage. It displays all the information entities and its main attributes as well as the nature of the relationships among them.

Both the process representations and the E-R model were instrumental for identifying the functional modules of the pulpwood supply information system (PSis). Accordingly, the Forest Patrimony Management sub-system (FPMss) handled forest properties management in the context of processes such as forestland registration and wood acquisitions and rentals. Forest roads management and annual auditing activities were also included.

The Forest Planning sub-system (FPss) encompassed strategic, tactical and operational forest planning, forest equipment management as well as remote Forest Operations Follow-up for updating biometrical data, events and forest operations historical records.

The third sub-system, Wood Supply Management sub-system (SMss) addressed the definition of pulpwood market volumes and self-supply volumes demanded by the mills. It would further support the assessment of the third-party entrepreneurs that conduct the forest operations, based on the information provided by the forest operations follow-up.

The Work-orders Management sub-system (WOMss) created and controlled the execution of work-orders for budgeted forest operations, road management activities and transportation requests.

The Wood Logistics sub-system (WLss) planned the wood flows across the procurement network. It further addressed the daily scheduling of trucks and equipment/crews. The Wood Reception sub-system (WRss) managed wood loads quantification and qualification at the industrial unit entrance. It also planned trucks unload sequence and internal destination (e.g. wood yards, truck park or directly into the wood digesters).

Finally, the Forest Inventory sub-system (FIss) supported the forest inventory process (logistics, procedures, and plots location) and stored the data collected during this process. These modules shared a common database management system and were accessed by graphical user interfaces (Figure 16).

The Technological Architecture established several principles and recommendations for developing the future system, namely the Network Infra-structure, Servers structure, Data Base Management System, Geographical Information System, Middleware, Decision Support Systems and Security Server.

Additionally, Study III further proved that the proposed approach did address the experts' concerns thus acknowledging the human organizational dimensions of information systems (Reynolds et al. 2007). Systems functional requirements were defined according to stakeholders' know-how and expertise. The proposed architecture approach further promoted stakeholders involvement in all stages of system design taking advantage of participatory methods that are deemed critical to the success of decision support systems (Kangas et al. 2008). Nevertheless, forest business experts' successful involvement requires stakeholder's time availability and prior training on the EA terminology.

Other positive effect of this methodology was fostering multi-department and multi-role interactions over abstract drawings and representations. These multidisciplinary discussion forums are uncommon in many forest-based companies. Yet, the adoption of these new working practices may facilitate the change that is needed to integrate business process over the whole pulpwood supply.
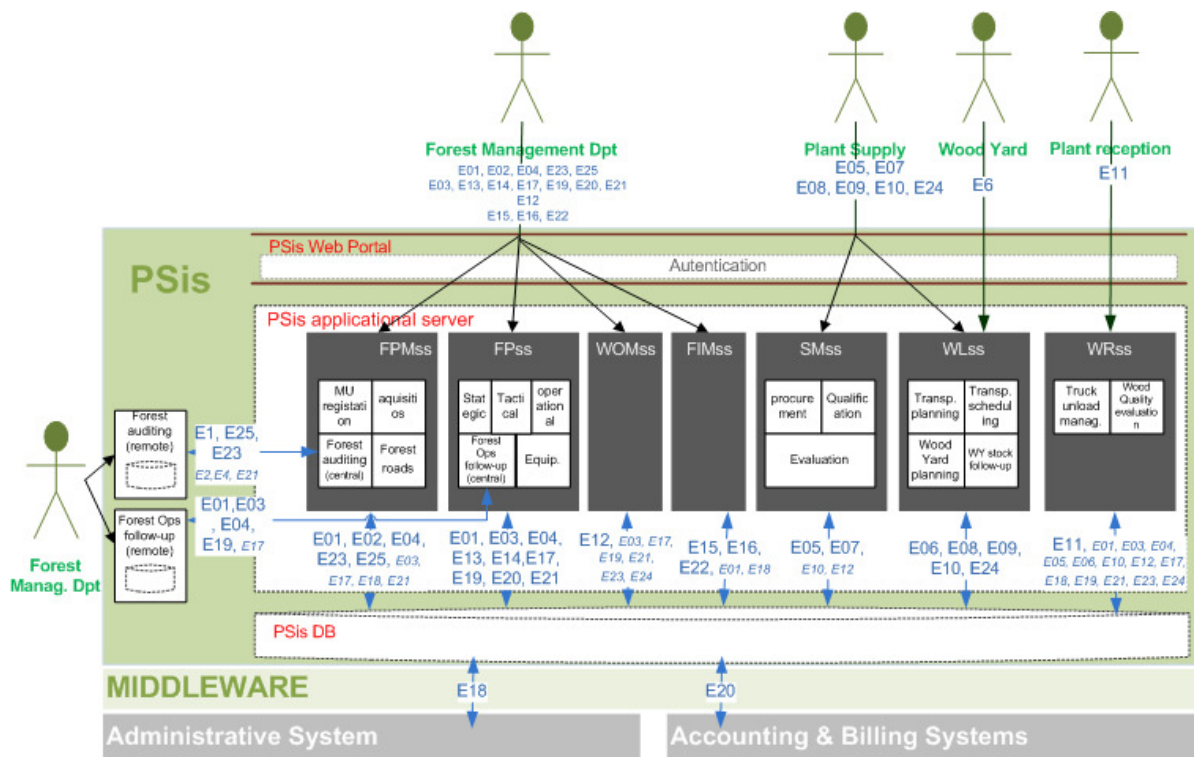
Figure 16 – The proposed pulpwood supply information system (PSis) three-layer schema, obtained at the Applications Architecture stage, represents the 7 proposed sub-systems, namely: Forest Patrimony Management sub-system (FPMss), Forest Planning sub-system (FPss), Wood Supply Management sub-system (SMss), Work-orders Management sub-system (WOMss), Wood Logistics sub-system (WLss), Wood Reception sub-system (WRss) and Forest Inventory sub-system (FIss). It also identifies their main user and the information entities handled, such as: Management Unit (E1), Forest Property (E2), Harvesting Unit (E3), Silvicultural Operation (E4), Industrial Unit (E5), Wood Yard (E6), Forest Product (E7), Transp. Flow (E8), Transp. Trip (E9), Transportation Vehicle (E10), Supplier (E11), Work order (E12), Strategic Scenario (E13), Silvicultural Model (E14), Forest Inventory (E15), Inventory plot (E16), Operational Plan (E17), Forest Administrative Region (E18), Forest project (E19), Bill (E20), Equipment (E21), Production Model (E22), Forest road (E23), Crew (E24) and Auditing (E25).

4.4. Architecture of the regional forest management planning toolbox (study IV)

This research addressed the need to acknowledge both the forest management decision processes by individual stakeholders and the complex regional interactions network. The resulting regional forest management planning toolbox (RgTbx) may enhance the development of individual decision processes by providing access to innovative decision support tools (e.g. models, methods and procedures). It may further support the stakeholders' regional interaction network with adequate communication, cooperation, negotiation and information sharing procedures and techniques. It will thus be influential for improving forest management planning at regional level.

The engagement of stakeholders in the design of the RgTbx was a major concern of this research. Therefore, participatory planning techniques were applied, particularly during the process architecture workshops, according to the enterprise architecture methodological approach. These workshops were instrumental for documenting the stakeholders' current decision processes as well as for identifying their concerns and expectations.

The individual and the integrated context diagrams provided a good representation of the complexity of the regional interaction network. As an example, the context diagram of ACHAR encompassed 13 entities with whom this forestland owners association exchanged regular information flows. The integrated context diagram identified 42 distinct entities. Over 85 information flows were reported to be exchanged among entities. The complexity of this diagram made it unreadable outside the dynamic HTML repository.

The intermediate level of the process hierarchical representation - business model – brought light the scope of action of each stakeholder in respect to forest planning at regional level. In particular, it was clear that ACHAR participation extended beyond the support to forestland owners decision-making. In the case of ACHAR, only two business processes (Figure 17) were directly related with providing management planning services to the forest owners (P1) or with providing support to their forest products commercialization (P4).
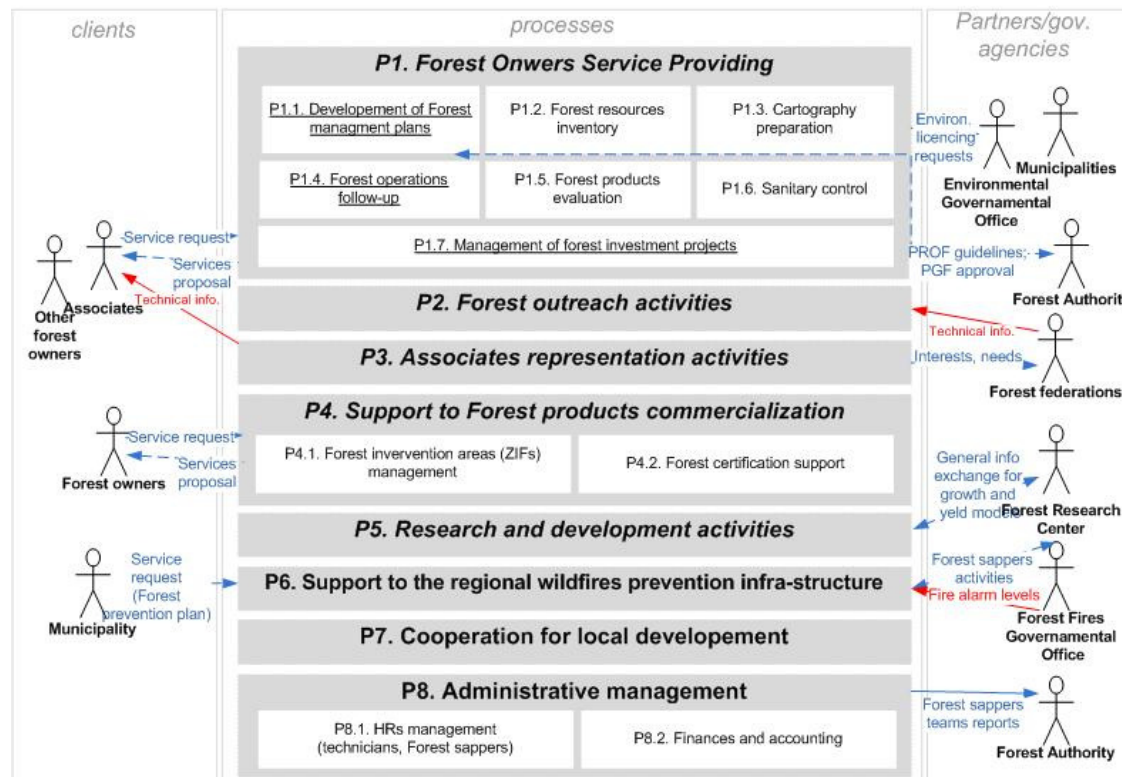
Figure 17 – ACHAR business model

The Forest Owners Service Providing process included the development of forest management plans (P1.1), forest resources inventory (P1.2), cartography (P1.3), forest operations follow-up (P1.4), forest products evaluation (P1.5), sanitary control (P1.6) and forest investment projects formatted for application to public subsidies to forest activities (P1.7). Other business processes by ACHAR included the support to the regional wildfire prevention infra-structure (P6) and non-commercial activities, such as outreach activities (P2), associates' representation activities (P3), research and development activities (P5), cooperation for local development (P7) and administrative management (P8).

The third representation level consisted on a flowchart built using the BPMN that revealed the sequence of activities usually conducted in the framework of each process. As an example the development of the forest management plan, according to existing forestry regulations, encompasses a number of activities carried out by the ACHAR forest technicians at the request of an associate (P1.1.) (Figure 18). This process started with an expedite site characterization based on data publically available (e.g. at the forest authority offices) such as forest cover maps and PROF guidelines and recommendations for the zone where the property or set of properties was located. If needed, it could include visits to the forest site to collect forest inventory data. Afterwards, the property was classified into homogenous management units. The identification of management goals generally took place in a meeting with the owner. Typically they addressed revenue concerns and they thus focus on the supply of the most important market products (timber and cork). Yet, the ACHAR technicians could highlight the economic benefits of new prescription models, alternative species and other non-wood productions and services. Environmental and social concerns were typically met through the compliance with PROF guidelines. In the end, the management plan (PGF) suggested one prescription for each stand and provided a rough estimate of the operations/investment costs.
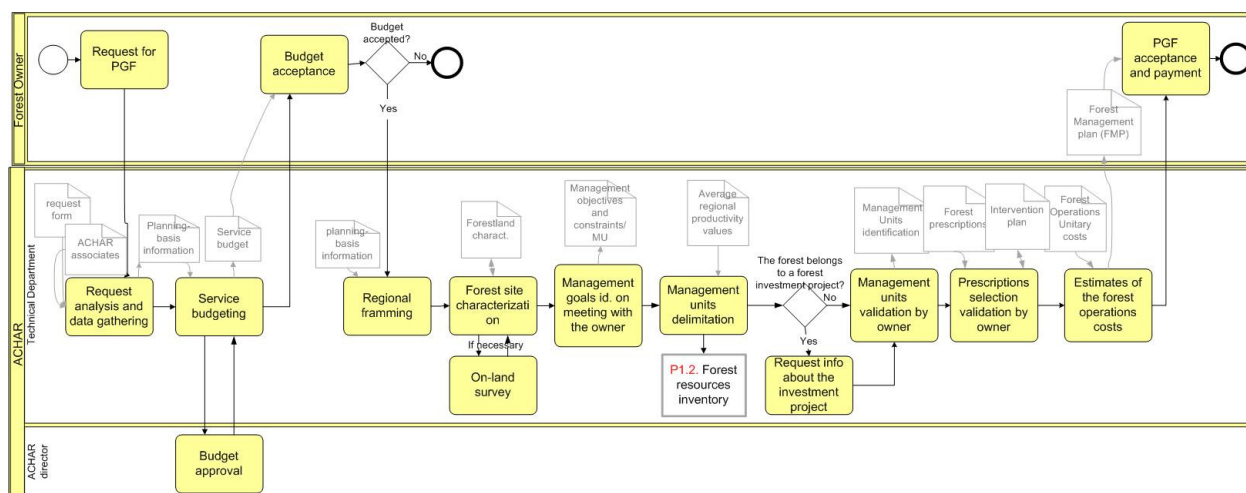
Figure 18 – Process of Forest management plan preparation (P1.1)

The integrated stakeholders' analysis identified the contribution of all the stakeholders in the regional forest management planning framework. In particular, it identified the main individual decision processes addressed by the key decision-makers (industry, NIPF, forest investment fund and regional office of the forest authority). There were few explicit interactions between the first-level stakeholders. They were more prone to happen in the interface between NIPF and the forest fund in the case of properties that were included in the fund. Yet, implicit interactions were reported among NIPF, namely regarding the setting of prices in forest products on the selling agreements. At some extent, all first-level stakeholders were influenced by other active stakeholders, such as the Forest Associations, the Forest Service Providers, Forest-based industries and Municipalities. The analysis further identified a group of passive stakeholders that do not interact so frequently with the key stakeholders and yet they provide information and support to enhance forest management planning at the Chamusca County. They included local communities, forest research centers, non-governmental organizations, forest federations, industry associations and hunting associations.

This third stage of the engagement plan further identified the role of each stakeholder in the regional forest management planning framework. The readers are directed to the article on Study IV for further information on the matrix used for this analysis.

The stakeholder groups' replies to the questionnaire handled during the last stage of the engagement plan led to the listing of 20 tools needed to support their current and future individual decision processes within the forests management planning problems prevalent in the region (first part of Table 3). Furthermore, the core information needed by individual processes and further exchanged within the regional interactions network was classified into 25 information elements to be address by the RgTbx (second part of Table 3). The readers are directed to the article referring to Study IV for additional information about this matter.

Table 3 – Components of the forest management planning RgTbx. It includes the models/methods and the procedures/documents needed to support both individual processes developed by stakeholders groups and the stakeholders' network interaction. It further describes the way each stakeholder group interacts with each data and information elements classified as Create (C), Read (R), Update (U); Delete (D). (*: GIS-based information); The stakeholders groups were: Non-industrial private forestland owner (NIPF), industrial owner (IPF), Forest Investment Fund (FIF), Forest Authority regional and national offices (FAr, FAn), Forest Service Provider (FSP), Forest Association (FA), Forest-based industry (I), Municipality (M), Forest Research Center (FRC), Forest Federation (FF), Local community (LC) and Non-Governmental Organization (NGO)

Decision Support tools	NIPF	IPF	FIF	FAr	FSP	FA	I	M	FAn	FRC	FF	LC	NGO	Total
Models/methods:														
Q1. Forest productivity zoning	x	x	x			x	x		x	x				6
Q2. Regional growth and yield models	x	x	x	x		x			x	x				6
Q3. Fruit production estimation model	x	x	x	x		x			x	x				7
Q4. Cork quality & quantity prediction models	x	x	x	x		x				x				6
Q5. Harvesting/stripping opt. Models	x	x	x	x		x				x				6
Q6. Impacts of fertilization into production	x	x	x	x		x				x				6
Q7. Forest market evolution models	x	x	x	x		x	x		x	x	x		x	9
Q8. Product distrib. Routing, storing		x	x	x		x	x			x				5
Q9. Optimal equipment allocation models		x	x	x		x	x			x				5
Q10. Risk prediction models		x	x	x						x				4
Procedures/documents:														
q1. Forest operations and prescriptions for market goods, Prescription models/ productivity classes	x	x	x	x		x			x	x				7
q2. Forest operations and prescriptions for non-market goods and services	x	x	x	x		x			x	x				7
q3. Forest Management standard procedures	x	x	x	x	x	x			x	x	x			10
q4. Conservation prescriptions	x	x	x	x		x			x	x	x			8
q5. Participatory techniques for public forests management and ZIF management	x			x		x		x	x	x	x		x	8
Other tools:														
t1. Training courses on planning tools	x	x	x	x	x	x	x		x	x	x			10
t2. Training and support on non-wood products and services management	x			x		x				x	x			5
t3. Collective forest equip. owning/renting	x					x	x			x	x			5
t4. Portable devices for forest surveys	x	x	x	x	x	x	x		x	x	x			10
t5. Online Forum	x	x		x		x		x	x	x	x	x	x	10
Data and information elements:														
i1. Municipallity Management Plan*	R	R	R	R		R		CRUD		R				8
i2. Protected Areas*, meteo.*, land uses*	R	R	R	R		R		R	R	R				8
i3. Hunting areas*	R	R	R	R		R		CRUD		R				7
i4. Forest Intervention Zones (ZIF)*	R	R	R	R		CRUD		R	RU	R				8
i5. Historic record of the area burned annually	R	R	R	R		R		R	CRUD	R				8
i6. Regional Forest Management Plan*	R	R	R	R		R	R		CRUD	R				8
i7. BD Regional forest inventory data*	R	CRU	CRU	CRU		CRUD			CRU	R				7
i8. BD product prices	RU	R	R	R	R	CRUD	R		R	R			R	10
i9. BD forest operations costs	RU	R	RU	R	RU	CRUD			R	R			R	9
i10. General info. on forest product markets	R	R	R	RU		R	R	CRUD	R	R	CRU		R	11
i11. BD Service providers characterization	RU		RU	R		CRUD	R			R	R			7
i12. Technical forest bibliography				RU		R	R			CRUD	RU			5
i13. BD Properties and forest operations*	CRUD	CRUD	CRUD	CRUD	R	CRUD		R	RU	R	R			10
i14. BD forest investment support	R	CRUD			R	CRUD			CRUD	R	R			7
i15. Legislation analysis	R	R	R			R	R	R	CRUD	R	CRUD	R		10
i16. Forest sectorial statistics				R			R	RU	CRUD	R		R		5
i17. BD ownership structure	R	R	R			CRUD		RU	R	R	R	R		9
i18. BD conservation interests	RU	CRUD	CRUD	CRUD		CRUD		RU	RU	R	R		R	10
i19. Watercourses and water repositories*	RU	RU	RU	RU		CRUD			R	R	R			8
i20. Forest fires prevention plans*	R	R	R	R		R		CRUD	R	R	R			9
i21. Forest roads*	R	RU	RU	RU		CRUD		R	R	R	R			9
i22. BD Administrative info.	CRUD	R	R	R	CRUD	CRUD					CRUD			7
i23. BD equipment	R	R	R	CRUD		CRUD	R			R	R			9
i24. BD licensing requests & Infractions	R	R	R	R		CRUD		CRUD	CRUD			R		8
i25. Wood demand estimates	R	R	R	R	R		CRUD							6

4.5. Architecture of the Forest Products Supply Chain Management System (study V)

The Enterprise Architecture approach was used to provide standard descriptions for the process elements related with the forest production, wood logistics and plant supply. The research addressed both the pulp and paper and the lumber supply chains in Portugal. These descriptions included the activities and information flows produced/consumed during the activities execution. The process elements were grouped into a high level representation. The FPSC Process Architecture Framework may serve as a reference guide, leading to individual agent efficiency improvements and enhancing its collaboration with the other supply chain counterparts. It can be mapped into individual agent specific procedures. The readers are directed to the article on Study V or Marques et al. (2012) for further information on the proposed Process Architecture Framework.

All the input and output information flows associated to the Forest Production process elements were grouped into 15 information entities (IEs). The confrontment between the process elements and EIs within the CRUD matrix and the application of IT alignment rules lead to the identification of the 12 modular components of the FPSC management system (Figure 19). These modular components encompassed both planning DSS and mobile solutions for operations control. The forest and industry experts used the DSS to produce the plans for forest production, wood logistics and mills supply plans. The mobile solutions encompassed several mobile devices used by the on-land agents' profiles to collect real-time execution metrics, which should be centrally consolidated for operations monitoring (BackOffice) and then shared among the agents.

According to the applications architecture, the Forest production processes were addressed by 1 planning sub-system and 4 control sub-systems. The Forest Operations Planning System (S1) produced all the forest management plans (E21), including the strategic, tactic and operational plans used by the industrial forestland owners, the PGF template adopted by public and small-scaled managers and other collective forest management plans. It also established the harvest units (E5) and the forest roads interventions schedules (E15).

The Properties Management System (S2) relied on mobile GPS devices for property delimitation (included on E2) and on-land data collection (e.g. biophysical characteristics of the forest properties, forest operations performed (E1)).

Similar devices may be used as part of the Forest Inventory System (S4) and on-land Forest Operations Management System (S5). In the first case, they provided the location of the pre-defined forest inventory plots (E20) and recorded its biometrical data, according to the inventory protocol previously established. Their main users may be forestry planners, possible outsourced inventory teams conducting national forest inventory or for entrepreneurs requiring precise wood estimates

during the negotiations with the landowners. In the second case, these devices may provide the geographical coordinates of the forest and road management operations (E1) and allow the user to record some execution metrics. The information collected was synchronized to central data repositories, subjected to validation schemas and then distributed to other systems.
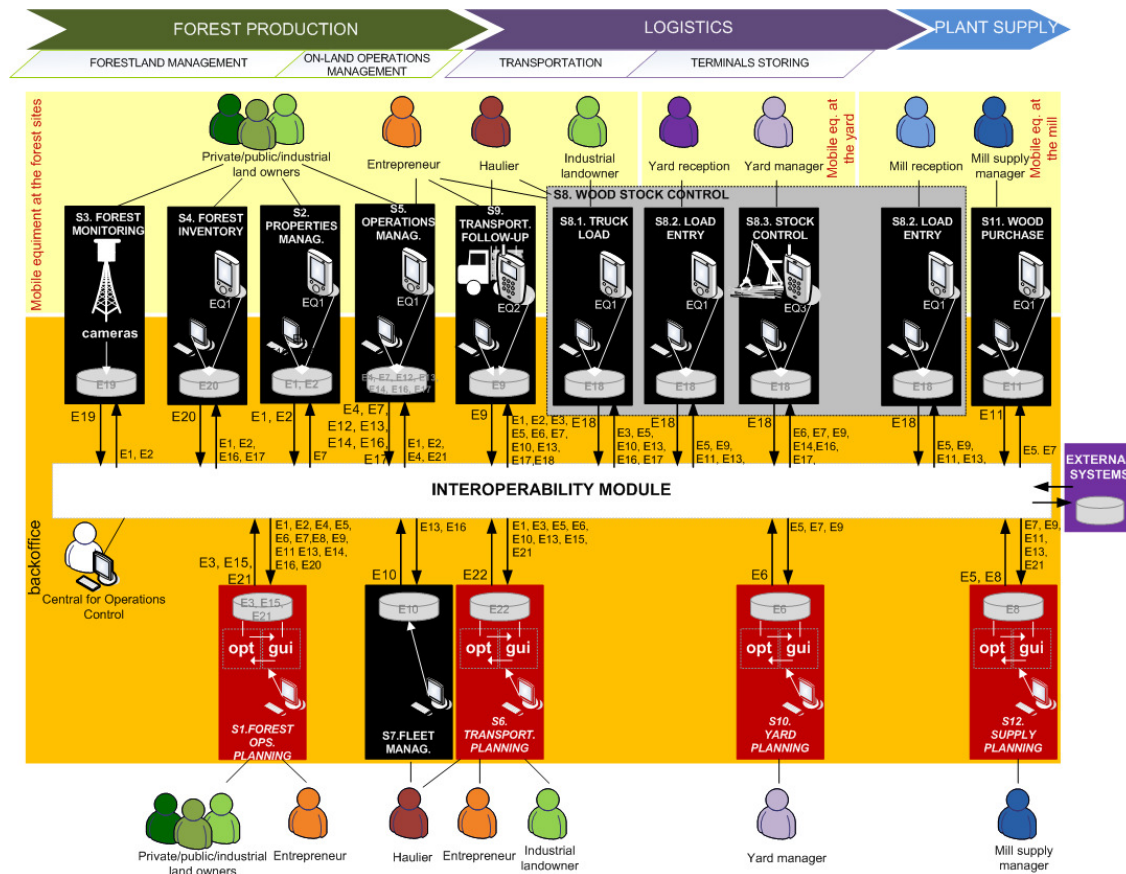
Figure 19 - **FPSC management system application architecture diagram, representing the 12 modular components (sub-systems) identified from the CRUD matrix analysis.**

The Forest Monitoring System (S3), encompassed surveillance cameras and other fixed equipment for early forest hazards detection (E19), as well as a central backoffice for alarms management and recording the following monitoring events.

The Wood Logistic processes were addressed by 2 planning sub-systems and 3 operations control subsystems. The Wood Transportation Planning System (S6) provided the wood distribution plans, the daily trucks and crews schedules and budgeting estimates (E22), according to the specificities of the transportation planner (e.g. haulier, entrepreneur, industrial landowner). The Fleet Management System (S7) handled the status of the entire wood transportation fleet under the haulier perspective.

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The daily Transportation Monitoring System (S9) relied on embedded devices that displayed the trucks location (and other information recorded by the driver) on a Central BackOffice managed by the haulier. This information was instrumental for managing the wood reception on the yards and mills, under a just-in-time delivery schema.

The Yard Planning System (S10) addressed the internal configuration of the wood yards, the daily schedules for the loading/unloading equipment and crew as well as the qualified daily stock management.

The Wood Stock Control System (S8), encompassed a series of mobile devices grouped into sub-modules aiming Truck load (S8.1), Load reception at the yards and mills (S8.2.) and wood stock control at the yards (S8.3). This was a transversal system thus assuring the wood flows quantitative control across the entire wood procurement network, according to industrial owners' requirements.

Finally, the supply of sawmills, pulp mills and biomass centers relied on 1 planning sub-system and 2 wood deliveries control sub-systems. The Wood Supply Planning system (S12) defined the strategic target levels for self-supply and national/international market acquisitions, based on the approved production plans, which were mandatory for the transportation and supply contracts/agreements. Moreover, it produced the daily delivery plans at the yards and mills based on the actual agreements and the transportation/crews/equipment daily availabilities.

The entrepreneurs are other wood suppliers prior qualification process and negotiation terms were supported on the Wood Purchase System (S11).

The applications architecture further encompassed the characterization of the high level functional requirements for the systems and their interfaces with other internal and external systems. As an example, the Load Entry module (S8.2), used on the yard and mill reception had the following functional requirements: a) receive the real-time estimates for truck arrivals and update the daily delivery plans; b) display an alarm for truck delays and trigger new daily delivery plans; c) consolidate and display information on the next arriving truck (e.g. truck and driver identification, load characteristics, origin); d) consolidate and display information on the truck unload operations (e.g., destination, unload equipment, crew); e) query/edition/exportation/report of truck entry records; f) automatic integration with the weighing-machine records; g) automatic record the truck exiting hour.

The last transversal components of the applications architecture were the Interoperability Module and the Central for Operations Control. The first handled automatic information exchange among the internal and external systems. It also recognized and handled triggering events among systems. Specifically, when certain events were recorded on a given sub-system, a specific message was delivered to other related systems where it would trigger the execution other events. As an example, when a truck damage record was created on the Fleet Management System (S7), a replan event should

be received at the Transportation Planning System (S6) for updating the daily truck schedules. This module did not implement specific business processes and so it was considered invisible for the supply chain agents.

The second transversal component intended to consolidate and display real-time information collected by the mobile devices. It may be operated by an independent IT team. Their mission may include handling trouble-shooting situations and assured the integration of legacy systems into the overall solution. It could also aggregate the BackOffice Operations consolidation modules, foreseen for sub-systems S2., S3., S4., S5., S8., S9., especially useful for integrated industries.

The technological architecture discussed the IT solutions that best fit the functional requirements. Specifically, it suggested the use of PDA devices to support the systems S2., S4., S5., S8.1., S8.2. and S11. These devices should incorporate GPS features and enable GIS queries and remote edition. Adequate synchronization mechanisms were further required to overcome the difficulties of mobile computation, mainly related with the frequent lack of internet connectivity on the forest sites. The robustness and autonomy of the devices were also key aspects for selecting among concurrent commercial solutions.

The use of an embedded truck GPS-based tracking device could support the transportation follow-up system (S9). There were several commercial solutions found on the market to address the requirements. Like the xTRAN solution by Tecmic (http://www.tecmic.pt/por/xtran/xtran_intro.html).

Lastly, the already installed CICLOPE surveillance cameras network (www.inov.pt) may provide information on forest fires detection. No solution was found to support the detection of forest diseases.

The technological architecture further argue the need for developing the Interoperability Module using commercial Middleware solutions, such as the EAI (Enterprise Application Integration) often used for supply chain applications. The middleware software consisted of a set of technologies and services provided by the sub-systems, allowing its interactions while working simultaneously. It was considered a key component to support and simplify complex distributed applications (O'Brien and Marakas 2009).

5. Conclusions

In Portugal there was considerable experience on applying operations research techniques to enhance forest planning, especially for long-term decisions (e.g. Falcão and Borges 2001; Borges, Marques et al. 2008; Borges, Fragoso et al. 2010). This thesis extends this research to address tactical and operational forest planning problems. Emphasis was on the nature of the nuclear decisions related with each problem as well as on the computerized tools available to support their related decision-making processes.

This research was anchored on a comprehensive review about the state-of-the-art on FTOPP. This review was a contribution for extending the knowledge on this domain. It further highlighted some open questions that motivated the current thesis scope as well as future research work.

The thesis proposed innovative OR methods and DSS for some of the FTOPP prevalent in Portugal and sheldom addressed on the forestry literature. Specifically, Study I integrated harvest scheduling, pulpwood assortment, and assignment decisions at tactical level. It focused on the role of the intermediate wood yard as part of the strategy for pulpwood supply on the vertically integrated pulp mill. The problem decomposition approach, combining heuristics and mathematical programming algorithms proved to be adequate to address the MIP formulation.

Study II introduced the Raw Materials Reception Problem. To our knowledge, this operational problem had not been addressed on the literature. The proposed solution approach based on Revenue Management principles led to 55% cost reduction on the total reception costs for this case study, 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 times for the planned deliveries arriving on-time as well as inferior waiting time for the trucks on higher segments.

The results of studies III to V proved that the proposed Enterprise Architecture approach may effectively be used to design DSS that could cope with the complexity of the FTOPP. These studies cover the main research challenges on this domain (D'Amours et al 2008). They addressed the integration among the operations performed over the pulpwood supply chain; the interactions among the agents engaged on forest planning and the combination of forest planning with forest operations control.

Future research will approach both generic aspects related with FTOPP and specific work lines anchored on the results of the 5 studies here presented.

In general terms, effort will be done to pursue with the research of new solution methods for FTOPP, particularly for those problems that remain unaddressed at the forestry literature (such as harvest

services adjudication and Harvest & transportation synchronization). Future work will foster the application of the existing methods into new real-world situations. Consequently, work will be done on improving the quality and the quantity of the information used for planning. Complementary, the research on FTOPP will persecute new techniques for tactical and operational planning under uncertainty (Martel et al 1998).

Furthermore, the deployment of the proposed methods to final users within decision support systems tailored to meet specific users' requirements or integrated with existing Advanced Planning and Scheduling Systems (e.g. Hill 2000) will also the attempted.

Specific work lines for studies I and II will focus on the informatics domain. The challenges relate to improvements to the SADPOF decision support system. These improvements will extend the existing functionalities as well as introducing new features that can enhance its utilization by the future users. As an example, sophisticated reporting interfaces may improve the users' easy access to the results of the OR models and methods. It also may favor the comparison among what-if scenarios, thus enhancing use of trade-off analysis to support decision-making processes. Furthermore, the use of simulation systems to display the optimization results may be instrumental for promoting the utilization of the existing DSS by the forest and industry practitioners.

Future work on study I on the OR domain will investigate alternative objective functions for the problem that do not take into account the prices of the assortments at the possible pulpwood destinations. It will further test the performance of alternative open source OR solvers for the LP sub-problem. It will directly address the problems related with the quality and quantity of the data used for planning, and implement adequate growth and yield models for projecting the growth of the stands across the 12 months of the planning horizon.

Future developments of study II on the OR domain will address the paradigm of time slot discretization. In fact, the use of time slots with the length of the service and unloading operations led to an increase of the waiting time. Future work will test the use of smaller time slots, especially at the production lines. The delivery could use more than one consecutive slot, depending on the efficiency of the unloading equipment and the truck capacity. Alternatively, the use of larger time slots will also be considered. For example, supplanting the rule of "1 truck/15 min" by the rule "3trucks/45min". This approach may lead to higher flexibility on assigning late-arrivals to new slots. It may further enhance the use of over-booking strategies under the phase 1 - Time Slot Reservation. The 3-Phase method may further be improved with innovative cost functions, taking into account distinct unit costs per segment.

Specific work lines related with studies III to V will seek for the implementation of the proposed Process Frameworks as well as the development and use of the DSS designed. The use of standard

process frameworks is particularly relevant in cases of multiple decision-makers/stakeholders or complex interaction networks among the agents of the supply chain. In these cases, the research will evolve to the definition of governance models that can regulate the exchange of information among the players. The development of effective interoperability mechanisms still poses as an informatics challenge. Future research will establish an ontology on forest tactical and operational planning, acknowledged by all the players. The work will follow with the definition of data exchange formats and communication protocols, preferably within a context of a new service-oriented architecture anchored on the existing EA artifacts.

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Integrating harvest scheduling and timber assortment and assignment planning processes. An application to forest tactical planning by a pulpwood company in Portugal

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Abstract

Forest tactical planning encompasses harvest scheduling as well as timber assortment and assignment processes. Nevertheless these processes are often conducted independently. Typically, annual forest planning in vertically integrated industries starts with the monthly scheduling of harvests taking into account both budget and stand adjacency constraints. Subsequently, regional monthly-basis logistics planning addresses timber assortment and assignment decisions according to the mills' demands and to the available transportation and storage capacities. The efficiency and the effectiveness of forest tactical planning may be increased by integrating these processes. Operations costs may be reduced by synchronizing harvesting and timber logistics processes. In this article, we present a mixed integer linear programming (MIP) formulation for an integrated forest tactical planning problem. The problem components include harvest scheduling and pulpwood assortment and assignment over a distribution network encompassing stands, intermediate storage yards and pulp and bio-energy plants. The proposed solution approach relies on problem decomposition and combines the use of heuristic and mathematical programming algorithms to solve its MIP formulation. The master harvest scheduling problem is solved using simulated annealing. Each iteration of this meta-heuristic, encompasses a 2-Opt solution procedure for the integer harvest scheduling sub-problem and either a newly developed greedy Admissible Flow Solution Heuristic (AFSH) or a linear programming solution for the product assortment and assignment sub-problem. Results from its application to a problem encompassing twelve 1-month temporal horizon, 4 pulp mills, 1 bio-energy plant, 3 intermediate storage yards, 6 product assortments and a forest area with 700 eucalypt stands extending over 4888 ha in South-Central Portugal are discussed. Several "what-if" scenarios were compared. Results suggest that the proposed model and solution approach may be used to address the complexity of integrated forest tactical planning, providing useful outputs to support decision making.

Keywords: Forest tactical planning, harvest scheduling, pulpwood assortment, pulpwood assignment, heuristics

1. Introduction

Forest tactical planning addresses medium-term decisions extending over a few years. Typically it encompasses monthly harvest scheduling as well as product assortment and assignment decisions. Apparently there is lack of consensus over ontology and some authors use the terms annual or operational planning to refer to this problem (e.g. Murray and Church 1995, Epstein, Nieto et al. 1999). In this research we will use the term tactical, according to most forestry literature (e.g. Karlsson, Ronnqvist et al. 2004). Often tactical problems have been addressed within hierarchical planning approaches (Weintraub and Cholaky 1991) or else in conjunction with complementary problems such as road network design and maintenance (Barros and Weintraub 1982; Kirby, Hager et al. 1986; Jones, Hyde et al. 1986; Weintraub, Jones et al. 1995; Guignard, Ryu et al. 1998; (Epstein, Morales et al. 1999; Clark, Meller et al. 2000; Cea and Jofre 2000; Richards and Gunn 2000). Most tactical harvest scheduling problems have been formulated as mixed-integer programming models (Weintraub, Church et al. 2000), where integer decision variables represent feasible stand harvest and road building or maintenance timings, while continuous variables correspond to timber flows over a timber distribution network. The literature also reports more complex models to address issues such as log assortment, crews scheduling and harvest machinery selection (Andalaft, Andalaft et al. 2003; Karlsson, Ronnqvist et al. 2003; Karlsson, Ronnqvist et al. 2004).

Product assortment and assignment problems are often combined into integer or mixed-integer formulations (e.g. Carlsson and Ronnqvist 1998; Carlgren, Carlsson et al. 2006). The former addresses the selection of the combination of species and/or log sizes from a harvest site that may meet demand requirements at a minimum operational cost. The latter, also referred to as raw material distribution or medium-term transportation planning problem, aims at identifying the stands (or catchment area) that may provide the raw material needed by individual transformation units at a minimum transportation cost.

Up to now, the integration of harvest scheduling with product assortment and assignment only had been addressed in the scope of large-scale overall supply chain optimization problems (Ronnqvist 2003; Fleishchmann, Meyr et al. 2005; Weintraub and Romero 2006). Emphasis was on the interdependencies between supply chain decisions that encompass harvest scheduling, wood assortment and assignment, production, transportation and storage. Both (Carlsson, D'Amours et al. 2006) and (Karlsson, Ronnqvist

et al. 2003) addressed simultaneously the pulpwood and biomass supply chains. Nevertheless, the problem scale precluded the use of more detailed information about individual operations within a tactical planning framework (e.g. stands adjacency information needed to address harvest operations ecological sustainability).

In this article, we introduce the integrated forest tactical planning problem (IFTPP) and develop a mixed integer linear programming formulation to represent it. The problem components include harvest scheduling and pulpwood assortment and assignment over a distribution network encompassing stands, intermediate storage yards and pulp and bio-energy plants. The solution to the IFTPP aims at global net present value maximization and it encompasses the solution of a harvest scheduling sub-problem subject to temporal and spatial constraints. It further encompasses the solution to a product assortment and assignment sub-problem consisting of the distribution of the monthly pulpwood and biomass assortments supply to meet the plants targeted assortment demand.

An innovative solution approach to address the IFTPP requirements is further presented. The literature reports the use of exact approaches to solve harvest scheduling problems that involve both temporal and spatial constraints (e.g. Kirby, Wong et al. 1980, Covington, Wood et al. 1988, Torres Rojo and Brodie 1990, Jones, Weintraub et al. 1991, Hof and Joyce 1993, Yoshimoto and Brodie 1994, Murray and Church 1995b, Snyder and Revelle 1997, Guignard, Ryu et al. 1998, Borges, Hoganson et al. 1999, Murray 1999, McDill, Rebain et al. 2002, Crowe, Nelson et al. 2003, Andalaft, Andalaft et al. 2003, Goycoolea, Murray et al. 2005, Martins, Constantino et al. 2005, Weintraub and Murray 2006, Constantino, Martins et al. 2008). It further highlights the use of heuristics within tactical/operational decision support systems since they may provide near optimal or near feasible solutions within reasonable computing time (e.g. Nelson and Brodie 1990, Richards and Gunn 2000, Falcão and Borges 2001, Caro, Constantino et al. 2003). In particular, simulated annealing (SA) has been widely used in forest management planning (e.g. Dahlin and Sallnas 1993, Lookwood and Moore 1993, Murray and Church 1995b, Tarp and Helles 1997, Boston and Bettinger 1999, Falcão and Borges 2002, Heinonen and Pukkala 2004, Falcão and Borges 2005). The solution of mixed integer models may also be facilitated by decomposition approaches where e.g. the first integer sub-problem (IP) is solved with a heuristic approach and subsequently, its solution is input to a linear programming sub-problem (LP) addressed with a common LP solver (Cea and Jofre 2000) or a greedy heuristic (Wikstrom and Eriksson

2000). The proposed solution method for the IFTPP problem complies with this approach. It combines the use of heuristic and mathematical programming algorithms within a problem decomposition approach. The master problem is solved using simulated annealing. Each iteration of this meta-heuristic encompasses a 2-Opt solution procedure for the integer harvest scheduling sub-problem and either a newly developed Admissible Flow Solution Heuristic AFSH or a linear programming solution for the product assortment and assignment sub-problem. Afterwards, the current iteration candidate solution is evaluated and can be selected according to the usual SA meta-parameters and cooling mechanisms.

This approach was tested using a pulpwood and biomass distribution network from a vertically integrated pulp and paper company, encompassing 4 pulp mills, 1 bio-energy plant, 3 intermediate storage yards and a forest area with 700 eucalypt stands extending over 4888ha in South-Central Portugal. The problem encompassed a twelve 1-month planning horizon and 6 product assortments. Model building encompassed the generation of 699 binary variables, 234837 continuous variables and 84946 constraints. SA meta-parameters were properly calibrated for the current problem instance. Results of more than 120 test computer runs corresponding to several "what-if" scenarios are discussed for application to the IFTPP.

2. Material and methods

2.1. Case study

This work involved both researchers and forest managers from the Portuguese pulp and paper company Grupo Portucel-Soporcel. The research used inventory and topological data from eucalypt stands located at Serra de Ossa at the Évora district located south of Portugal. It further considered the economic data and parameters on the management planning constraints (Table 1). The storage yards and the pulpwood and biomass transformation facilities were located so that this research could take advantage of available road and railway network data (Figure 3).

Harvest units

The pulpwood and forest residues procurement area includes 700 even-aged eucalypt stands (self-owned or rented). The stands were at their rotation age. This fact, combined with the high risk of wildlife fires in the region, suggested that all the 700 stands are to be harvested over the current planning horizon.

Each stand is characterized by a geographical location and area as well as by inventory estimates of total eucalypt commercial volume and weight and of forest residues weight in each planning period. All stands have an area between the minimum and the maximum clearcut opening sizes. The database further included information about each stand rental contract expiration date and about the months when it was feasible to harvest each stand according to the road access conditions during winter time. A GIS cluster analysis took the location of each stand and of the three exit points from the forest to the main road network to identify the most adequate wood pile locations.

Product assortments

Each harvest unit produces at least one pulpwood and one biomass assortment. The former includes eucalypt pulpwood logs with length of 2 or 4 meters, barked and un-barked (B, UB) while the latter is characterized by the forest residues chipping status at the destination entrance (chipped (C) or non-chipped (NC)). Forest residues include harvest by-products e.g. branches, bark and foliage. The harvesting costs vary according to stand characteristics (e.g. slope, area) and are higher in the case of the barked and chipped assortments. The unit transportation cost is identical for all pulpwood assortments and it is higher for chipped forest residues that require closed trailers. Transportation was forced to occur during the harvest month due to the high risk of wildfires in the region. The research assumed non-growth across the planning period. It further assumed that the sum of the log volumes obtained after harvesting match volume estimates for that stand at the beginning of the planning horizon. The later were computed with the GLOBULUS growth model (Tomé, Ribeiro et al. 2001). The logs' weight estimates at the harvest sites are then obtained by multiplying the volume estimates by an empirical drying factor and the average wood density. The empirical drying factor developed by Portucel Soporcel estimates the wood weight decrease according to the storage time at the storage yards or at the woodpiles in the harvest sites. The forest residues weight is computed at the harvest sites as a fixed empiric amount of the logs initial weight.

Pulpwood and Biomass Transformation facilities

Harvest scheduling and product assortment aim to fulfill strategic target self-supply levels to help meet monthly demand by the transformation facilities, including 2 pulp mills (Beja and Setil), 1 bio-energy plant (Entroncamento) and 2 mills that require both logs and forest residues (Setubal and Badajoz). Each demand point is characterized by the proposed geographical location, assortments monthly demand

levels and unit price per assortment (assumed constant over the planning period). It was assumed that their storage capacity was unlimited.

Intermediate storage yards

The 3 proposed locations for storage yards were Casa Branca, Portalegre and Vendas Novas (Figure 3). These terminals are simultaneously supply and demand points. They are demand points as they store the wood products delivered from the harvest units. They are supply points as they provide the supply to the transformation facilities. They play an important role in the company strategy as they contribute to avoid uneven seasonal supply of raw material from the harvest units. They further contribute to a reduction of the transportation costs as logs drying under open air conditions leads to lower weights and as railway transportation from these yards to the mills is possible. Each storage yard is characterized by its location, maximum storage capacity, storage costs and maximum allowable storage duration for the product assortments. The latter is key to avoid decay and devaluation of product assortments. They further include a hypothetic price that varies per assortment. They were considered empty at the beginning of the planning horizon.

Railway and road networks

All the distribution network points are connected by a road network which can be represented by a complete and oriented graph. The storage yards are also connected to the mills by a railway network. The transportation costs are proportional to the distance multiplied by a unit cost that depends both on the assortment and the type of transportation. The distance matrix was computed inputting the Portuguese road and railway geographical networks into ArcGis 9.2 and using its shortest path algorithm.

Spatial constraints

Concerns with the environmental impacts of timber harvesting have been often formalized in legal restrictions on clearcut opening size (Borges and Hoganson 2000). The harvest scheduling may be thus constrained by the definition of an exclusion period correspondent to the minimum number of months between clearcuts of neighboring harvest units (Richards and Gunn 2000). Nevertheless, operational concerns suggest also the concentration of harvests. Thus in this case study clearcut openings had to

meet a minimum size in order to address harvest machinery utilization efficiency concerns (e.g. the reduction of costly movements between distant harvest areas).

2.2. Integrated forest tactical planning problem model

The mixed-integer formulation to the integrate harvest scheduling, product assortment and assignment problem within a tactical planning framework can be described as:

$$\max Z = \sum_{j\in J}\frac{\sum_{i\in I}\sum_{f\in F}\sum_{p\in P}(PR_{pf}-CT_{ip}^{f}-CP_{p})q_{ijp}^{f}}{(1+tj)^{j-1}} + \sum_{j\in J}\frac{\sum_{f\in F_{T}}\sum_{f\in F_{M}}\sum_{p\in P}(PR_{pf}-CF_{pf}^{f})t_{fjp}^{f}}{(1+tj)^{j-1}} - \sum_{j\in J}\frac{\sum_{i\in I}CH_{i}x_{ij}}{(1+tj)^{j-1}} \tag{1}$$

$$\textit{Subject to: } \sum_{j\in J}x_{ij}=1 \qquad\qquad \forall i\in I \tag{2}$$

$$\sum_{j-PE<j'<j+PE}\sum_{i'\in adj_{i}}A_{i'}\,x_{i'j'}+A_{i}\,x_{ij}\leq A\max{}_{PE} \qquad\qquad \forall i\in I\,,\forall j\in J \tag{3}$$

$$\sum_{i'\in adj_{i}}A_{i'}\,x_{i'j}+A_{i}\,x_{ij}\geq A\min{}_{j} \qquad\qquad \forall i\in I\,,\forall j\in J \tag{4}$$

$$\sum_{p\in P^{L}}\sum_{f\in F}q_{ijp}^{f}\leq AV_{i}^{L}x_{ij} \qquad\qquad \forall i\in I\,,\forall j\in J \tag{5.1}$$

$$\sum_{p\in P^{FR}}\sum_{f\in F}q_{ijp}^{f}\leq AV_{i}^{FR}x_{ij} \qquad\qquad \forall i\in I\,,\forall j\in J \tag{5.2}$$

$$\sum_{i\in I}\sum_{f\in F}\sum_{p\in P_{B}^{L}}q_{ijp}^{f}=B_{j} \qquad\qquad \forall j\in J \tag{6}$$

$$\sum_{i\in I}q_{ijp}^{f}+\sum_{f\in F_{T}}t_{fjp}^{f}\geq TG_{pj}^{f} \qquad\qquad \forall j\in J\,,\forall p\in P\,,\forall f\in F_{M} \tag{7}$$

$$\sum_{j'=1}^{j'=j-1}(\sum_{i\in I}\sum_{p\in P}q_{ij'p}^{f}-\sum_{p\in P}\sum_{f\in F_{M}}t_{fj'p}^{f})=\sum_{p\in P}E_{fp}^{j'} \qquad\qquad \forall f\in F_{T}\,,\forall j\in J:j\geq2 \tag{8.1a}$$

$$\sum_{p\in P}E_{fp}^{j}=0 \qquad\qquad \forall f\in F_{T}\,,\ j=1 \tag{8.1b}$$

$$\sum_{p\in P}E_{fp}^{j}+\sum_{i\in I}\sum_{p\in P}q_{ijp}^{f'}-\sum_{p\in P}\sum_{f\in F_{M}}t_{fjp}^{f}\leq CMax_{f} \qquad\qquad \forall j\in J\,,\forall f\in F_{T} \tag{8.2}$$

$$\sum_{i\in I}DP_{ip}^{f}\leq D\max{}_{pf} \qquad\qquad \forall p\in P\,,\forall f\in F_{T}\,, \tag{9}$$

$$\sum_{j'=1}^{j}\sum_{i \in I} q_{ij'p}^{f} - \sum_{j'=1}^{j-1}\sum_{f \in F_M} t_{fj'p}^{f} \geq \sum_{f \in F_M} t_{fjp}^{f} \qquad \forall\, j \in J\,, \forall\, p \in P\,, \forall f \in F_T \qquad (10)$$

$$q_{ijp}^{f} \geq 0 \qquad \forall i \in I\,, \forall\, j \in J\,, p \in P\,, \forall f \in F \qquad (11.1)$$

$$t_{fjp}^{f} \geq 0 \qquad \forall\, j \in J\,, \forall\, p \in P\,, \forall f \in F_T\,, \forall f \in F_M\,, \qquad (11.2)$$

$$x_{ij} \in \{0,1\} \qquad \forall i \in I\,, \forall\, j \in J \qquad (11.3)$$

Where:

J	Set of months of the planning horizon, j=1,…, 12
Tj	interest rate
I	Set of stands to be harvested over the planning horizon, i=1,…, 700
A_i	Area of the stand i (m^2)
adj$_i$	Set of stands adjacent to stand i (within a distance from i less than DISTMIN)
P	Set of assortments, p=1,…, 6 includes the subset of forest residues (P^{FR}), divided into chipped (P^{FR}$_C$:p=1) and non-chipped (P^{FR}$_{NC}$:p=2) and the subsetof logs (P^L), divided into barked (P^L$_B$: p=3,4) and unbarked (P^L$_{UB}$: p=5,6)
AV^L$_{i,}$	Total quantity of pulpwood produced at stand i (ton)
AV^{FR}$_i$	Total quantity of forest residues produced at stand i (ton)
F	Set of product destinations, f= 1, 2,…, 8; it includes the subset of storage yards (F$_T$:f=1,2,3) and the subset of mills and bio-energy plants (F$_M$:f=4, 5,…, 8),
Y_{pf}	Binary parameter set equal to 1 if assortment p is accepted at the storage yard $f \in F_T$ and to 0 otherwise
CT$_{ip}$^{f}	Total transportation cost (by road) of assortment p from stand i to transformation facility f (€/ton)
$CF^{f \in F_M}_{p, f \in F_T}$	Total transportation cost (by railway) of assortment p from the storage yard $f \in F_T$ to the mill $f \in F_M$ (€/ton)
CH$_i$	Total harvest cost of stand i (€) (includes, harvesting, forwarding, and planting if it occurs at the final coppice cycle within the rotation)
CP$_p$	Total product processing cost for assortment p
PR_{pf}	Price of assortment p on the destination $f \in F$ (€/ton)
$Amax_{PE}$	Maximum clearcut opening area over the exclusion period (ha)
DISTMIN	Minimum distance between adjacent stands
$Amin_j$	Minimum clearcut opening area in each period j
PE	Exclusion period (months)
TG_{pj}^{f}	Target flows from assortment p in period j to the mill $f \in F_M$ (ton)
B$_j$	Supply of barked logs in period j (m^3)
CMax$_f$	Maximum capacity of the storage yard $f \in F_T$ (ton)
Dmax$_{pf}$	Maximum allowable storage duration for assortment p in storage yard, $f \in F_T$ (months)
DP_{ip}^{f}	Storage duration of assortment p from stand i, in storage yard $f \in F_T$ (months)

The decision variables are:

x_{ij}	Binary variable set equal to 1 if stand i is harvested in period j and to 0 otherwise
q_{ijp}^{f}	Quantity of assortment p, produced in stand i, transported to destination f in period j, $\forall i \in I\,, \forall\, j \in J\,, \forall p \in P\,,$

$\forall f \in F$ (ton)

$t^{f \in F_M}_{f \in F_T, jp}$ Quantity of assortment p, transported from storage yard $f \in F_T$ to final destination $f \in F_M$ in period j, $\forall j \in J$, $\forall p \in P$ (ton)

The auxiliary variables are:

E^j_{fp} Quantity of product p, stocked at storage yard f, at the beginning of period j, $\forall j \in J$, $\forall p \in P$, $\forall f \in F_T$ (ton)

The model aims at maximizing the IFTPP net present value (Equation 1). All stands must be harvested exactly once over the planning horizon (Equation 2). Each clearcut opening areas must meet both a maximum size constraint over the exclusion period and a minimum operational size constraint (Equations 3 and 4, respectively). The total flow from each stand is constrained by the availability of both pulpwood and residues at the stand (Equation 5). A bookkeeping condition (Equations 6) was included to help keep track of the monthly supply of barked pulpwood logs. The solution must meet the target monthly demand of each product assortment by each pulp mill and bio-energy plant (Equation 7). Each storage yard is assumed to be empty at the beginning of the planning horizon (Equation 8.1b). The stock in each storage yard at the beginning of remaining 11 months is computed by adding the incoming flows and subtracting the outgoing flows (Equation 8.1a). This bookkeeping variable is used to ensure that the storage yard maximum capacity is not exceeded (Equation 8.2). The storage duration of each product in a yard is computed with a specific procedure described below in order to ensure that the maximum allowable storage duration is not exceeded (Equation 9). The outgoing flow of an assortment from each yard at the end of each period cannot exceed the current stock level computed as the difference between the assortment incoming and the outgoing flows up to the end of the period (Equation 10). Finally, equations (11) set the nature of the decision variables.

2.3. Solution method

This MIP formulation for the IFTPP is solved by a problem decomposition approach that addresses sequentially the harvest scheduling and the product assortment and distribution sub-problems by a combination of heuristic and mathematical programming algorithms (Figure 1). The master problem is solved using simulated annealing (SA) (Kirkpatrick, Gelatt et al. 1983). Typically, this meta-heuristic involves a sequence of iterations, each consisting of randomly changing the current solution to find a new solution in its neighborhood (Pham and Karaboga 2000). The new solution is evaluated using a fitness function. In order to avoid premature convergence to a local optimum, an inferior solution may

be accepted. Yet the frequency of these moves decreases with the number of iterations according to the value of a control parameter (temperature) and the quality of the solutions (Reeves 1993, Falcão and Borges 2001). The iterative search process may be stopped according to a wide range of criteria (e.g. no. of iterations, temperature, runtime). In this research, this meta-heuristic is adapted to generate both an admissible solution to the harvesting scheduling sub-problem and a matching solution to the product assortment and assignment sub-problem. In each SA iteration we thus get both the values of the integer variables of the former and the values of the continuous variables of the latter.

Specifically, the solution process starts by generating a random solution to the harvest scheduling sub-problem encompassing the third term in equation (1), equations (2) to (4) and (11.3). Each stand is assigned a harvest time such that the clearcut opening size constraints are met. Afterwards, a solution is found to the product assortment and assignment sub-problem i.e. timber harvested according to the timing and location in the solution to the first sub-problem is assorted into products and these products are assigned to destinations within the considered timber distribution network. This sub-problem is defined by the two first terms in Equation (1) and by Equations (5) to (10) and Equations (11.1) and (11.2). This is a variant of the linear programming transshipment problem with the particularity of including decisions on the type and amount of the assortments of timber harvested in each stand (supply points). The assortments are to be transshipped over a network of supply and demand points and intermediate storage yards. This solution is provided by either a newly developed heuristic procedure or a linear programming algorithm (e.g. the GNU mixed-integer programming solver LP SOLVE v.5.5.2.0).

The greedy Admissible Flow Solution Heuristic (AFSH) procedure is based on empirical transportation rules applied in current logistic planning to meet all demands. In summary, these rules aim at the distribution of all available supply at the harvest units to the most profitable destinations while ensuring that demands are met at all final transformation centers. Additionally, the procedure ensures that the outgoing flow of any assortment from each yard at the end of each period does not exceed its current stock level (Equation 10). The procedure may be illustrated by taking advantage of a transportation framework (Table 2). It consists of a sequence of timber distribution cycles (Figure 1), each encompassing a set of origins (including stands i and storage yards $f \epsilon F_T$), a set of destinations (including mills $f \epsilon F_M$ and storage yards $f \epsilon F_T$), the product available at the origin (AV_i^L or AV_i^{FR}), the

assortments' demands $(TG_p^f, f\epsilon F_M)$ and the unit net present value (NPV) of each triplet (origin, destination, assortment) (Table 2). The transportation framework further considers the products available at the yards $(AV_f^L$ or $AV_f^{FR}, f\epsilon F_T)$. Yards start empty and quantities available in each month correspond to the balance between the incoming and outgoing flows after each cycle. The storage space available at the yards $(SS^f, f\epsilon F_T)$ is computed as the difference between the yards maximum capacity and the quantities stored.

The first cycle – just like all remaining cycles - was inspired on the Minimum Cost Method for the Transportation Problem (e.g. Hillier and Lieberman 2005). It consists of a greedy approach to meet target demands at the mills based on what the harvest scheduling sub-problem made available each month as well as on what is available at each yard. Thus, it addresses the subset of origins and destinations that define the first and the third quadrant of the transportation framework matrix (Table 2). It orders the triplets according to the respective unit NPV. Then it goes down through the ordered list and at each position in the list it assigns an assortment quantity as large as possible to the network path between the respective triplet origin and destination (i.e. minimum $\{(AV_i^L$ or $AV_i^{FR})$, $(AV_f^L$ or $AV_f^{FR}, f\epsilon F_T)$, $(TG_p^f, f\epsilon F_M)$, $(SS^f, f\epsilon F_T)\}$). Thus after going through one triplet in the ordered list, either the supply is exhausted at the origin or the monthly demand is met at the destination. That triplet NPV is assigned the value -1 so that it is not considered anymore in the current cycle. The cycle ends when all NPV are set to -1 or else either if no more products are available at the yards or the target demands are met.

The next cycles provide the best allocation for the remaining supply from the harvest units. Specifically, the second cycle computes the unit NPV for the duplets (stands, yards) of the second quadrant of the matrix, in order to select the best storage yard for the logs remaining at the stands, considering their available storage capacity (Table 2). These logs are yet to be assorted according to final demand needs. If all storage yards reach the maximum capacity and yet there are still logs remaining at the harvest sites while demands have not been fully met, a third cycle is needed (Figure 2). The latter selects the assortment and destination for those remaining logs, based on the computation of the unit NPV for the triplets' corresponding to those stands and mills (first quadrant of the matrix). If either supply excess and/or shortages persist, two additional cycles are needed to direct the logs from the harvest sites to its

most profitable final destination, or from the yards to the mills that still require raw material. Consequently, the demand at the mills may be exceeded. In these cases, the surplus is stored at the mills internal wood yards. The last cycle is performed at each storage yard and it encompasses the sequencing of the outgoing flows according to their departure month and implements a First-In-First-Out (FIFO) approach to define the assortments of yet un-assorted flows from the stands. Finally, the solution of the assortment and assignment sub-problem is directly retrieved from the monthly triplets selected by this AFSH procedure.

After solving the second sub-problem we have completed the first iteration and we have the corresponding solution to the master IFTPP (equations (1) to (11)). This candidate solution is evaluated by a fitness function that includes two terms (Equation 12). The first is the objective function (equation 1). The second is a penalty function ϕ that assesses whether constraints in equations (2) to (9) are met and that assigns penalties to the deviations d_2, d_3, d_4, $d_{5.1}$, $d_{5.2}$, d_6, d_7, $d_{8.2}$ and d_9 between the current value cv and the target values (left-hand side term value pv in equations (2), (3), (4), (5.1), (5.2), (6), (7), (8.2) and (9)). Thus, higher constraint deviations are penalized although unfeasible solutions can be selected (Falcão and Borges 2001). The penalty weights w_2, w_3, w_4, $w_{5.1}$, $w_{5.2}$, w_6, w_7, $w_{8.2}$ and w_9 can be parameterized according to the forest planner perception of the constraints relative importance. Equation (10) is always met due to the structure of the AFSH procedure.

$$Z' = Z - \phi(w_2, w_3, w_4, w_{5.1}, w_{5.2}, w_6, w_7, w_{8.2}, w_9, \quad d_2, d_3, d_4, d_{5.1}, d_{5.2}, d_6, d_7, d_{8.2}, d_9), w_c \in [0,1] \qquad (12)$$

$$d_c = \begin{cases} 0 & , if \ (cv < pv \ and \ constraint \ "\geq") \ or \ (cv > pv \ and \ constraint "\leq") \\ |cv - pv| & , otherwise \end{cases} \qquad (13)$$

Deviations d_2, $d_{5.1}$, $d_{5.2}$, d_6 and d_7 are easily computed after getting the values of the decision variables in the current candidate solution. The computation of deviations d_3 and d_4 further requires the use of GIS in order to estimate the size of openings in every month and to check whether the exclusion period is met. Finally, the AFSH FIFO procedure is used to compute $d_{8.2}$ and d_9. This procedure computes the storage duration of the assortment p, produced in stand i, in the yard $f \epsilon F_T(DP_{ip}^f)$ by taking the difference between its outgoing and incoming months (j_{ipf}^{OUT} and j_{ipf}^{IN} respectively). The first month where transportation occurs is j_{ipf}^{IN}. Incoming flows from a stand occur whenever $q_{ijp}^f > 0$ and are ordered in a

two dimension FIFO list (origin, amount) according to the arrival month. The procedure then runs down through the FIFO ordered list and it decreases the incoming flows according to the outgoing flow variables values. The month when an incoming flow becomes zero is j_{ipf}^{OUT}. Both the outgoing and the incoming months are used in conjunction with an empirical wood drying equation to estimate the weight of all incoming flows in the yard and provide the information needed to compute deviations $d_{8.2}$.

Afterwards, the process unfolds according to the standard SA algorithm. If the iteration provides an IFTPP solution associated to a fitness evaluation function (Z') value that is higher than its best known value (BZ') than this current solution (CZ') is accepted and stored. If the iteration provides a solution CZ' inferior to BZ', the current IFTPP solution acceptance is determined by a probability function $P(CZ', BZ', T_k)$ (Equation 14). This function takes as input the difference between the CZ', BZ' and the value of the temperature parameter T_k. A random number $random \in [0,1]$ is generated and the current solution is accepted if this number is inferior to the current $P(CZ', BZ', T_k)$ value. The T_k starts with an initial pre-defined value (T_0) and decreases at the end of each iteration according to an exponential cooling scheme (equation 15) (e.g. Kirkpatrick, Gelatt et al. 1983, Nourani, 1998). Thus, the probability of accepting inferior solutions increases with the temperature and it decreases with the difference between CZ' and BZ'.

The next iteration starts with a new solution to the IP harvest scheduling sub-problem. A standard SA 2-Opt solution procedure is used for that purpose. Specifically, two stands are selected randomly to be assigned randomly another harvest time. The harvest scheduling solution is then input to the product assortment and assignment sub-problem that is solved according to the AFSH procedure just described. The SA algorithm iterates until the maximum number of iterations (Nit) is reached or T_k equals its pre-defined final temperature minimum value (T_f).

$$P(CZ', BZ', T_k) = e^{\frac{CZ' - BZ'}{T_k}} \tag{14}$$

$$T_{k+1} = \alpha T_k, \qquad \alpha \in [0,1] \tag{15}$$

The solution method application to the case study required prior calibration of the SA meta-parameters (Nit, T_0, T_f, α). Five test cases with 11 repetitions were generated for distinct T_0 and T_f trial values. Three additional test cases addressed the impact of Nit. They were compared according to its BZ' value,

the correspondent value of its objective function (removing penalties due to infeasibility) (*BZ*) and the number of iterations for convergence (sNit). It was assumed that the latter corresponded to the number of iterations needed to get a difference between the last iteration Z' value and *BZ'* lower than 1%. The trial values of T_0 and T_f were based on the BZ' obtained in preliminary trial runs (Table 3). As higher values of *P(CZ', BZ', T_k)* contribute to avoid premature convergence to a local optimum, we considered a T_0 equal or higher than the value of *BZ'* obtained in preliminary test runs. T_f took values from zero to $0,2T_0$.

After the SA parameters calibration, the solution approach was used to produce an integrated tactical plan to address the industry tactical management planning baseline scenario. Both the mathematical programming (LP) and the heuristic (AFSH) algorithms to solve the assortment and assignment sub-problem were tested. Two LP implementations were considered (LP Solve v5.5.2.0 API mode and CPLEX v12.1.0). One of the calibration runs with the best choice of SA parameters was elected the baseline scenario.

Finally, six "what-if" scenarios with 5 repetitions were generated. The first two scenarios assessed the impact of the monthly target demand levels of the mills on the objective function value as well as on the respective harvest schedule, and pulpwood and biomass assortments distribution plan. Accordingly, A_1 reduced the demand in all the mills to 80% of the values acknowledged in the baseline scenario, while A_2 considered null demand levels in all the mills. Two other scenarios were used to assess the impact of the storage yards location and maximum capacity in the IFTPP solution. B_1 increased the baseline scenario capacity of all storage yards by 20%, while in B_2 all the yards were closed. The two last scenarios addressed the impact of the maximum allowable clearcut opening area on the IFTPP solution. C_1 decreased $Amax_{PE}$ from 65ha to 30ha while C_2 increased it to 80ha. The best solution of each "what-if" scenario was selected and the resultant tactical plan was compared with the baseline scenario.

3. Results

All calibration tests and tactical management planning scenario runs were conducted within a Ms. Windows operating system in a 2.8 GHz and 2 Gb Pentium D desktop PC. The best value of the fitness evaluation function (BZ') was not very sensitive to variations of T_0 when all remaining SA meta-

parameters remained constant (Table 3). The calibration runs with T_0=iBZ'/100 and T_0=10iBZ' led to the maximum and the minimum values of BZ' obtained over all the 55 calibration runs (327.82 x10^4€ and 291.42 x10^4€), respectively, corresponding to a difference of over 10%. Yet, the maximum and minimum values for the average BZ' were obtained for T_0=iBZ'/10 (320.95x10^4€) and T_0=iBZ'/1000 (314.45x10^4€), corresponding to a difference of about 2%. Similar results were reported for the best value of the objective function (BZ) (Equation 1). Again, the tests with T_0=iBZ'/100 (332.91x10^4€) and T_0=iBZ'/10 (328.83x10^4€) presented the best values for the maximum BZ and average BZ, respectively.

Further the difference between the maximum fitness evaluation function values for all five T_0 was less than 1%. In average it took between 819 and 931 iterations for the process to converge, although some cases of early (sNit=401) and late (sNit=1000) convergence were reported (Table 3). As expected, larger values of T_0 were associated to higher average runtime if no changes are made to the cooling schedule. However the solution process extended at most to 7hr25min39sec (26738 sec), therefore below the 8 hours threshold established by the forest practitioners. Based on the results of these calibration runs, namely on the values of BZ', BZ, sNit and ET and its tradeoffs, we selected T_0=iBZ'/100 and proceeded with the calibration of other SA meta-parameters. Increasing Nit to 5000 and 10000 provided slight improvements of maximum *BZ'* over the 11 repetitions (0.6% and 1.67% respectively) while it increased the runtime (three and seven times, respectively). Reducing Nit and increasing T_f led to worst results according to all the criteria (Table 3). We thus decided to use the CT$_4$ set of meta-parameters to solve the current IFTPP (Table 3).

In all calibration tests no admissible solutions were found. Yet, the solution values obtained with the proposed solution approach for BZ' were 0.5% to 7.7% lower than BZ, thus suggesting solutions near-feasibility. In particular, feasibility was not reached in any iteration of the solution method for the baseline scenario. The best solution for this scenario showed a slight difference of 0.8% between BZ (324.70x10^4€) and BZ' (324.45x10^4€). Infeasibility was a consequence of the violation of the maximum and minimum allowable clearcut opening area constraints (Equations 3 and 4), with total deviations of 106.94ha and 12.01ha, respectively. All other targets and constraints were met in the solutions by the proposed IFTPP algorithmic approach. The infeasibility of the harvest scheduling sub-problem within this IFTPP problem instance was further confirmed with the commercial CPLEX MIP solver.

The thorough analysis conducted on the selected baseline scenario run (BL) revealed the contribution of each component of the objective function towards the global net present value. 64% of the revenue (207.86x10⁴€) resulted from the delivery of pulpwood and forest residues that were transported directly from the harvest units to the mills. The delivery of assortments transshipped over the wood yards led to about 36% (118.51x10⁴€) of the revenue. The harvest costs had little impact in the solution amounting to 1.67x10⁴€, that is less than 1% of the total revenue.

The solution for the baseline scenario reported an asymmetric distribution of the harvests over the 12 monthly planning periods (from August 2010 to July 2011). Over $^1/_3$ of the stands were scheduled to be harvested in the first 3 months (317 stands extending over 2718 ha or 56% of the total harvesting area) (Figure 2). Accordingly, 59% of the total supply of pulpwood and forest residues was scheduled to occur in this period (26087.0 ton). Harvesting levels were lower in subsequent months. Over the remaining 9 months an average of 42 stands were scheduled to be harvested each month leading to an average monthly supply schedule of about 203ton. Harvests concentrated most in August 2010 (139 stands, 1294ha, 13338.0 ton). The lowest harvest levels were scheduled to occur later in the planning horizon i.e. in May 2011 (36 stands, 143 ha, 1988.0 ton) and June 2011 (26 stands, 205 ha, 1413ton).

The overall production of pulpwood and forest residues exceeded the demand at the mills. The surplus was predominantly converted into barked and chipped assortments, thus suggesting the profitability of barking and chipping operations at the forest site. The dominant assortment produced during the planning horizon was L4B, corresponding to about 46% of total supply. Yet, it was the second most demanded assortment (21.79%) following L2B with 53.07%. The second and third most produced assortments were FRC (12%) and L2B (7%). The first two assortments were prevalent on most periods and were the only assortments supplied after February. The exceptions were September 2010 and January 2011 when L2B prevailed. The remaining assortments (L2UB, L4UB and FRNC) were supplied in earlier months, corresponding to about 7%, 4% and 4% of total production, respectively.

The tactical plan further assigned the product assortments to the demand points over the distribution network highlighting the role of intermediate storage in the yards in a context of such an excess of supply (Figure 3). The yards relative contribution to the supply of pulpwood and residues to the mills increased over the planning horizon. Direct transportation of the assortments from stands to mills

reached its maximum value in August when the yards were still empty and decreased afterwards until almost zero after February 2012. Over the whole planning horizon, the yards were in fact the preferential destination of stands' outgoing flows: yards incoming flows accounted for about 81% of the total stands' assortments supply.

Consequently, the yards were often at its full capacity (Figure 4). Casa Branca and Portalegre reached their full capacity after the first quarter. Vendas Novas also recorded the maximum stock levels in November (around 3300ton), although below its available storage capacity. Afterwards, high stock levels were kept until February, predominantly from the L2B assortment at Casa Branca (where it reached the maximum stock of 3929ton) and FRC in Vendas Novas (stable around 2000ton). Portalegre remained at full storage capacity, since outgoing flows of L2B were balanced by incoming flows of L4B. The last quarter presented a decreasing tendency of L2B, L2NB, L4B and FRNC stock levels until almost null values, while L4B and FRC increases until its maximum value was reached at the end of the planning horizon, corresponding to 5575ton and 2652ton respectively.

This storage pattern is a consequence of the substantial excess supply and the assumptions of non-growth over the 3-year planning horizon and of immediate transport of harvested products from stands to either mills or storage yards. The non-growth assumption leads to higher profitability of harvests that occur earlier in the planning horizon. The second assumption is due to the high incidence of wildlife fires in Portugal – that have burned over 3.8×10^6 ha in the period from 1975 to 2007, i. e. nearly 40% of the country area (Marques, Borges et al. 2011) – that discourages the storage at the harvest sites. The decreasing stock levels of L2B, L2NB, L4B and FRNC were an expected consequence of the need to spread the supply to the mills and the prevalence of the transportation from the harvest units to the storage yards. Complementary, the increasing stock levels of L4B and FRC reinforced the previous suggestions of higher profitability for these assortments.

Furthermore, the tactical plan suggested that the mills became predominantly served by its closest storage yard handling the demanded assortment (Figure 3). As such, the yard at Casa Branca provided pulpwood for Setil, Setubal and Beja, while the yard at Portalegre served exclusively the Badajoz pulp mill. Vendas Novas was the only yard supplying forest residues needed at Entroncamento, Setubal and Badajoz. The mills incoming flows often corresponded to the exact demand level, as expected due to the

prevalent transportation from the harvest units to the storage yards. Yet, there was an exceptional transportation of a total of 3413.47 ton of L4B from the harvest units to Badajoz during October, November, January and February, exceeding greatly this mill demand levels. It suggested that this assortment-destination combination was the most profitable solution when the yards reached its maximum storage capacity.

The comparison of the performance of the alternative solution methods for the IFTPP baseline scenario highlighted the quality of the SA+AFSH method. In fact, it provided the best solution of the objective function ($324.70x10^4$€) for this problem instance with 8400 integer variables, 235536 continuous variables and 85204 constraints, after 3h14min and almost 1000 SA iterations (about 12 sec per SA iteration) (Table 4). The alternative SA+LPSolve method could provide the optimal solution for the product assortment and assignment sub-problem although with substantially higher computational costs (2 hr per SA iteration, corresponding to more than 2000 hr for the 1000 SA iterations). The computational times could be decreased about two orders of magnitude with SA+CPLEX. Nevertheless, the difficulty of finding admissible solutions for this IFTPP and the fact that it does not support the computation of the maximum storage duration, made it inadequate to use during this research.

The solutions reported for the what-if scenarios did make sense. The best values of the BZ', BZ, sNit and ET were within the expected range of values obtained in the previous calibration runs. The results showed that the best value of the fitness evaluation function was not very sensitive to the variations on the demand levels, storage capacities of the yards and maximum size of the clearcut opening area, induced by the different what-if scenarios (Table 3). The average value of BZ' for the baseline scenario (BL) fitted within the interval defined between the minimum and maximum values of BZ' provided by the repetitions of several what-if scenarios (A_2, C_2, A_1 and B_1). Therefore, the analysis of the impact of the what-if scenarios over the baseline scenario was performed using the average BZ' considering the 5 repetitions of each what-if scenario. Results showed that the removal the demand levels in all mills (A_2) led to the highest improvement on the BZ' (plus $3.31x10^4$€, corresponding to 1%), considering the average of the results for the 5 repetitions of each scenario. The reduction of the demand levels in all the mills to 80% of the values considered on the baseline scenario (A_1) had a similar improvement of 0.7% of BZ'. This improvement resulted from higher flows to/from the yards and consequently, lower flows from the forest directly to the mills. The transshipment to the storage yards may decrease the overall

wood transportation costs due the timber weight reduction by dying under open air conditions as well as the lower unit transportation costs using the railway network connecting the yards to the transformation centers. This result is consistent with the previous analysis of the baseline scenario.

Increasing the maximum allowable clearcut opening areas from 65ha to 80ha (C_2) also led to an improvement of 0.9% on the BZ'. This highlights the impact of environmental constraints on revenues and is consistent with the motivation to concentrate harvest and transport in earlier periods.

Furthermore, increasing the capacity of all the yards by 20% of the baseline scenario (B_1) conducted to an improvement of 0.2% on the BZ'. This is also consistent with the previous results suggesting that the yards are working predominantly at its maximum capacity. Both the opposite scenarios C_1 (decease of $Amax_{PE}$ to 30ha) and B_2 (closing all the yards) led to a reduction of 1% and 9.4% on the BZ', respectively.

The run with the BZ' closest to the average BZ' for each what-if scenario was further analyzed. All the selected scenarios reported decreasing monthly harvested areas across the planning horizon. This tendency of concentrating harvest and transportation in the initial months was consistent with the baseline scenario and the non-growth and the immediate transportation assumptions (Figure 5). In fact, the highest harvest levels were scheduled to occur on the first trimester (more than 50% of the total harvest area for scenarios A_1, A_2 and B_2), reaching the maximum on August 2010. The maximum harvest areas vary among the scenarios (between 1040.62ha for A_2 and 607.84ha for C_1) and are generally inferior to the BL (1293.75ha). Most of the scenarios (A_1, A_2, B_1 and B_2) tend to stabilize the harvest levels around 300-400ha per month during the remaining months, although a slight decrease usually occurs during the last month (150-200ha). This harvest scheduling pattern, firstly reported on the BL, also applied to the scenarios with changes on the size of the clearcut opening areas (C_1 and C_2). Yet, the scenario C_1 – large number of small-sized clearcut openings - had the lowest monthly harvest levels, especially during the first trimester (607.84ha), followed by the decrease of the harvest levels around 300ha on the remaining months. Scenario C_2 – small number of large-sized clearcut openings - seemed to conduct to a more balanced distribution of the harvest levels around the planning horizon (average of 407ha per month).

The tactical plans of the selected what-if scenarios were further compared with the baseline (Table 5). As expected, the scenarios related with variations of the target demand levels of the mills (A_1 and A_2) reported the decrease of the flows from the forest to the mills, confirming that the yards were in fact the preferential destination of the stands outgoing flows. In particular, the timber assignment plan provided by scenario A_1 suggests that the demand levels were fully met, mostly by the flows coming from the yards (Figure 6). The direct flows from the forest to the mills mainly occur on the first period of the planning horizon, while the yards are still empty. The exception is the surplus of 5916.94ton of L4B transported to Badajoz during the last trimester of the planning horizon. This result confirmed that this assortment-destination combination may be the most profitable solution when the yards reached their maximum capacity. This scenario differs from the baseline on higher stock levels at the end of the planning horizon, particularly for L4B at Casa Branca and Portalegre (both closing near to their maximum storage capacity) and for FRC at Vendas Novas. Contrarily to the baseline, the scenario A_1 further suggested that the mills may be served by more than one yard. As an example, the pulpwood arriving at Setubal came predominantly from Casa Branca, yet Portalegre was also used for L2UB and L4UB on September and November, when these assortments were not available at the closest yard.

In the extreme situation where no target demand levels were considered (scenario A_2), the timber assignment plan reported high levels of pulpwood production on the August and September in line with the suggested by the analysis of the monthly harvested areas. It was exclusively converted into L4B and transported to Casa Branca and Vendas Novas, until both reached their maximum storage capacity. The same assortment was produced on the following months (an average of 2040ton per month) and transported exclusively to Badajoz, leading to a total surplus of 22548.92ton at this destination. As expected, this scenario had the highest stock levels at the yards at the end of the planning horizon (Table 5).

The scenario B_1 (Increasing 20% de capacity of all the yards) had a similar positive effect on the pulpwood stock at the yards at the end of the planning horizon. In fact, the stock levels in Portalegre and Casa Branca in July 2011 were near its maximum capacity (the first with 9000ton of L2B and the second with 7941ton of L4B). These larger yards stored all the excess of pulpwood production, therefore no surplus was sent to the mills. Their incoming flows match the target self-supply levels. They are predominantly supplied by the yards, in consistency with the baseline results (Figure 6). Yet, this

scenario B_1 reported some pulpwood flows from the harvest units to the mills during the end of the first trimester (e.g. total of 532ton of different pulpwood assortments to Setubal, in September and December, and 2000ton of L2B to Beja in September to December). This may be a consequence of the absence of these assortments on the yards closest to these mills during those months. As expected, increasing the capacity of Vendas Novas did not impacted of the forest residues flows, since it's stock levels were always below the maximum capacity (its maximum stock levels here 2603ton in July 2011). Consequently, Vendas Novas remained the only storing location for the production surplus of forest residues.

Conversely, closing all the yards (B_2) and only considering direct wood assortment flows from the stands to the mills, had a significant impact on the tactical plan firstly provided by the BL, justifying the negative effect on the BZ' reported previously. As expected, the direct flows match the target demand levels at the mills. Consequently, this scenario reported the highest level of pulpwood surplus (16668.94ton). This surplus, produced mainly during August to February, has converted into L4B at the forest sites and transported to Badajoz, with an average of 2547ton per month instead of the 200ton required to fulfill this pulp mill target demand levels. Badajoz was also the destination for the surplus of forest residues chipped at the harvest sites. There was an average transport of 420.5ton per month of FRC to Badajoz, instead of the 50.4ton required.

The scenarios related with variations on the maximum allowable opening area (C_1 and C_2) provided identical timber assignment plans (Figure 6) with similarities with the baseline scenario. The target demand levels were fully satisfied mostly with assortments coming from the yards. Yet, these scenarios presented a slight increase of the pulpwood flows from the harvest units directly to the mills. As an example, scenario C_1 assigned a total of 869ton of pulpwood to the pulp mill at Setubal between September and November and 1500ton of L2B to Beja on the same periods. This effect was also previously reported on scenario B_1. The pulpwood storage yards reached the end of the planning horizon at their full capacity (the stock in July 2011 in Casa Branca was 7500ton of L4B in scenarios C_1 and C_2, while in Portalegre was 7500ton of L2B in the scenario C_2 and 6491.6ton of L2B in the scenario $C_{1)}$. The lack of storage space at the yards justified the production of L4B at the harvest sites, followed by its transport to Badajoz, particularly during the last trimester (average flows of 647.23 and 983.35 ton per month on C_2 and C_1, respectively). These scenarios further suggested that the pulpwood target levels at

Setubal and Setil may be supplied by Portalegre and Casa Branca. Scenario B_1 only acknowledged more than one yard associated with the pulpmill at Setubal. Scenarios C_1 and C_2 mainly differ on the total amount of pulpwood transported from the harvest units to the yards, the stock levels at the yards at the end of the planning horizon and the yard firstly used for intermediate storing. Specifically, scenario C_2 recorded higher flows from the harvest unit to the yards (38900.56ton against 38731.68ton for C_1) as well as higher stock levels in July 2011 (17590.34ton against 16581.96ton). Scenario C_2 further reported earlier transportation of pulpwood to Casa Branca (starting in October, while in C_1 only in started November). Additionally, the harvesting costs reported for C_2 were slightly inferior than C_1 (16598€ and 16623€, respectively). The combination of all these minor effects may justify the higher improvement on BZ' achieved with C_2.

4. Discussion

This research aims at improving forest planning through the integration of the main tactical decisions. The monthly harvest schedules are set according to the assortment demands at the mills and will condition the pulpwood/forest residues assortments produced at the harvest sites as well as its assignment to the pulp mills, bio-energy plants or wood yards for intermediate storing.

The proposed MIP formulation for this integrated forest tactical planning problem (IFTPP) effectively addressed the requirements stated by the forest practitioners of the Portuguese integrated pulpwood industry Grupo Portucel Soporcel engaged in this research. The problem decomposition approach proved to be adequate to address the complexity of the IFTPP. The main IP sub-problem related with harvest scheduling, included maximum opening size constraints within a typical area restriction framework (e.g. Murray 1999; Borges and Hoganson 1999; Richards and Gunn 2000; McDill et al. 2002, Caro, Constantino et al. 2003; Baskent and Keles 2005; Weintraub and Murray 2006). The second LP sub-problem established the quantities produced of each assortment and its assignment to the transformation centers. It has similarities with the problems addressed by (Andalaft, Andalaft et al. 2003) and (Karlsson, Ronnqvist et al. 2003). Yet these authors targeted assortments of logs of distinct species while our research considers just one species (*Eucaliptus globulus* Labill*)*. The log size classes and biomass products are assorted to better fit the operations requirements of the mills owned by the

pulpwood company. The IFTPP further presents similarities with the bucking problem. Yet, the former is a forest level management planning problem, while the latter focuses on the optimization of bucking operations of individual trees (Epstein, Morales et al. 1999; Epstein, Nieto et al. 1999). The IFTPP introduced by this research further aims at addressing the role of intermediate storage yards in reducing timber transportation costs. Finally, no road building and maintenance decisions were considered as this was not required by the pulpwood company.

The current implementation of the solution method was computationally effective. It combined the use of simulated annealing to solve the master problem with the use of exact or heuristic procedures to solve the LP sub-problem. For the current problem instance (average of 699 binary variables, 234837 continuous variables and 84946 constraints) the proposed solution method reported 11.68sec, 6288sec and 62sec per SA iteration when using the AFSH procedure, the LPSOLVE and the CPLEX respectively. Taking into account that SA was expected to converge after almost 1000 iteractions, only the performance of the AFSH procedure (3hr14min) stood below the threshold of 8hr established by the technicians engaged on the decision-making processes at the woodpulp company. Nevertheless, coding improvements may further lead to better computational performances.

The fitness evaluation function used to evaluate the solution generated in each SA iteration performed successfully on the current problem instance. It aimed at providing results even for unfeasible parameter combinations. Feasibility seamed to by impossible to achieve with the exact solution methods for the MIP problem, probably due to the size of the current problem instance and the complexity of the spatial constraints. This precluded the use of an exact method to evaluate the solution provided by the heuristic.

This fitness evaluation function relies on the computation of a penalty function that assesses whether the model constraints are met and assigns penalties to the encountered deviations. The computation of the deviations posed as a challenge for some of the constraints. In particular, the estimative of the storage time in the yard for a certain load relied on a Fist-In-First-Out procedure based on the analysis of the incoming and outcoming wood flows. Yet, FIFO strategies may not be currently prevailing in all wood storage yards layouts (e.g. Last-In-First-Out may the prevalent strategy for wood stock management on a single woodpile in a small yard). Nevertheless, the use of FIFO strategy may increase in the future as it promotes the quantitative and qualitative track of the logs inside the yard, which constitutes a

requirement of the ongoing forest certification schemas. The adaptation of such a strategy will require new policies in respect to the yard management, aiming logs physical separation by provenience and arrival date. This can be enhanced by using innovative wood tracking devices (e.g. RFID tags) which could lead to an increase of the storage costs.

The solution method was successfully applied to produce forest tactical plans for a given IFTPP problem instance. The 55 calibration runs were instrumental for setting the best values of the meta-parameters for the current IFTPP problem instance (Nit=1000, α=0.98, T_0=BZ'/100, T_f=0.2.T_0). Although the best value of the fitness evaluation function was not very sensitive to variations of T_0. The behavior of the solution method to different meta-parameters combinations was in line with the expected. Further calibration tests, possible with new initial values for T_0, and the trial of alternative cooling schemas (e.g. Falcão and Borges 2002) could improve the performance of SA for this problem instance. Yet these meta-parameters are problem-specific, thus further research is required when applying the solution method to different case studies.

The tactical plan for the selected run of the baseline scenario reported a global net present value of $324.70 \times 10^4 \text{€}$ correspondent to the integration of harvesting with products assortment and assignment processes. Yet, this value was computed under the assumption of distinct prices paid by the mills and the storage yards for the product assortments. It may not be the case of real-world situations on vertically integrated industries. Practical aspects related with the ownership and confidentiality of the information prevented the quantification of the earnings in respect to the current situation where these processes are conducted independently.

Yet, significant reductions of the operations costs are expected. Firstly, the scheduling of harvests according to the spatial constraints as well as the monthly demand levels at the mills and the available storing capacities at the wood yards fosters the best use of the harvesting equipment and crews. It may also improve the management of the timber at the harvest sites. Contrary to the current situation, harvesting and pulpwood transportation from the forest occurs simultaneously, thus avoiding wood decay at the forest sites, deft and timber losses due to forest fires. Furthermore, higher revenues were gained due to the concentration of harvesting and transportation on the first trimester of the planning horizon. It reflects the anticipation of the wood revenues fostered by the applied economical function

and the possibility of transporting large volumes of timber to the yards. Other scenarios with higher target demand levels at the mills may lead to a more balanced distribution of harvesting over the planning horizon.

Earnings are also expected from producing the assortments that best fit the demand levels and distinct prices offered at the different wood consumption locations. The scenarios performed for the current IFTPP instance revealed a clear predominance of the assortments L4B, FRC and L2B, thus suggesting the profitability of barking and chipping operations at the forest site. Nevertheless, these results reflect the tradeoff between the harvest costs structure and the prices for the different assortments at the mills. This information is scarce and often incomplete. Improving the quality of the information used for planning is instrumental for increasing the robustness of the results, thus enhancing the use the proposed solution method on real-world planning processes.

Finally, the pulpwood assignment plans provided by the several scenarios suggested a reduction on the timber transportation costs due to the use of the intermediate storage yards for this particular case study. The importance of the storage yards to the pulpwood supply strategy already had been suggested in other studies (Karlsson, Ronnqvist et al 2003). In this case, there was a predominance of direct transportation from the forest to the yards during the first planning months until they reached the maximum capacity. Two of these yards were almost permanently at its full storage capacity. They were the preferential suppliers for the mills, taking advantage of the decrease of the logs weight as a result of dying under open air conditions and the lower unit transportation costs associated to the railway transportation between the yards and the mills.

Yet, these results may be confined to the context of the case study approached. On one hand, the changing the geographical location of the mills, the storage yards and the stands impacts on the transportation costs and may lead to different conclusions. Likewise with variations of the pulpwood price, the pulp wood storage cost or the proportion among both may also impact on the results. On the other hand, acknowledging the stands growth across the planning period, addressing the relation between the stand volume estimates and the sum of the volume of the logs forwarded to the woodpiles ready for transport and also improving the wood drying equations will provide robustness to the results.

The comparison among the "what-if" scenarios proved to be adequate to assess the impact of the variations of the constraint parameters over the value of the objective function and the tactical plan provided by the baseline scenario for the current IFTPP instance. Yet, conclusive tradeoff analyses were only obtained when considering the average values of several runs for the same scenario. The scenarios related with decreasing the demand levels at the mills (A_1 and A_2), increasing the storage capacity at the yards (B_1) and increasing the maximum allowable clearcut opening area to 80ha (C_2) seemed to have a positive impact on the value of the fitness evaluation function. The opposite effect was obtained when closing all the yards (B_2) and reducing the maximum allowable clearcut opening area to 30ha (C_1). These results were in line with the expected since these what-if scenarios act upon active constraints of the model of the baseline scenario. The improvements on the objective function were generally associated with higher pulpwood flows to and from the yards as well as higher stock levels at the yards at the end of the planning horizon. The pulpwood yards often reached its maximum capacity at the end of the planning horizon while the remaining production surplus was converted into the most profitable assortment-destination (L4B to Badajoz).

Furthermore, the generation of what-if scenarios was considered key to support decision making. The forest practitioners valued the possibility to change the parameter values for the model's constraints and to use the weights on the penalty function to accommodate their preferences in respect to the constraints relative importance. Obtaining solutions within a few hours was also a major concern when dealing with reactive tactical/operational planning. They were willing to use sub-optimal solutions whenever optimality could not be achieved within reasonable computational times. In fact, optimality may not even be a major concern when the tactical plan is expected to change during the negotiations among the company departments, prior to its implementation. Furthermore, the lack of quality on the baseline information (e.g. disconnected road network shapefile) as well as the absence of adequate estimates on the model parameters (e.g. operational costs, transportation costs, temporal series for the product prices and target demands at the mills) may decrease the robustness of the model and affect the reliability on the results.

Additional positive effects of integrating harvesting with assortment and assignment decisions are the increasing efficiency and effectiveness of forest tactical planning due to the simplification of the processes. On the perspective of those responsible for forest production, the decisions related with

harvesting and transportation are conducted simultaneously, possibly within an unique simpler and central organizational structure. It will provide additional valuable information for the wood transportation outsourcing negotiations with the hauliers. On the perspective of those responsible for the mill supply, the anticipation of the assortment deliveries provided by the wood assignment plan is instrumental for negotiating the additional marked wood supplies for the entire planning horizon as well as planning in advance the wood reception and storing.

5.   Conclusions

In Portugal there was considerable experience on applying operations research techniques to enhance forest planning, especially for long-term decisions (e.g. Falcão and Borges 2001; Borges, Marques et al. 2008; Borges, Fragoso et al. 2009). This article extends this research to address tactical decisions concerning the integration of harvest scheduling, wood assortment and assignment processes.

The integrated forest tactical planning problem (IFTPP) was firstly described, an innovative MIP formulation as proposed and solved combining heuristic and mathematical programming algorithms. To the best of our knowledge, the proposed approach for integrating the main forest tactical decisions had never been suggested in the forestry literature.

This article showed that problem decomposition may be used to address complex IFTPP instances. An IP harvest scheduling sub-problem considering its temporal and spatial constraints was firstly solved with Simulated Annealing (SA). It provided input for the LP product assortment and assignment sub-problem solved with a linear programming algorithm or the newly developed Admissible Flow Solution Heuristic (AFSH). The solution method then unfolded according to the standard SA algorithm.

The use of the AFSH proved to be more adequate to the current IFTPP instance, encompassing twelve 1-month temporal horizon, 4 pulp mills, 1 bio-energy plant, 3 intermediate storage yards, 6 product assortments and a forest area with 700 eucalypt stands extending over 4888 ha in South-Central Portugal. It presented better computational performances when compared with the tested LP solvers (11.68sec per SA iteration, contrary to the 6288sec and 62sec obtained with LPSOLVE and CPLEX respectively).

The results of more than 120 computer runs proved the advantages of integrating the decisions harvest scheduling as well as timber assortment decisions. Furthermore, the information provided by this tactical plan was considered key to support decision making. The SA meta-parameters were firstly calibrated (Nit=1000, α=0.98, T_0=BZ'/100, T_f=0.2.T_0). Then the selected run for the baseline scenario was thoroughly analyzed. Afterwards, several "what-if" scenarios were generated to assess the impact of the variations of the constraint parameters over the value of the objective function and the tactical plan provided by the selected baseline scenario. In general terms, all the scenarios suggested concentrating harvesting and transportation of the first trimester of the planning period. The pulpwood flows to and from the yards prevailed over the direct transport from the harvest sites to the mills. The transport to the mills often matched the demand levels. Consequently, most of the scenarios presented high stock levels at the yards at the end of the planning horizon, mostly with pulpwood barked assortments and chipped forest residues.

Future research will embed this solution method in a decision support system for forest tactical planning (SADPOF). This system may also include other short-term problems arising from the IFTPP solution, such as the wood trucks scheduling and routing problems usually conducted at the daily basis. The role of the future system users will also be acknowledged in all the phases of the future SADPOF design. They play a key role on collecting reliable data for the model, validating the model results and promoting the system use to support decision-making processes.

A complementary research topic will be the integration of the SADPOF with other electronic devices used to collect data during the forest operations and wood transportation (e.g. PDA, RFID track and trace devices, truck geographical positioning devices). The use of such devices can be influential for improving the quality of the data used in forest tactical planning. They further can lead towards a new forest planning paradigm where new tactical and operational plans are generated in response to unpredictable events reported during the forest operations follow-up.

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Tables

Table 1 – Case study characteristics

Parameters	Values
Forest area	4,888 ha
Number of stand (i)	700
Planning horizon (j)	12 monthly periods
N. Final destinations ($f \in F_M$)	2 pulp mills (Beja, Setil), 1 bio-energy plant (Entroncamento), 2 mixed facilities (Setubal, Badajoz)
N. Intermediate storage yards ($f \in F_T$)	3 (Casa Branca, Portalegre and Vendas Novas)
N. Assortments (p)	4 pulpwood assortments, including unbarked and barked logs with 2 or 4 meters length (L2UB, L4UB, L2B, L4B, respectively) as well as 2 forest residues assortments, including chipped and non-chipped forest residues (FRC, FRNC, respectively)
Maximum Clearcut Opening Area over the exclusion period ($Amax_{PE}$)	65ha
Minimum Clearcut Opening Area ($Amin_j$)	0,3ha
Exclusion period	6 months
Minimum distance between adjacent stands ($DISTMIN$)	15 m
Interest rate (Tj)	0,4%
Unit harvest costs	Forwarder: 2.975€/ha; Manual harvest: 5.1€/ha; Harvester: 3.1 €/ha; Barking: 0.5€/m^3; Chipping: 5.33 €/ton; Soil preparation and planting: 114€/ha
Unit transportation costs	Logs by road: 0.02€/km/ton; Logs by train: 0.01€/km/ton Chipped forest residues by road in distances >50km: 11 €/ton; <50km: 6 €/ton
Assortments monthly target demand levels and prices at the mills ($TG_{pj}{}^{f}$, $PR_{pf} \in FM$)	Setubal: L2UB (200ton, 3.3€/ton), L4UB (70ton, 3.5€/ton), L2B (60ton, 4.3€/ton), L4B (100ton, 4.5€/ton), FRC (151ton, 33,5€/ton), FRNC (65,8ton, 31€/ton) Setil: L2UB (90ton, 3.2€/ton), L4UB (90ton, 3.4€/ton), L2B (90ton, 4.0€/ton), L4B (90ton, 4.2€/ton) Beja: L2B (550ton, 4€/ton) Entroncamento: FRC (43.2ton, 30.0€/ton), FRNC (57.6ton, 28.0€/ton) Badajoz: L2B (250ton, 5.0€/ton), L4B (200ton, 5.2€/ton), FRC (50.4ton, 35,0€/ton), FRNC (43.5ton, 32.0€/ton)
Assortments prices at the storage yards ($PR_{pf} \in FT$)	Casa Branca: L2UB 2.0€/ton, L4UB 2.4€/ton, L2B 3.0€/ton, L4B 3.4€/ton Portalegre: L2UB 3.0€/ton, L4UB 3.0€/ton, L2B 4.0€/ton, L4B 4.0€/ton Vendas Novas: FRC 29.0€/ton; FRNC 24.0€/ton;
Storage yards max. capacity ($CMax_f$)	15000 ton for Vendas Novas, 7500 ton for the others
Maximum storage duration ($Dmax_{pf}$)	6 months
Unit storage costs for pulp wood assortments	1€/ton

Note: The remaining combinations without a price value correspond to assortments not accepted at the mill or the yard.

Table 2 – Matrix used for computing the unit NPV in each timber distribution cycle performed by the AFSH procedure. It includes a set of origins (stands i and storage yards $f \epsilon F_T$), a set of destinations (mills $f \epsilon F_M$ and yards $f \epsilon F_T$), the product available at the origins ($AV_i^L, AV_i^{FR}; AV_f^L, AV_f^{FR}, f \epsilon F_T$)), the demands at the mills ($TG_p^f, f \epsilon F_M$) and storage space at the yards ($SS^f, f \epsilon F_T$) and the unit net present value of each triplet (npv). The first timber distribution cycle addresses simultaneously the triplets at the first and second quadrants of the matrix. The second cycle focus on the transportation to the yards, correspondent to the third quadrant of the matrix. The next cycles are based on sub-sets of triplets from the first and second quadrants. The transportation among storage yards is not allowed, consequently, NPV of the fourth quadrant of the matrix is set to -1 for all the yards.

	For all $f \epsilon F_M$ and $p \epsilon P^L$ or $p \in P^{FR}$	For all $f \epsilon F_T$	
For all $i \in I$	$npv_{ifp}^1 = PR_{pf} - CT_{if}$	$npv_{if}^3 = \dfrac{\sum_p PR_{pf}}{\#p} - CT_{if,}$ $\forall p \epsilon P^L$ or $p \in P^{FR}$	AV_i^L or AV_i^{FR}
For all $f \epsilon F_T$	$npv_{ffp}^2 = \begin{cases} -1, if\ j = 1 \\ PR_{pf} - CT_{ff} - CM_f \end{cases}, if\ j \neq 1$	$npv_{ff}^4 = -1$	AV_f^L or AV_f^{FR}
	TG_p^f	SS^f	

Table 3 – Test runs for SA-AFSH. CT_1 to CT_8 are calibration tests, BL is the baseline scenario and A_1 to C_2 are what-if scenarios.
Best known final value of the fitness evaluation function (BZ'), correspondent value of the objective function (BZ), number of iterations for stabilization (sNit) and execution time (ET).

Test Runs	Test description	BZ' (x10^4€)				BZ (x10^4€)				sNit				ET (sec)			
		Avg	Std	Min	Max	Avg	Std	Min	Max	avg	std	Min	Max	Avg	Std	min	max
CT_1	T_0=iBZ'; T_f=0.2T_0; Nit=1000; α=0.98	318.55	7.74	299.25	326.77	328.64	2.05	324.22	332.01	931	60	837	999	12043	580	11065	12963
CT_2	T_0=10iBZ'; T_f=0.2T_0; Nit=1000; α=0.98	316.70	10.71	**291.46**	326.02	326.39	5.04	312.46	331.10	916	64	788	*1000*	23152	4805	13746	26738
CT_3	T_0=iBZ'/10; T_f=0.2T_0; Nit=1000; α=0.98	**320.95**	6.63	304.30	325.21	**328.83**	1.43	325.23	330.32	877	77	725	965	10909	715	9502	11939
CT_4	T_0=iBZ'/100; T_f=0.2T_0; Nit=1000; α=0.98	319.29	9.71	303.73	**327.82**	324.20	9.28	309.16	**332.91**	*819*	202	*401*	990	9858	310	9358	*10251*
CT_5	T_0=iBZ'/1000; T_f=0.2T_0; Nit=1000; α=0.98	314.45	10.81	301.04	326.68	321.45	10.95	**306.63**	332.18	838	83	645	954	*8324*	898	*6891*	10262
CT_6	Nit=5000; T_0=iBZ'/100; T_f=0.2T_0; α=0.98	321.35	6.91	307.90	329.39	330.44	2.42	327.87	334.70	4234	419	3530	4976	33424	938	31696	34475
CT_7	Nit=100; T_f=0.9T_0; T_0=iBZ'/100; α=0.98	304.31	6.50	294.57	315.12	310.94	6.48	**299.85**	320.49	*91*	*10*	*72*	*100*	*1753*	*87*	*1596*	*1879*
CT_8	Nit=10000; T_0=iBZ'/100; T_f=0.2T_0; α=0.98	**324.62**	6.23	**312.53**	**330.92**	**332.91**	2.45	327.47	**334.95**	8431	263	8011	8836	65626	1900	63622	69209
BL	Baseline scenario with the meta-parameters of CT_4	323.75	1.74	320.67	324.76	324.00	1.69	321.00	325.00	990	7	981	998	10778	630	9674	11216
A_1	Reducing demand in all mills to 80% of BL	326.86	2.59	323.51	330.41	327.00	2.62	323.59	330.50	993	3	989	996	10197	1160	9046	11462
A_2	Removing demand levels in all mills	327.75	3.35	322.95	332.09	327.86	3.36	323.04	332.22	990	5	984	996	10525	474	9860	11028
B_1	Increasing capacity of all yards by 20% of BL	324.95	2.39	320.72	326.56	325.09	2.37	320.93	326.88	993	6	986	998	10368	352	9925	10721
B_2	Closing all the yards	293.84	0.23	293.62	294.14	297.83	0.46	297.26	298.35	990	8	978	998	13181	225	12897	13481
C_1	Decreasing Amax from 65ha to 30ha	321.20	1.83	317.99	322.54	321.54	1.85	318.34	323.02	992	2	989	994	9468	523	8751	9907
C_2	Increasing Amax from 65ha to 80ha	327.24	2.78	323.67	330.05	327.36	2.76	323.75	330.20	995	4	989	998	9679	1100	8649	10870

iBZ': Initial estimate of the best value for the fitness evaluation function (before calibration tests) = 190×10^4€

Table 4 – Comparison among different solution methods for the IFTPP baseline scenario. Presents the problem characteristics and the optimization results in terms of the best known value of the fitness evaluation function (*BZ'*), execution time for 1 iteration (ET1it) and total execution time (ET) and Number of iterations (Nit)

Solution method	No. integer variables	No. continuous variables	No. Constraints	BZ' (x10^4€)	ET1it (sec)	ET (sec)	Nit
SA+AFSH	**8400**	**235536**	**85204**	**324.45**	**11.68**	**11677**	**1000**
SA+LPSOLVE	8400	235536	85222	---	6288	---	118306
SA+CPLEX	8400	235536	85222	---	62	---	2668

Table 5 – Comparison among different scenarios "what-if" for the IFTPP problem instance solved with SA+ AFSH. Presents the results in terms of the best known value of the fitness evaluation function (*BZ'*), the best value of the objective function (*BZ*), total execution time (ET) and difference between the BZ' of the current scenario and the baseline scenario (BZ'$_i$-BZ'$_{BL}$).

	BL	A$_1$	A$_2$	B$_1$	B$_2$	C$_1$	C$_2$
Objective function							
BZ' (x10^4€)	**324.45**	326.45	326.51	325.69	293.82	321.52	328.23
BZ (x10^4€)	**324.70**	326.46	326.63	325.80	297.87	321.71	328.28
ET (sec)	**11677**	9402	10631	10721	13321	8751	9284
BZ'$_i$-BZ'$_{BL}$	**--**	2.00	2.06	1.24	-30.63	-2.93	3.78
Flow variables							
L2UB F->M	**290.00**	232.00	0.00	792.40	3480.00	490.00	597.46
F->Y	**3190.00**	2480.66	0.00	2687.60	0.00	2990.00	2882.54
Y->M	**3190.00**	2480.66	0.00	2687.60	0.00	2990.00	2882.54
Stock (Y)	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00
Surplus (M)	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00
L4UB F->M	**160.00**	128.00	0.00	300.00	1920.00	230.00	300,00
F->Y	**1760.00**	1408.00	0.00	1620.00	0.00	1690.00	1620,00
Y->M	**1760.00**	1408.00	0.00	1620.00	0.00	1690.00	1620,00
Stock (Y)	**0.00**	0.00	0.00	0.00	0.00	0.00	0,00
Surplus (M)	**0.00**	0.00	0.00	0.00	0.00	0.00	0,00
L2B F->M	**950.00**	760.00	0.00	3020.00	10800.00	1960.00	2522,04
F->Y	**10450.00**	7872.00	0.00	16780.00	0.00	16340.00	15777,96
Y->M	**10450.00**	7872.00	0.00	7780.00	0.00	8840.00	8277,96
Stock (Y)	**0.00**	0.00	0.00	9000.00	0.00	7500.00	7500,00
Surplus (M)	**0.00**	0.00	0.00	0.00	0.00	0.00	0,00
L4B F->M	**3203.47**	6308.28	22548.92	790.00	21348.94	3267.31	2358,94
F->Y	**17545.47**	18360.00	15000.02	11558.94	0.00	10581.63	11490,00
Y->M	**4290.00**	3432.00	0.00	3890.00	0.00	4090.00	3990,00
Stock (Y)	**13255.47**	14928.00	15000.02	7668.94	0.00	6491.63	7500,00
Surplus (M)	**3413.47**	5916.94	0.00	0.00	16668.94	2677.31	1668,94
FRC F->M	**258.00**	195.84	0.00	244.60	5538.76	244.60	244,60
F->Y	**5296.36**	5060.72	7541.56	5294.16	0.00	5294.16	5294,16
Y->M	**2692.80**	1457.28	0.00	2690.60	0.00	2690.60	2690,60
Stock (Y)	**2603.56**	3415.06	7541.56	2603.56	0.00	2590.34	2590,34
Surplus (M)	**0.00**	0.00	0.00	0.00	2603.56	0.00	0,00
FRNC F->M	**165.60**	132.48	0.00	166.90	2002.80	166,90	166,90
F->Y	**1821.60**	2152.52	0.00	1835.90	0.00	1835,90	1835,90
Y->M	**1821.60**	2152.52	0.00	1835.90	0.00	1835,90	1835,90
Stock (Y)	**0.00**	0.00	0.00	0.00	0.00	0,00	0,00
Surplus (M)	**0.00**	0.00	0.00	0.00	0.00	0,00	0,00
Total mills consumption (ton)	**29231.47**	26559.07	22548.92	25818.00	45090.50	28495.31	27486.94
Stock at the yards (end of PH)(ton)	**15859.03**	18343.06	22541.58	19272.50	0.00	16581.96	17590.34

Presents the flow variables per assortment, summarized according to direct transportation to mills (F->M) or to yards (F->Y) and indirect transportation from the yards (Y->M). Also presents the stock in the yards at the end of the planning horizon (stock (Y)) and the surplus of pulpwood transported to the mills (Surplus (M)). The assortments are 2m logs barked and unbarked (L2B, L2UB), 4m logs barked and unbarked (L4B, L4UB), Forest residues chipped and not-chipped (FRC, FRNC). The scenarios are: Baseline scenario (BL); reducing demand in all mills to 80% of BL (A$_1$); removing demand levels in all mills (A$_2$); increasing capacity of all yards by 20% of BL (B$_1$); closing all the yards (B$_2$); decreasing maximum allowable clearcut opening to 30ha (C$_1$); increasing maximum allowable clearcut opening area to 80ha (C$_2$)

Figures

START for each j, $p \in P^L$ or $p \in P^{FR}$

Flows from stands & yards to mills,
Compute NPV^1, NPV^2
$Cycle^1$ (until all NPV^1 and $NPV^2 = -1$)

∃ both products available at the stands AND available capacity at the yards? — Yes → **Non-qualified flows from stands to yards** Compute NPV^3; $Cycle^2$ (until all $NPV^3 = -1$ or exceeds yards capacity)

No

∃ both products available at the stands AND unsat. demand at the mills? — Yes → **Flows from stands to mills** Recompute NPV^1 for the affected (stands, mills); $Cycle^{3.1}$ (until all $NPV^1 = -1$)

No

∃ still product available at the stands? — Yes → **Flows from stands to best destination** Recompute NPV^1 for the affected stands; $Cycle^{3.2}$ (until all $NPV^1 = -1$)

No

∃ still unsatisfied demand at the mills? — Yes → **Flows from yards to unsatisfied mills** Recompute NPV^2 for the affected plants; $Cycle^{3.3}$ (until all $NPV^2 = -1$)

No

Last j,p? — No → (loop back)

Yes

Qualify the flows from stands to yards using a FIFO approach

Get variables q_{ijp}^f and t_{fjp}^f based on qualified flows

End

Generate Initial Random Solution (Binary and continuous)

Evaluate the solution

Has the maximum iteration number been reached? — Yes → End

No

Generate new binary solution

Calculate continuous solution (PL or AFSH)

Evaluate the new solution

Is the new solution better than the "best"? — Yes → Accept the new solution

No

Randomly accept the new solution? — Yes → Accept the new solution

No

Update cooling parameters

(a)

(b)

Figure 1 – The solution method for the IFTPP, including Simulated Annealing (a) and the Admissible Flow Solution Heuristic (AFSH) flowchart (b)

Figure 2 – Total monthly target levels of the assortments in all the mills (MILL_TG) and destination of the assortments produced each month at the harvest areas (to the mills – mill_in – or yard) (primary axis). Includes the total harvesting area per month (secondary axis). The assortments considered were 2m logs barked and unbarked (L2B, L2UB), 4m logs barked and unbarked (L4B, L4UB), Forest residues chipped and not-chipped (FRC, FRNC)
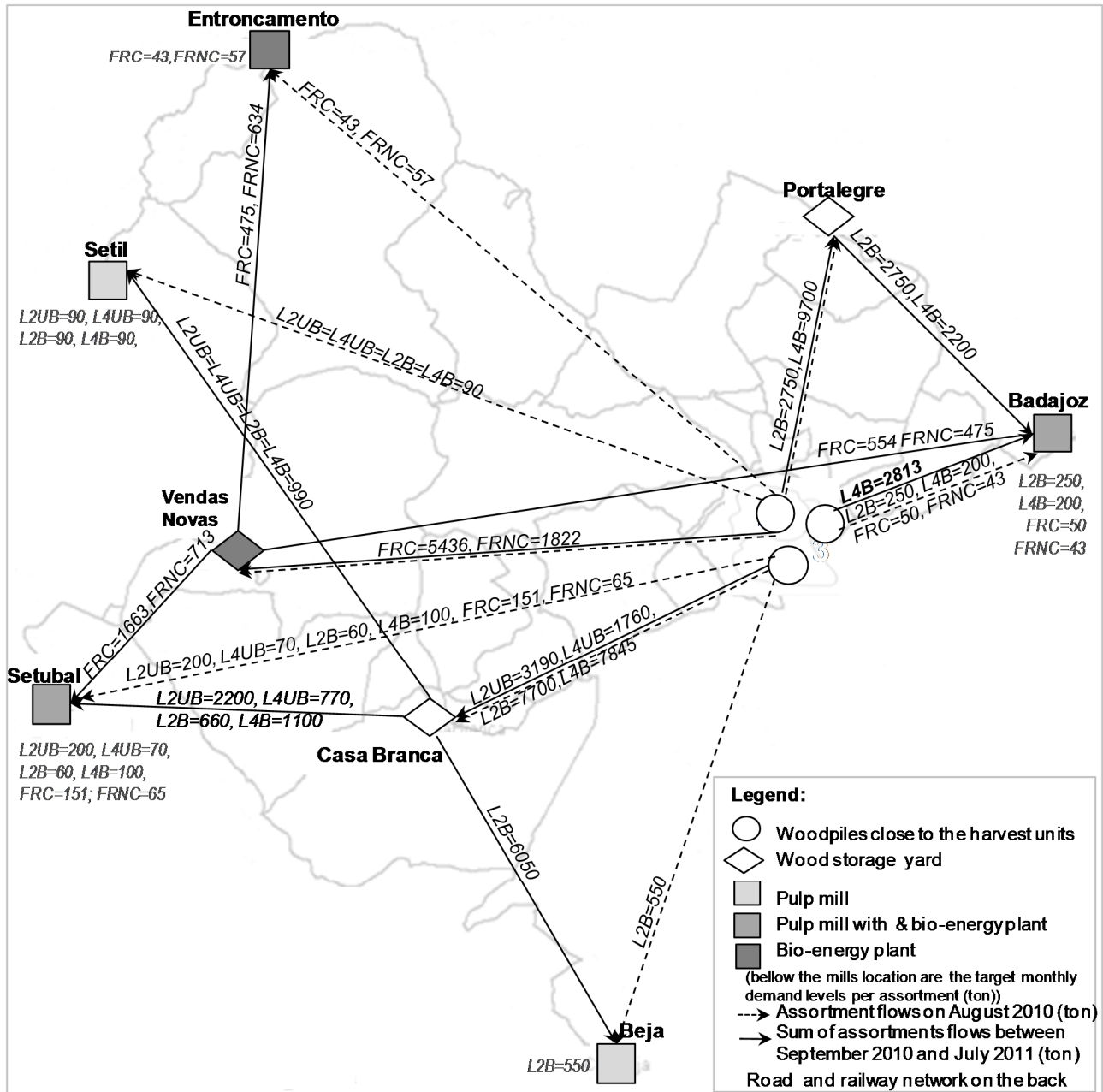
Figure 3 – Timber assortment plan for the IFTPP baseline scenario. Presents the assortments of pulpwood and forest residues produced on the forest units and its assignment to mills and yards over the distribution network. The considered assortments were 2m logs barked and unbarked (L2B, L2UB), 4m logs barked and unbarked (L4B, L4UB), forest residues chipped and not-chipped (FRC, FRNC)
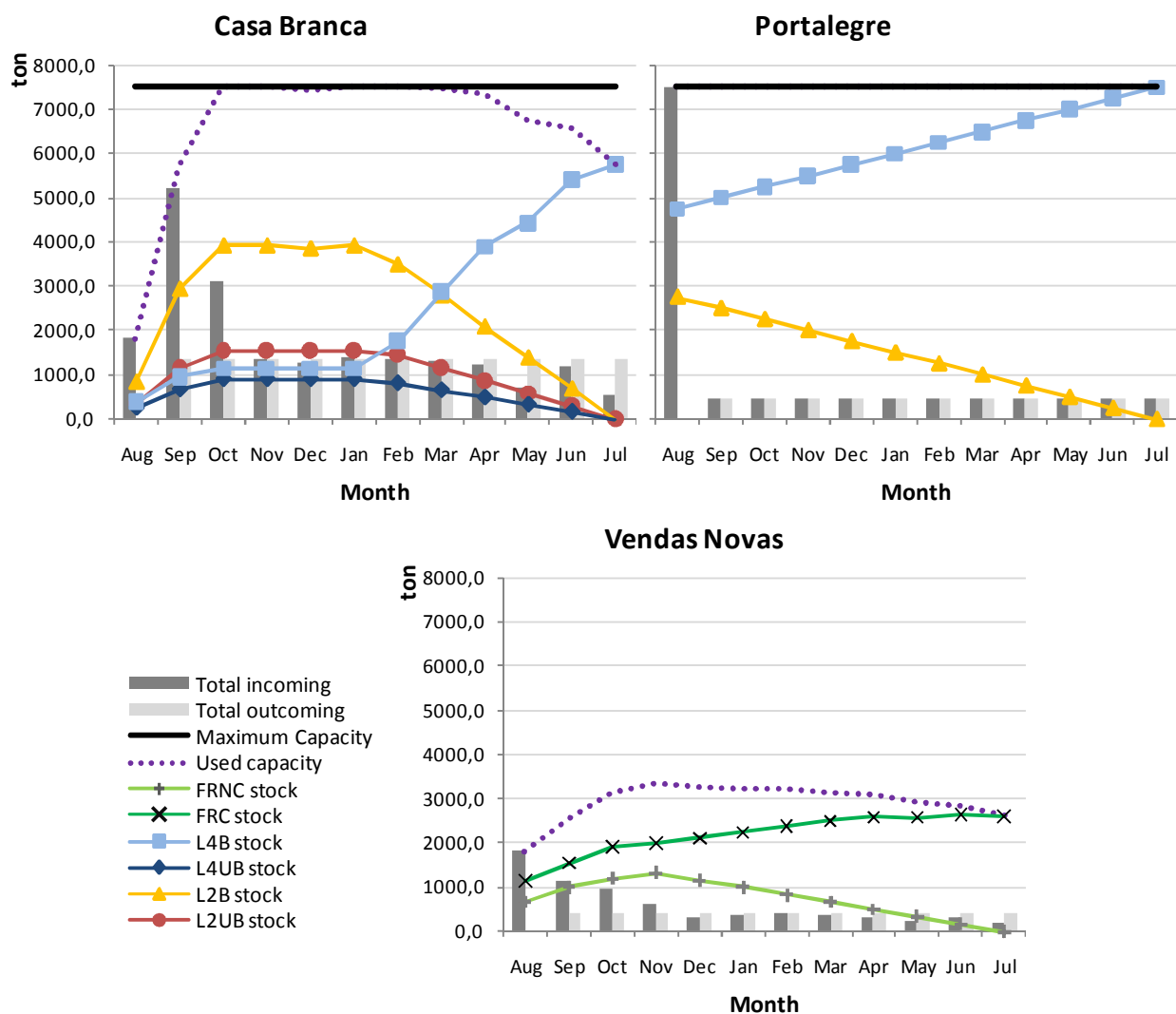
Figure 4 – Monthly incoming outgoing flows, stock levels for the assortments accepted in the storage yards and the yards used capacity for the IFTPP baseline scenario. The considered wood product assortments were 2m logs barked and unbarked (L2B, L2UB), 4m logs barked and unbarked (L4B, L4UB), Forest residues chipped and not-chipped (FRC, FRNC)
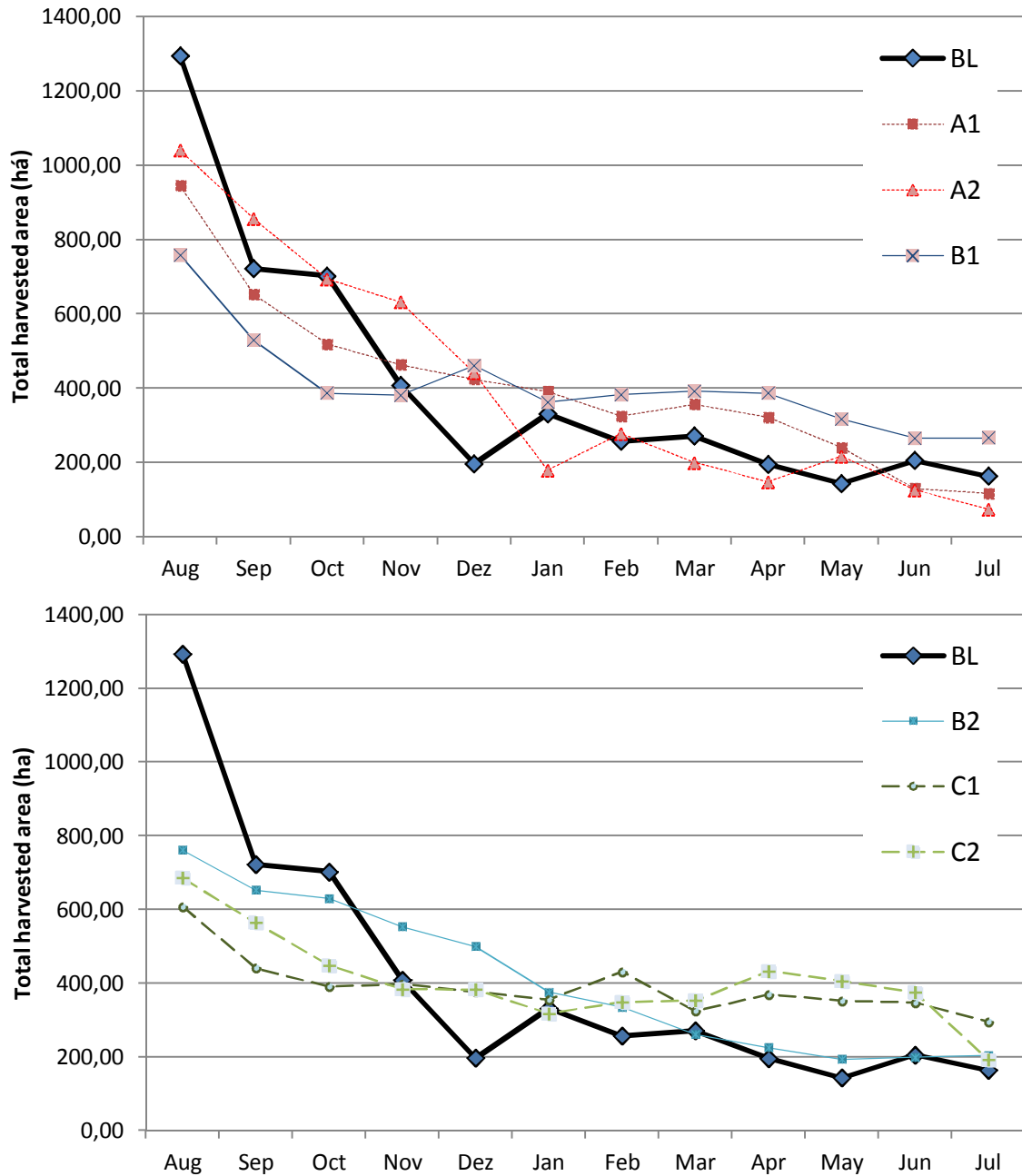
Figure 5 –Comparison of the evolution of the total monthly harvested area across the planning period among the different "what-if" scenarios for the IFTPP problem instance. The scenarios are: Baseline scenario (BL); reducing demand in all mills to 80% of BL (A_1); removing demand levels in all mills (A_2); increasing capacity of all yards by 20% of BL (B_1); closing all the yards (B_2); decreasing maximum allowable clearcut opening area to 30ha (C_1); increasing maximum allowable clearcut opening area to 80ha (C_2).
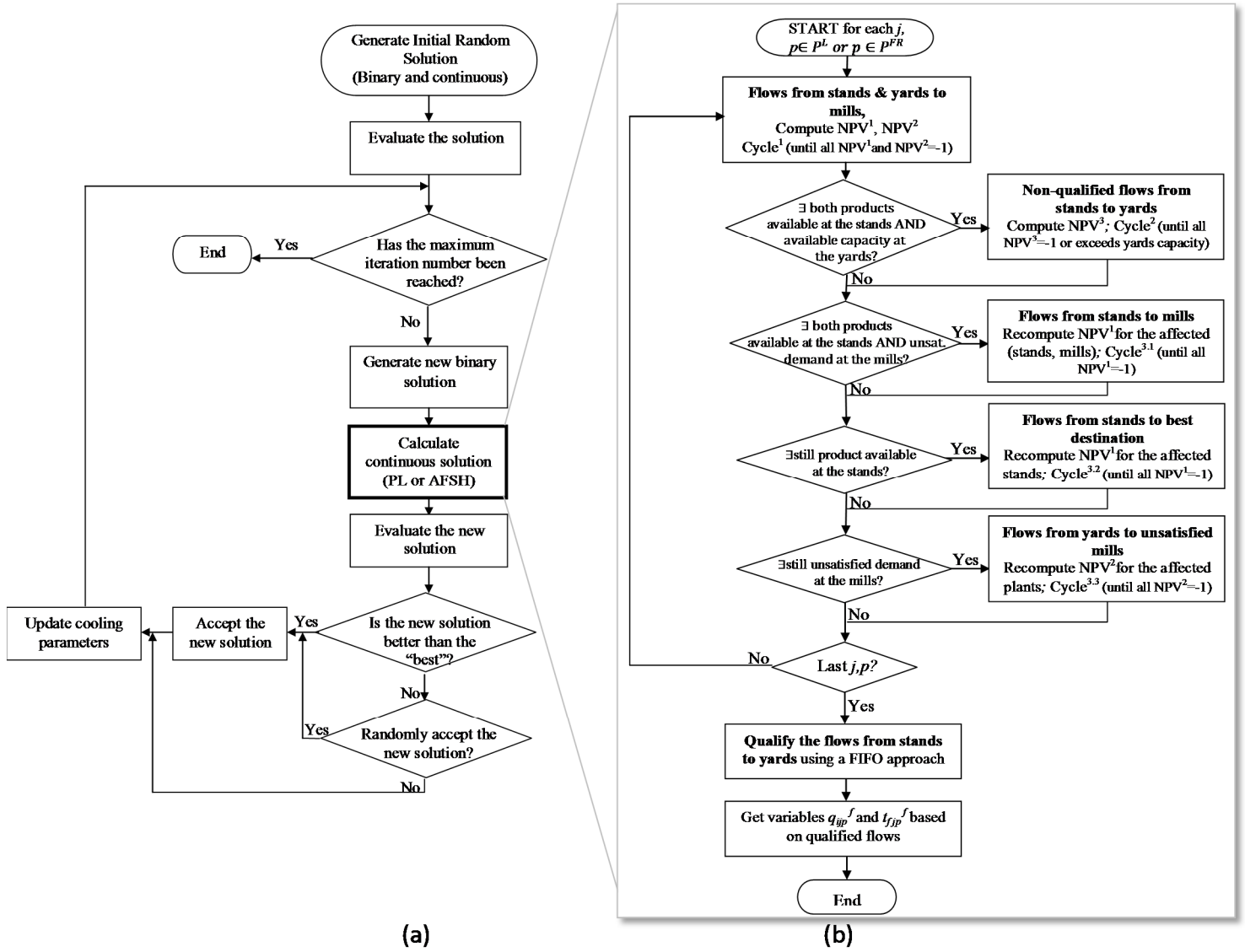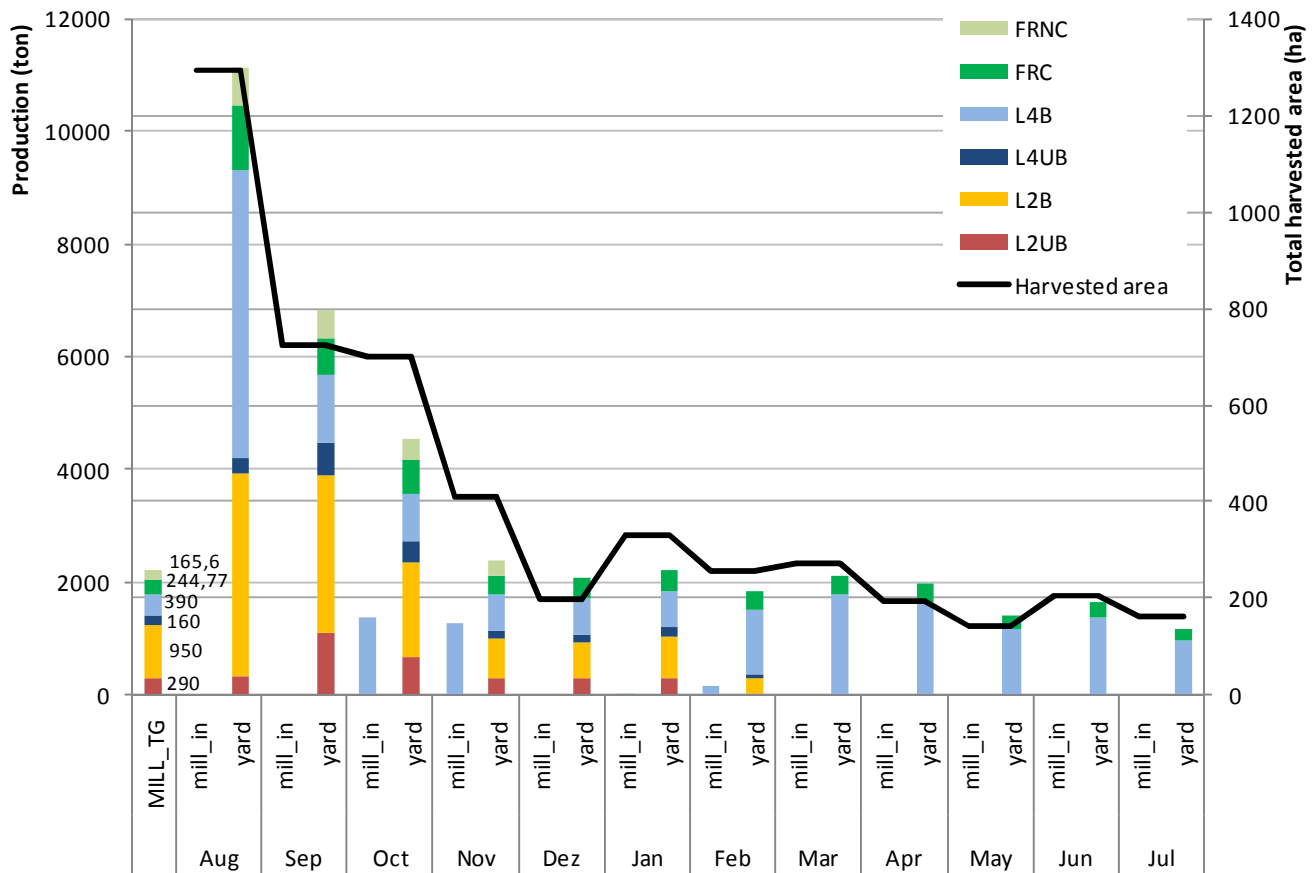
Figure 6 – Timber assortment plan for the several "what-if" scenarios. The considered wood assortments were 2m logs barked and unbarked (L2B, L2UB), 4m logs barked and unbarked (L4B, L4UB), Forest residues chipped and not-chipped (FRC, FRNC). The scenarios are: Baseline scenario (BL); reducing demand in all mills to 80% of BL (A₁); removing demand levels in all mills (A₂); increasing capacity of all yards by 20% of BL (B₁); closing all the yards (B₂); decreasing maximum allowable clearcut opening area to 30ha (C₁); increasing maximum allowable clearcut opening area to 80ha (C₂).

Solving the Raw Materials Reception Problem using Revenue Management principles: an application to a Portuguese pulp mill

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Abstract

The significant contribution of raw materials inbound logistics to the attainment 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 mills' gates. Yet, little attention is given to the trucks reception, unloading and internal movements until exiting the facilities. Consequently, congestion and queuing of 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 its real-time 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 warehouses, 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 wood daily deliveries on 6 possible docking stations inside the mill. The proposed approach led to a reduction of 55% on the total raw material reception costs 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 further used for conducting "what-if" scenario analysis, providing valuable results to support decision-making processes.

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 production mills are key processes on the inbound logistics that supply the value chains based on natural resources. The raw materials are often transported by road from the extraction sites to the mills on specially adapted trucks. The trucks wait in line to entry the mill at the service gate. There, the freight is audited and the truck is assigned to an internal docking station. It is usually an intermediate warehouse where the raw materials are temporarily stored. Later, the raw materials will be transported to the industrial production lines where they are transformed into intermediate or finished products. The traffic at the service gate and at the unloading docks, particularly on certain rush hours, causes congestion and queuing. The prolonged delivery time of these trucks leads to the increase the duration and cost of the transportation services. Consequently leading to the increase of the raw materials procurement cost. Particularly on the forest 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. [11]).

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

The literature on raw materials reception planning is scarce. Recent studies ([6]) 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 on the rush hours.

The paper firstly introduces the Raw Materials Reception Problem (RMRP) and then discusses one possible modeling and solution approach. The RMRP problem addresses a three-stage process there the trucks are progressively assigned to available slots at the service gate, at the intermediate warehouses and at the production lines. It has similarities with other airline and hotel booking problems where Revenue management (RM) techniques have been successfully applied. Revenue gains of 4-5% were reported in some airline industries ([7]). The readers are directed to [7], [10] and [8] for a complete overview of RM principles. In general terms, the capacity-based RM techniques rely on clustering the resources into price classes and managing over time the amount of resources available at each class. As an example, the application of this approach to the airline booking problem encompasses the definition of fare classes 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 classes 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. An average increase of 3-4% on the firm's net revenue was reported due to prior allocation of not yet reserved stock and planned production quantities to different customer segments, clustered based on their profitability and other priority measures.

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 RM-based approach for the RMRP relies on the carriers/trucks segmentation into priority classes followed by the minimum cost assignment of the truck to one time slot at one unloading location that is accessible for its priority class. The segmentation phase may be exclusively based on the trucks real arrival time leading to a FIFO approach. Yet, additional criteria can be considered, like the compliance with a previously planned arrival time, awarding on-time arrivals. Consequently, the trucks within the high priority class will have a larger range of available slots than the ones on the lower priority classes. The high class slots are reserved for high priority trucks as long as possible. Nevertheless, some minutes before starting a new slot, even low priority trucks can be assigned to high class slots if no other truck with higher priorities is waiting at the queue.

The proposed solution method is a $3-$phase procedure that runs in distinct time frames. The first phase $-$ Time Slot Allocation Planning $-$ runs before a given delivery day. It receives the planned deliveries that are the outcome of daily routing processes, and provides their optimal assignment to the slots available at unloading locations, according to their priority class. The second phase $-$ Time Slot Order Promising $-$ runs after each arrival during that day. It allocates the arriving truck to a time slot at one unloading location, preferably a production line, after computing the truck delay that may lead to its downgrade to a lower priority class. The third phase $-$ Time Slot Order Allocation $-$ runs just before starting each slot at the production lines, assuring that there is one truck ready for unloading. It handles the multiple-reservation situations, upgrades and load requests to the warehouse. It ultimately provides the real unloading time for the truck.

This solution approach was 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 docking stations 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. Furthermore, several "what-if" scenarios were solved with the 3-Phase method in order to test the potential of this technique inspired on the RM principles to support decision-making processes. The paper further discusses the real-life implications of the technique under the mills and the hauliers perspectives.

2. Problem statement

The reception of raw materials at the transformation mills encompasses three main stages that occur simultaneously during the mills opening hours. The service stage handles the trucks arriving at the mill gate. The truck arrival time and the freight characteristics are used to establish its priority class and set its position at the service queue (figure 1). The truck waits outside the mill facilities until it ascends to the front of the queue. Then, the receptionist at the service gate verifies the transportation documentation, performs security controls and the freight quantitative and qualitative evaluation. It further sets its unloading location. It is often an intermediate warehouse for temporary storing or directly to the docking stations that feed the raw materials

production lines. The delivery stage handles the trucks assigned to each docking station. The truck waits on the delivery queue while unloading usually takes place on an first-in-first-out (FIFO) basis, using the stationary equipment associated to the location. Finally, the truck exit the facilities usually using the same service gate. The line supply stage assures the continuous supply of raw materials to the production lines, either by direct freights or internal movement of the stocked material from the intermediate warehouses.
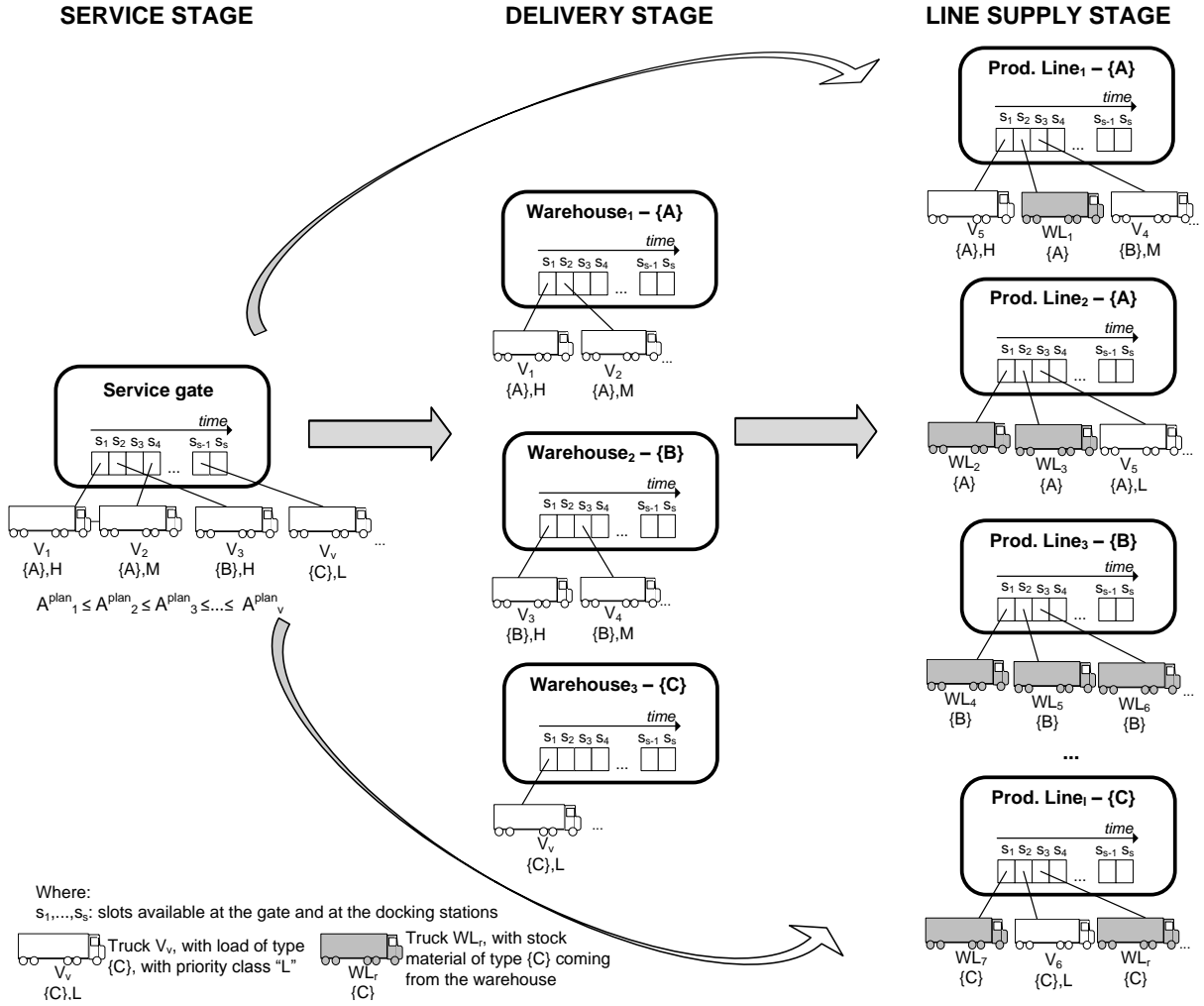
Figure 1: Graphical representation of the raw materials reception problem

The Raw Materials Reception Problem (RMRP) addresses all of these stages. It consists on sequencing the trucks at the service gate and conducting its optimal assignment to the time slots at the gate and at the unloading locations in order to minimize the raw materials reception costs. It acknowledges both the cost of materials handling at the warehouse and from there to the unloading dock and the cost of having the trucks stationary inside the mill waiting for service or delivery. The problem further acknowledges the arrival time for the expected deliveries and awards with direct entrance the on-time arrivals. Consequently, the trucks are compelled to arrive within the reserved service slots and are preferentially assigned directly to the production lines. The outcome of the RMRP problem further impacts on the raw materials transportation planning and on the management of the intermediate warehouses. In fact, it fosters the

compliance with the hauliers routing and scheduling plans. It also may improve the efficiency of the stock handling processes by enhancing the synchronization of the working shift of the warehouse stationary equipment with the delivery slots for the expected trucks.

3. 3-phase solution method for the RMRP

The 3-phase solution method is anchored on the RM principles. It is build on segmenting the expected trucks and progressively managing their assignment to the time slots at the unloading locations currently available slots for its segment (figure 2).
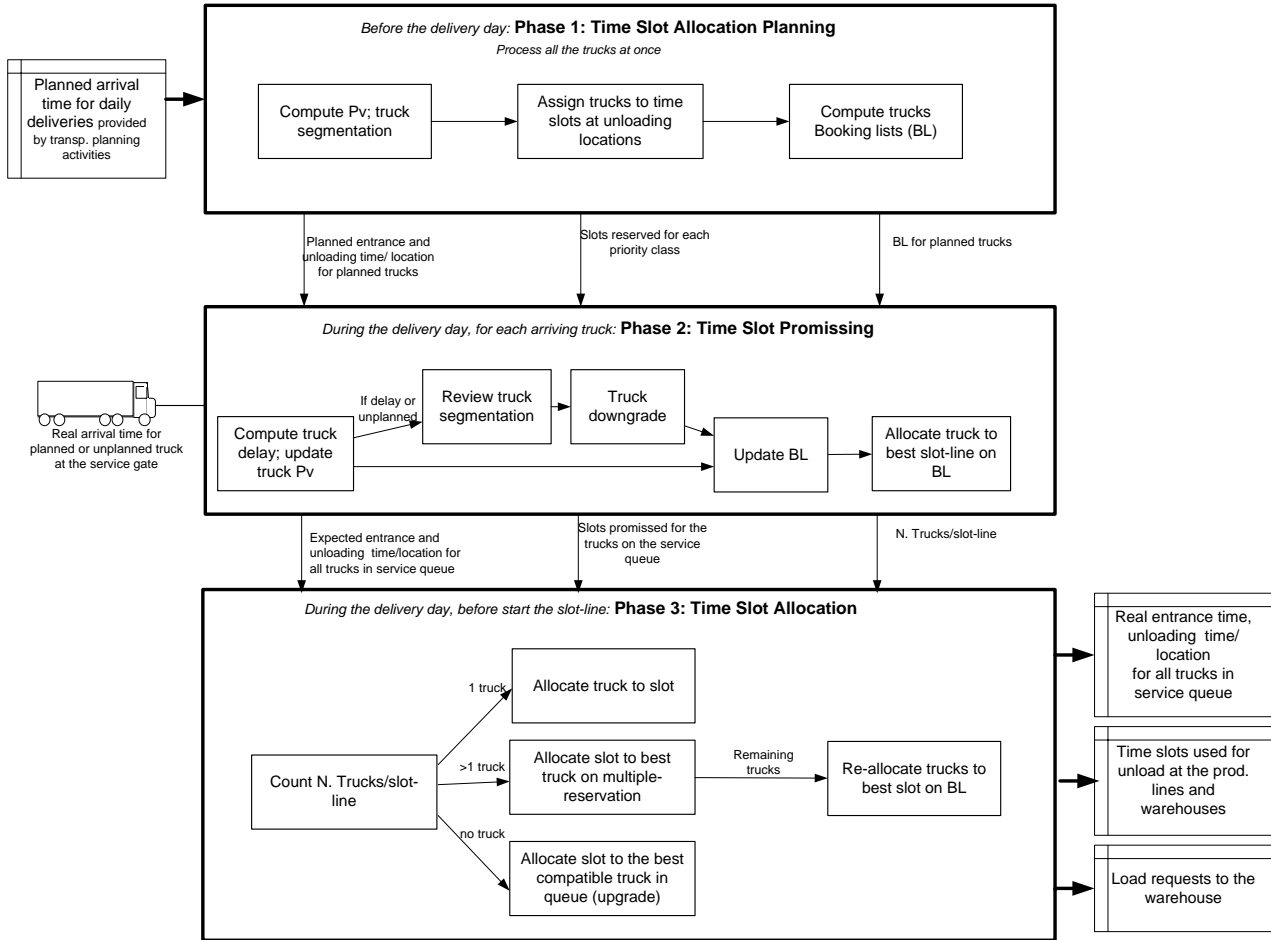
Figure 2: Structure of the proposed solution method for the RMRP

The phase 1 - **Time Slot Allocation Planning** - focus on the assignment problem of the expected delivery requests to the time slots available at the docking stations. It processes the expected delivery requests individually or in batch-mode before the target delivery day. It relies on an estimate of the planned arrival time for all the trucks, that can be previously established by a daily routing procedure in the course of the transportation planning activities. ([6]).

This phase starts by computing the time slots at the gate and at the unloading locations. The slots are set according to the working shift duration. The shift may be divided into 1-2hr time

windows, each in turn split into time slots with a few minutes duration. The length of the time slots at the gate and at the docking stations 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.

The phase proceeds with the carriers/trucks segmentation into a closed-set of previously established priority classes (or segments), based on the value of its priority index (P_v^i). This index 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 set during the transportation planning activities (Equation 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 hauliers transportation services. Furthermore, threshold parameters γ_{n-1} are further used to set the minimum value of the priority index above which the truck is classified into a priority class.

The priority index is further used to compute the raw materials reception cost (C_{vs}). On equal values for the remaining cost components, the truck with the highest priority index should come forward on the queue. The remaining cost components are the cost of having the trucks stationary inside the mill waiting for service or delivery, the cost of the materials handling when unloading occurs at the intermediate warehouses and the cost of keeping the unloading resources available overtime (Equation 2). The first is the product of truck total waiting time (W_v^{plan}) by the unit cost for each minute spend by the loaded truck at the queue (C^W). The W_v^{plan} may be computed as the time difference between the beginning of unloading operations (U_{vsd}^{plan}) and arriving at the service gate (A_v^{plan}), including the duration of the service stage (L^G) and the ride from the gate to the unloading location (t_d) (Equation 3). 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 the unloading takes place at the intermediate warehouses. It is the product of the unit cost materials handling (C^M) by the amount of material transported by the truck (l_v). While the third component is the product of the unit cost for overtime work (C^O) by the number of minutes beyond the line closing time when unloading should take place, either because the truck already after hours or its overall waiting time for unloading was prolonged. Whenever the transported raw material assortment is not accepted at a unloading location, C_{vs} takes a very high value "M"'.

$$
\begin{aligned}
P_v^i &= \sum_i \lambda_i \sigma_i, \sum_i \lambda_i = 1, 0 \le \lambda_i \le 1 & \text{(Equation 1)} \\
C_{vs} &= \frac{C^W W_v^{plan} + C^M l_v + C^O (U_{vsd}^{plan} - b^E)}{P_v^i}, \forall v : p_v = p_d, s \in S & \text{(Equation 2)} \\
W_v^{plan} &= (U_{vsd}^{plan} - (A_v^{plan} + L^G + t_d)) & \text{(Equation 3)}
\end{aligned}
$$

Nomenclature:

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 docking stations at the production lines (D^L) and at the warehouses (D^Y)
S^G	Set of time slots available at the gate
S	Set of time slots available at the unloading locations including the lines (S^L) and at the warehouse (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 intermediate warehouses (min)
b^S	Shift beginning time at the unloading locations
b^E	Shift ending time at the unloading locations
g^S	Shift beginning time at the service gate
g^E	Shift ending time at the service gate
t_d	Duration of the ride between the service gate and the unloading location d (min)
p_d	Raw material assortment accepted at the unloading location d
p_v	Raw material assortment transported by truck v
l_v	Weight of the raw material load delivered by truck v (ton)
C^W	Unit cost of each minute spent by an loaded truck at the queue (ϵ/min)
C^M	Unit cost of the raw materials handling operations at the warehouse (ϵ/ton)
C^O	Unit cost of one employee working overtime (ϵ/min)
n	Number of segments considered
π	Percentage of slots kept available for unplanned trucks
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	No. minutes before starting the slot at the line when the real allocation occurs (min)
A_v^{plan}	Planned arrival time for truck v at the service gate (min)
A_v^{real}	Real arrival time for truck v at the service gate (min)
W_v^{plan}	Planned waiting time for truck v at the service gate (min)
W_v^{real}	Real waiting time for truck v at the service gate (min)
W_v^{bef}	Waiting time for truck v arriving before the gate opening hours (min)
U_{vsd}^{plan}	Planned unloading time for truck v, when using the slot s at the unloading location d (min)
U_{vsd}^{exp}	Estimated unloading time for truck v, when using the slot s at the unloading location d (min)
U_{vsd}^{real}	Real unloading time for truck v, when using the slot s at the unloading location d (min)

The minimum cost assignment of the v expected deliveries to the s time slots available at each unloading location d is then formulated as an Integer Programming problem. The decision variables X_{vsd} are set to 1 if truck $v \in V$ is assigned to slot $s \in S$ at the unloading location $d \in D$ and 0 otherwise. It can be describe as:

$$\min z \;=\; \sum_{v\in V}\sum_{d\in D}\sum_{s\in S} c_{vsd}x_{vsd} \qquad (A)$$

s.t.
$$\sum_{d\in D}\sum_{s\in S} x_{vsd} \;=\; 1, \qquad \forall v\in V \qquad (B)$$

$$\sum_{v\in V} x_{vsd} \;\leq\; 1, \qquad \forall s\in S, d\in D \qquad (C)$$

$$\sum_{d\in D^L}\sum_{s\in S}\sum_{v\in V^M} x_{vsd} + \sum_{d\in D^L}\sum_{s\in S}\sum_{v\in V^F} x_{vsd} \;\leq\; \pi' \qquad (D)$$

$$x_{vsd} \;\in\; \{0,1\} \qquad \forall v\in V, s\in S, d\in D \qquad (E)$$

The objective function aims at minimizing the raw materials reception cost through the optimal assignment of the trucks with the daily deliveries to the available time slots at the unloading locations (equation A). The remaining equations set the problem constraints. The daily delivery must be assigned to exactly one time slot (Equation B). 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 sets the time slots length according to the maximum duration of the unloading operation. Reciprocally, it is imposed the assignment of the time slot to one truck at the most (Equation C). It is not mandatory to have the time slots at the docks all assigned during this phase. In fact, these slots may be allocated further on to freights from the intermediate warehouses. Contrarily, the majority of the slots at the warehouses 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 total number of deliveries to the lines in order to keep π' slots available for unplanned trucks ($\pi' = \sum_{s\in S^L}(1\text{-}\pi)$) (Equation D). Finally, equations (E) 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 delivery requests. The compliance with the A_v^{plan} during the delivery day are considered maximum priority. These trucks will take the lead on the service queue, therefore their waiting time to service and delivery will be minimized.

The solution further provides the sets of time slots reserved for each segment, that are used on the truck booking list (BL_v). The BL_v groups all the feasible slots reserved to the truck segment and to lower segments, considering its planned arrival time. As an example, the high priority truck arriving at 10hr can access the slots reserved for high, medium and low segments starting after that date, while those with low priority can only access the slots reserved for the lower segment since 10hr. Yet, any truck can access the unreserved slots. During phase 2, the reserved slots will be kept reserved for the planned truck segment as long as possible.

The following phases of the solution method were designed for real-time slots re-assignment, triggered by delays of the expected deliveries or the arrival of unplanned trucks. Specifically, phase 2 - **Time Slot Promising** - rely on the re-segmenting the trucks and updating their booking lists according to the real arrival time and possible downgrade to lower segments, followed by the truck re-assignment to a slot within its booking list. It starts by computing the delay of each truck arriving at the service gate (L_v) and updating its priority index (P_v^u). The parameter

8

σ signals on-time arrivals, corresponding to null delays. It relies on a tolerance parameter (α) set by the mill as a tolerance interval around the planned arrival time where the truck is still considered to arrive on-time. Positive delays correspond to the time difference between the real arrival time and σ, normalized by the shift ending time in order to get values between 0 and 1 (Equation 4). The P_v^u reflects the impact of the trucks delay on its given priority classification (Equation 5). Consequently, on-time arrivals keep their priority class, yet, late arrivals can lead to the downgrading process.

$$
\begin{aligned}
L_v &= \frac{A_v^{real}-\sigma}{b^E}, if A_v^{real} > \sigma; 0\, otherwise && \text{(Equation 4)}\\
&\text{with}\,\sigma = min\left\{\left(A_v^{plan}+\alpha\right);\left(U_{vsd}^{plan}-t_d-L^G\right)\right\}\\
P_v^u &= \delta_1 P_v^i + \delta_2\left(1-L_v\right); \delta_1+\delta_2=1; 0\le\delta_1,\delta_2\le 1 && \text{(Equation 5)}\\
\gamma_n^u &= \delta_1\gamma_n+\delta_2\left(1-\frac{\Delta}{b^E}\right) && \text{(Equation 6)}
\end{aligned}
$$

The downgrading process consists in re-classifying the truck into a lower priority class, according to its updated priority index and the revised values of the threshold parameters (γ_n^u) (Equation 6). It will lead to the reduction of the slots available at its BL_v. This process is 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 class will be downgraded. This parameter is further used to identify the new priority class for the late arrivals. Accordingly, all the delays equal or below Δ will keep its priority class. While delays above Δ will depend on the value of P_v^i. The trucks with higher P_v^i will keep their priority class even for higher delays. Yet, even the high priority trucks can be downgraded to the lowest priority class when very long delays occur. Even low priority trucks can be downgraded to a very low priority class only used for this process.

The unplanned trucks have null P_v^u corresponding to the lowest priority class.

At the end of phase 2, the allocation of the arriving truck to the best slot available at its updated BL_v is based on a minimum assignment cost criteria (Equation 1). It provides the truck expected unloading time/location U_{vsd}^{esp} and consequently, the best entrance time at the service gate. At this stage, delayed trucks high high priority may be assigned to slots previously reserved to lower priority trucks, leading to the multiple-reservation situations that are addressed on the next phase.

The phase 3 - **Time Slot Allocation** - focus on the line supply stage and checks the arrived trucks previously assigned to the dock β minutes before the beginning of each slot. It starts by counting the number of trucks promised to that 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 slot is finally used by the truck arriving on-time or by the truck with the minimum assignment cost (equation 2). The remaining trucks are re-assigned to the best slot on its BL_v (also considering a minimum cost criteria). When re-assignment occurs on a slot at the gate it leads to a postponement of the service stage that may impact on the feasibility of the expected unloading time. In this case, the truck is further re-assigned to a new slot at an unloading location. This stage may lead to new multiple-reservation situations for later slots that will be handled afterwards equally.

When there is no truck promised for that slot, the method proceeds with the upgrading process. It anticipates the delivery phase of the best compatible truck waiting in the queue, selected based on the minimum assignment cost criteria. In the case of a slot at the unloading location, the truck if compatible when the both the processed and the transported raw material assortment are the same and the anticipation of the delivery time is feasible considering the truck entrance time. When upgrading occurs, the slot initially reserved to upgraded truck becomes vacant. Finally, no truck is available at the service queue, the procedure triggers a freight request of stocked materials from the warehouses.

4. Case study: Pulpwood reception at a Portuguese pulp mill

The proposed solution approach was applied to the particular case of RMRP related with pulpwood reception at a pulp mill. The case study was inspired on 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 4th main European producer of Kraftliner for paper and board products. Operates in 30 industrial unit located at Portugal, Spain and France. The unit Europac Kraft Viana at Viana do Castelo 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 $350x10^3$ton of paper, consuming about $700x10^3$ton of maritime pine and $180x10^3$ton 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 of the wood procurement processes. Specifically, 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 (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 fleet used for transporting pulpwood from the self-managed forests is outsourced. Yet, the company relies on few transportation cooperatives, each with 20 to 40 hauliers. The market wood is supplied usually by small-scaled entrepreneurs. They often conduct the 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 typically encompasses an initial service stage that starts when the truck arrives at the mill and is placed on the service queue. The first truck v at the queue passes trough a weighing machine located at the service gate. The receptionist then decides its unloading location d, taking into account freight/truck characteristics. The intermediate wood yard is the preferential 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 docking stations that feed the production lines ($d \in D^L$). Then, the delivery stage starts when the truck reaches the assigned unloading location. Unloading operations often take only a few minutes as they are performed by stationary electric cranes positioned at those locations. The empty truck uses the same gate for departure and a new weighting estimate is recorded. Both measurements are then used to compute the pulpwood weight that will dictate the final price payed to the supplier. 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 lumber 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 increase 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 locations. The trucks can take up to 4 hours to complete the unloading operation, when it should take about 40-45 min. The maximum waiting time should be below 4hr for any delivery. The prolonged time periods when the truck is stationary inside the mill waiting for service or unload represent a cost for the haulier, that can be estimate a fraction of the fixed costs related with the truck maintenance and the drivers costs (C^W). It further impacts on the fleet sub-optimal utilization and causes disruption on their transportation schedules. Consequently, the hauliers 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. The trucks congestion may also impact on the mills internal operations and on the layout.

Case Simulation

The data set used in this study relates to one working day from 06hr to 21hr at the service gate of the pulp mill (Table 1). The 2hr time windows were split into 17 time slots (L^G) of 7min duration. The mill accepts three product assortments, generically named product A, B and C. The unloading locations include one active cell at the intermediate wood yard for each assortment, as well as 2 unloading docking stations for product A and one for product B. The working shift starts 1hr after the gate and it is split into 15min time slots (L^L and L^Y). The length of the time slots corresponds to the maximum duration on the truck unloading operation using the electric crane stationary in each location. The ride between the gate and the unloading destinations (t_d) takes about 10min.

Two separate data sets of daily trucks schedules were considered. The first - planned deliveries - corresponded to the deliveries requests (v) planned in advance to arrive on that day. The delivery request was characterized by the truck planned arrival time (A_v^{plan}), the type of wood product transported (p_v), the number of trips planned for that day and the estimate of the load weight (l_v). 72 planned deliveries were considered, 40% of these coming from market wood suppliers. The remaining deliveries came from self-managed forests. Therefore, the data set further included the identification of the harvest site. Both the delivery key-identifier and truck key-identifier may be of importance. There may be less trucks than the number of deliveries since the same truck can perform more than one trip during the day. This data set may be the outcome of the transportation planning activities (e.g. [6]) or may be randomly generated. This study applied random functions to set the number of deliveries in each time window, using

Table 1: Characteristics of the case study for the baseline scenario

Constant		Value
V	$=$	$\{1, 2, ..., 120\}$, with $V^F = \{1, ..., 57\}$, $V^M = \{58, ..., 72\}$, $V^U = \{73, ..., 120\}$
D	$=$	$\{1, 2, ..., 6\}$, with $D^L = \{1, 2, 3\}$, $D^Y = \{4, 5, 6\}$
S^G	$=$	$\{(364; 0), (371; 0), (378; 0), ..., (1245; 0), (1252; 0)\}$
S	$=$	$S^L \bigcup S^G$
S^L	$=$	$\{(420; 1), (420; 2), (420; 3), (427; 1), (427; 2), ..., (1245; 2), (1245; 3)\}$
S^Y	$=$	$\{(420; 4), (420; 5), (420; 6), (427; 4), (427; 5), ..., (1245; 5), (1245; 6)\}$
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	$=$	0.51€/min
C^M	$=$	0.35€/ton
C^O	$=$	0.1€/min
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

higher probabilities for arrivals on the rush hours. About 40% of the deliveries occurred on 7hr-9hr, 11hr-13hr and 19hr-21hr. The average number of 17 trucks per time window could rise up to 20 in the rush hours. In each time window the deliveries were regularly spread across the time slots at the entrance gate. Then, random values were obtained for the remaining attributes.

The second data set - real deliveries - encompassed all the deliveries that actually arrive at the service gate during that day. It included the same planned trucks as the first data set plus 48 unplanned trucks of market wood suppliers. These unplanned trucks may arrive before the gate opening hours or during the working shift. Arrivals after the working shift were received on the next day. The delivery was characterized as before yet replacing the A_v^{plan} by the the real arrival time A_v^{real} and including the waiting time for the truck arriving before the gate opening hours (W_v^{bef}). Random functions were further used to generate the A_v^{real} for all the deliveries as well as the remaining information related with the unplanned trucks.

Solution approaches

The case study was solved using the 3-phase method for the RMRP. The data set of the planned deliveries was used on the phase 1 - Time Slot Allocation Planning. This phase performed the

trucks segmentation into 3 priority classes (high, medium and low) according to the value of their priority index. Two threshold parameters were further used to set the minimum value of the priority index above which the truck was classified as high (γ_1) or medium priority (γ_2). Accordingly, 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 $0 \leq P_v^i < \gamma_2$. In this case, the γ_1 and γ_2 were set to 0.6 and 0.3.

The priority index of the truck was computed as a pondered sum of five sequencing criteria (Equation 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 docking stations; 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 take values between 0 and 1. σ_1 and σ_2 were considered the most important criteria, thus having the higher weights values ($\lambda_1 = 0.5$, $\lambda_2 = 0.2$). The remaining criteria were weighted with 0.1.

Phase 1 proceeded with the pulpwood reception cost computation, then used on the truck-slot assignment problem. The unit costs "C_W" and C_M were set to 0.51€/min and 0.35€/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 (total cost=19.2*0.51€). Above this value, if was preferably assigned to the warehouse if no waiting time was foreseen (total cost=28*0.35€).

The trucks booking lists were computed at the end of phase 1. It included the slots up to 240min after the truck planned arrival time which remained unassigned as well as those assigned to trucks on its priority class and those assigned to other trucks on lower priority classes.

The data set of the real deliveries, variant 1 was used on the phase 2 - Time Slot Promising. It encompassed the computation of the truck delay and new priority index, using the α tolerance parameter of 4 min. Unplanned trucks had null priority indexes. 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 as well as on the previous γ_n parameters. As an example, consider trucks v_1 and v_2 with $P_v^i = 0.6$ and $P_v^i = 0.9$. Since $\gamma_1 = 0.6$ both are classified as high priority. Yet, v_1 is at the edge of its class. If it arrives 30min late it will keep the high priority class, but if it arrives 31min late it will be downgraded to medium. v_2 keeps the high priority until higher delays (up to 428min). Yet, it will be downgraded from high to low priority if the delay is higher than 819min.The updated booking list had the same length as the previous.

The phase 3 - Time Slot Allocation was conducted 10min before starting each slot at the gate and at the unloading locations.

The results of the proposed solution method were compared against the current raw materials reception process. Emphasis was on the total raw material reception cost, as well as other indicators retrieved from the daily delivery schedules, such as the sum of the trucks waiting time to complete the service and the delivery stage, the maximum, average and minimum waiting time for trucks per segment and the number of deliveries unloaded directly at the production lines.

The current situation consists on a First-In-First-Out (FIFO) sequencing procedure for the trucks arriving at the gate, based exclusively on their real arrival time. The truck segmentation was not performed nor the direct unload at the production lines. It did not acknowledge any reception planning phase therefore all the arrivals were unplanned. Yet, for the purpose of comparison with the 3-Phase method, the same data set of the real deliveries was used for conducting this FIFO procedure.

Furthermore, this procedure did not acknowledged time slots at the gate nor at the unloading locations. 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 (Equations 7 and 8).

$$
\begin{array}{rcll}
E_v^{real} &=& max\left\{A_v^{real}; (E_{v-1}^{real} + L^G)\right\} & \text{(Equation 7)} \\
U_v^{real} &=& max\left\{(E_v^{real} + t_d); (U_{v-1}^{real} + L^Y)\right\} & \text{(Equation 8)}
\end{array}
$$

The analysis of potential of the 3-Phase method to support the reception planning and the underlying decision-making processes conducted at the mill, further encompassed the comparison among several "what-if"' scenarios. These scenarios were generated in order to access the impact of key parameter values used both on the case simulation and on the solution method over the results of the main problem instance (the baseline scenario). Scenarios 1 to 3 accessed the impact of reducing the length of the time slots at the gate and the unloading locations. SCN_1 reduced the L^G to 5 min, while SCN_2 and $SCEN_3$ reduced L^Y and L^L to 10min, respectively. SCN_4 considered one additional production line processing the assortment type B. SCN_5 changed the proportion of unplanned arrivals from 40% to 70%. The new data set for the real deliveries used in this scenario included 168 unplanned arrivals and a total of 240 deliveries per day. SCN_6 increased the proportion of the trucks arriving at the rush hours to 65%. SCN_7 removed the direct unloading a the lines, therefore considering only the 3 active cells at the warehouse.

The FIFO procedure and the 3-phase solution method were coded on VB.NET using the Visual Studio 2008 environment. The phase 1 of the solution method used the GNU GLPK v4.34 for windows [4] to write the current problem instance into a mps file format. This file was the input of the COIN-OR CBC solver [5] used to solve the assignment problem.

5. Results and discussion

All runs were conducted within a Ms. 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 is due to the optimal solution of the assignment problem during phase 1. For the baseline scenario it encompasses 28008 decision variables (72 deliveries and 389 time slots) and 462 constraints.

Testing the 3-phase method on the baseline scenario

The 3-phase solution method was successfully applied for scheduling the daily deliveries at the mill. It was firstly applied to the baseline scenario encompassing a total of 120 daily deliveries; 72 were planned, including 15 from market suppliers and 57 from self-owned forest sites (Tables 1 and 2).

The daily reception schedule at the service gate, obtained after running phase 3 - Time Slot Allocation, displayed the entrance time for the first 20 trucks arriving at the service gate until 9 a.m. (Figure 3). At this time window, 11 of the trucks were unplanned (301 to 311), therefore included on the low priority segment. Only 2 of the deliveries were classified high priority. 21% of the time slots at the gate were not used which suggested that the service gate could accept more deliveries in this period, especially if the trucks would arrive before the opening hours.

The complementary view on the daily reception schedules at the unloading locations revealed that 60% of deliveries were unloaded at the docking stations at the production lines (locations 1 to 3, figure 3) without passing trough the warehouse. In this time window, only the unplanned arrivals were directed to the warehouse (locations 4 to 6, figure 3), particularly those trucks arriving before the lines opening hours.

Additionally, from the 27 time slots to be completed at the lines during the line supply stage, only 15 (55,6%) corresponded to internal freights from the warehouse. The sum of waiting time for all the trucks arriving in this time window was 356 min, leading to a total raw material reception cost of 237.21ϵ. The maximum waiting time for a truck in this time window was 43 min. It corresponded to the three unplanned trucks arriving before the gate opening hours (301-303). The average waiting time was 18.7min, corresponding to 9.58min at the gate, 13.6min at the warehouses and 7.57min at the lines. The waiting time recorded for priority trucks is significantly improved for high priority trucks, although the results may be biased by the reduced number of trucks included in this segment (total of 2 trucks with average overall waiting time of 14.0min, 4.5 min at the gate and 9.5min at the lines). Furthermore, the goal of completing the entire reception process in less than 45min is achieved in 45% of the trucks that recorded total waiting times inferior to 13min. The minimum duration for the entire process is 32min, corresponding to 7min for the service stage, 10min on transit inside the min, 15min to unload.

Integrated daily results were further obtained for the baseline scenario after phase 3. The total waiting time summed 4192.9min. 80 of the 120 deliveries were unloaded directly at the lines during the 6 time windows that comprise the daily shift, corresponding to a total reception cost of 2670.5ϵ. Only 52.4% of the time slots at the lines were supplied by freights from the warehouse. 78.4% of the time slots at the gates were used for receiving deliveries in the course of the service stage.

The maximum waiting time for any truck was 162 min, therefore close to the the threshold of 160 min aimed by the mill. The average waiting time to complete the reception process increase for 34.94min, mainly due to the high values recorded on the rush hours (average of 36.3min and 36.06min in time window [11hr, 13hr[and [19hr, 21hr[, respectively).

The 3-Phase method further accomplished the reduction of the waiting times for the planned deliveries arriving on-time. For these 33 trucks, their average waiting time was 10.22min,

independently from their priority class. For the delayed and unplanned, the average waiting time for high and medium segments was less than 20min, while for low and very low segments could go up to 63min. The minimum waiting time for medium priority trucks was 0min, thus inferior than for high priority trucks (8min). It was due to the small proportion of trucks classified as high priority (3.3% were high priority while 42.5% were medium), all of them arriving later than their planned arrival time. The waiting time for the deliveries classified as low (24.2%) or very low priority (30%, during phase 2) varied between 5min and 152.2min.

These results mainly reflected the increase of the average waiting time at the service stage (29.04min at the first and 26.13min at the second rush period), since the average waiting time at the delivery stage remained within the range of values obtained in the remaining time windows (variations between 7.37min in [17hr,19hr[and 9.94min in[19hr, 21hr[. Thus, suggesting that reducing the 7min duration of the service stage at the rush hours may lead to a significant reduction of the cost of the raw material reception process.

The consequence of the increased traffic at the rush hour at the end of the day was an high percentage of operations performed after hours. In fact, 9.2% of the trucks were received after the gate closing hours and 12.5% were unloaded after the lines closing hours. Only the warehouse was assumed to work overtime. The last reception took place at 22hr38min, and unloading occurred 17min afterwards. The impact of the overtime work of the receptionist and the warehouse employees, represented an extra cost of 39.8ϵ.
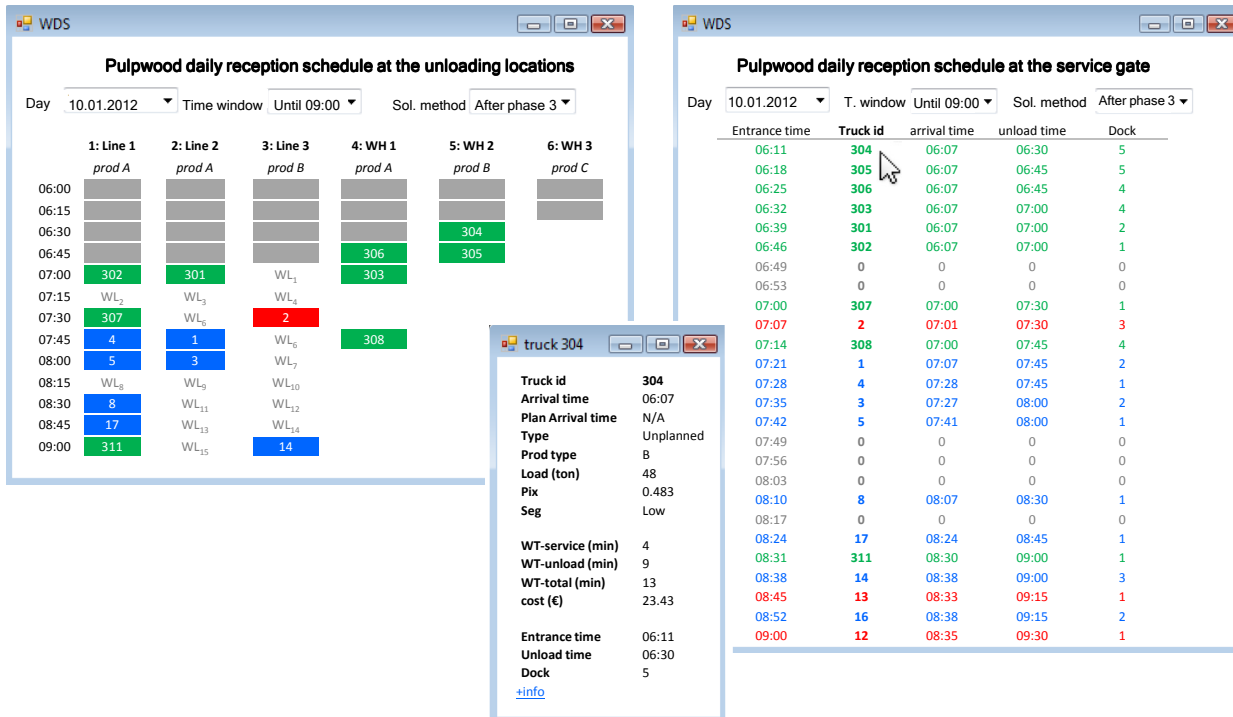

Figure 3: Pulpwood reception schedule for the first time window of the day at the service gate and at the unloading locations for the baseline scenario obtained at the end of 3-phase method

The daily reception schedules provided by phases 1 and 2 led to similar conclusions. Specifically for phase 2 - Time Slot Promising, 11,7% of the trucks were received after hours. The

maximum waiting time recorded for a single truck was 159.9min, therefore identical to phase 3 (162min). Yet, the sum of the waiting time for all the deliveries after phase 2 was 16% higher than in phase 3 (4192.9min for phase 2), resulting on an higher cost for the entire reception process (3034.9ϵ). It reflected the effect of having slots reserved for high and medium priority trucks as long as possible during phase 2. These slots were unaccessible for low priority trucks arriving at the gate, that were assigned to latter slots conducting to longer waiting times. Yet, the non attendance of the higher priority trucks triggered the upgrade process during phase 3. It anticipated service and unloading for these low priority trucks, leading to the reduction of the total waiting time. It is noteworthy that the multiple-reservation situations only allowed during phase 2 have the contrary effect and tend to reduce the total waiting time for the deliveries. Consequently, results for phase 2 better than those of phase 3 may be obtained, particularly when there is a reduced number of higher priority trucks planned to arrive.

As expected, the outcome of Phase 1 - Time Slot Allocation Planning was significantly better than the following phases. The total reception cost was a small fraction of the cost obtained during phase 3 (413.2ϵ for phase 1), as it only took into account the sub-set of the planned trucks.

The optimal solution of the assignment problem revealed the preferential assignment of the deliveries to the production lines. In fact, the lines recorded a total of 61 deliveries (18 for line 1, 19 for line 2 and 24 for line 3), while the warehouses summed 11 deliveries. Consequently, the percentage of slots left at the lines for unplanned trucks was 36.3% (107 time slots). Therefore higher than the minimum limit of 10% previously set by constraint D. These value further sets the maximum number of freights expected from the internal warehouse, assuming the attendance of all the planned deliveries and no additional unplanned trucks.

This solution led to a maximum waiting time of 29min for low priority deliveries and 28min, 14min for medium and high priorities. The total waiting time summed 678min. It corresponded exclusively to the delivery stage, since the arrival times were previously planned and spread across the time slots at the gate. Only one truck was expected to arrive after hours.

Comparing the 3-phase method with FIFO for the baseline scenario

The 3-phase method led to substantially better results than the FIFO procedure used today. Specifically, the cost of the entire daily reception process was reduced from 6023.4ϵ to 2670.5ϵ. The 55% cost reduction was a direct consequence of the 80 freights unloading directly at the lines. The higher number of possible unloading locations led to a drastic reduction of the sum of the waiting time for all the trucks at the delivery stage from 6084.9min to 1206.0min. Likewise, the maximum and the average waiting time for any truck to complete the reception process was reduced in about 28 min and 38 min, respectively. Direct unloading at the production lines further enabled 887.25ϵ of savings related with the abolished materials handling operations.

Yet, the FIFO procedure conducted to better results on the sum of the waiting time at the service stage (2694.9min against 2896.9min). This procedure did not rely on time slot discretization, 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 closing with the FIFO procedure is also slightly inferior than with the 3-Phase method (12, 10

respectively).

Additional positive results of the 3-phase method was the stabilization of the queue size at the delivery stage (figure 4). In fact, the number of trucks waiting at the queue for unloading varied between 0 and 2 during the entire delivery day. While the FIFO procedure was particularly sensitive to the increase of the traffic during the rush hours ([7hr, 9hr[, [11hr, 13hr[and [19hr, 21hr[). The average queue size was 6.2 trucks and the number rose to 11 after the lines closing hours.

As expected, both methods presented large fluctuations on the size of the service queue across the delivery day. The number of trucks waiting to access the service gate varied between 0 and 10, reaching the maximum during the rush hours of the beginning and closing of the shift at the unloading locations (figure 4). Yet, the percentage of trucks arriving during the rush hours may easily increase from the 40% to close to 80% leading to larger queues, especially if a single service gate is considered.

"What-if" analysis

The comparison among "what-if" scenarios proved to be adequate to address the impact of key parameter values used both on the case simulation and on the solution method over the solution results.

Both methods showed that the total number of daily deliveries and its distribution across the delivery day had the greater impact on the total raw material reception cost (Table 2). In fact, SCN_6 concentrated 65% of the 120 daily deliveries within the rush hours increased the value of the objective function to 4566.5ϵ.

When the percentage of trucks arriving at the rush hours remained the same but the number of trucks rose to 168 trucks SCN_1, a 22% increase of the objective function was reported with the 3-phase method (3425.8ϵ). The same method presented up to 400% increase when the maximum number of 240 daily deliveries was considered (SCN_5). In the latter scenarios, the FIFO procedure recorded even higher uprise of the reception costs. The total reception costs of SCN_1 were almost two orders of magnitude higher than the 3-Phase method. It was of the same magnitude than the total cost obtained for SCN_5, although in this case 89 trucks were excluded from the cost computation as they could not be received before mid-night.

These results suggested that the adequate reception capacity at the baseline conditions was 100-140 daily deliveries. Above this threshold, some of the trucks were received after the gate normal opening period, therefore with additional costs for the employees working extra-hours. Furthermore, when the number of deliveries rose above 150, the reception of the last arriving trucks was delayed to the next working day.

The remaining parameter values tested related with the length of the time slots at the unloading locations led to variations of less than 10% of the receptions costs obtained for the baseline scenario.

This comparative analysis further showed that the possibility of direct unloading at the production lines considered only for the 3-Phase method was instrumental for improving the total
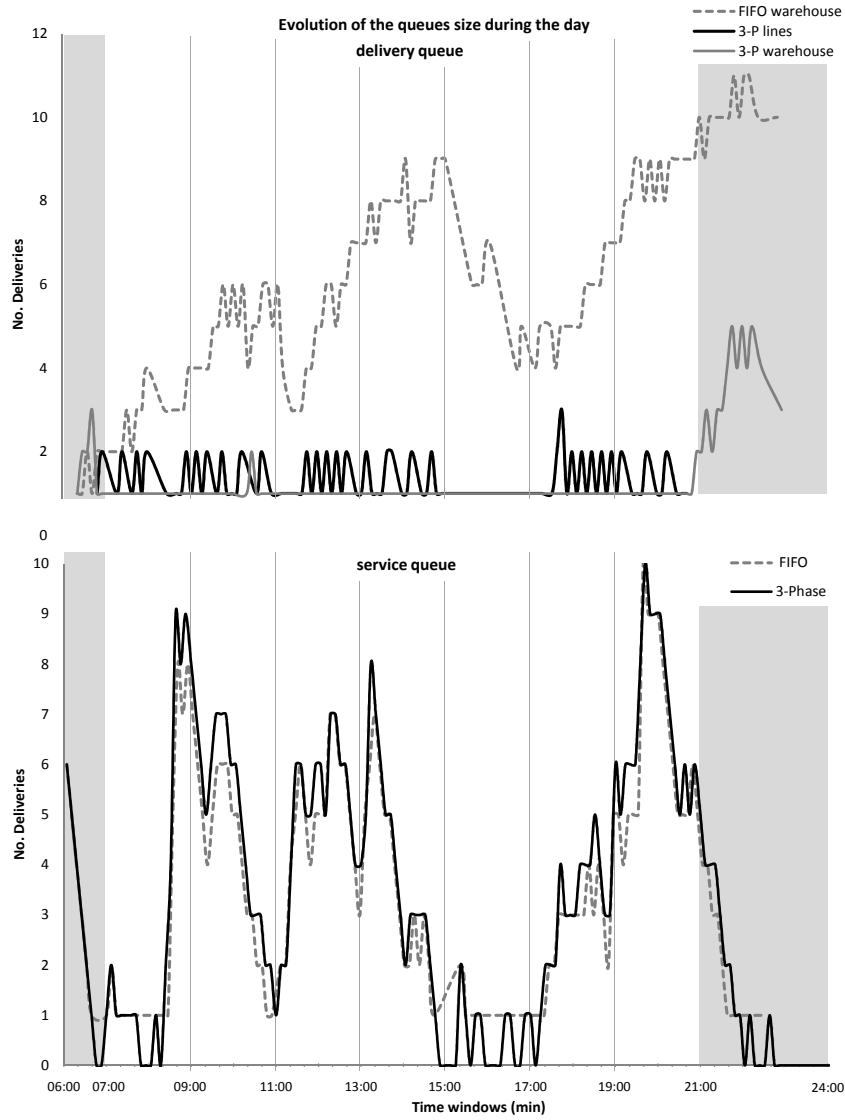
Figure 4: Evolution of the queue size at the service gate and unloading locations for the baseline scenario solved with the 3-Phase method and FIFO

Table 2: Results for all the scenarios obtained with the 3-Phase solution method and FIFO

		Baseline	SCN_1	SCN_2	SCN_3	SCN_4	SCN_5	SCN_6	SCN_7
total 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
slots at gate		153	216	153	153	153	153	153	153
slots at prod.lines		168	168	168	252	224	168	168	0
slots at warehouse		221	221	327	221	221	221	221	221
2l**Recep. cost (ϵ)**	3-P	2670.5	3425.8	2406.1	2542.4	2615.2	13139.6	4566.5	6805.4
	FIFO	6023.4	22279.2	2913.4	6023.4	6023.4	19849.4	6852.3	6023.4
2l**WT service (min)**	3-P	2986.9	3474.3	2986.9	2986.9	2986.9	22825.4	6454.0	2976.3
	FIFO	2694.9	2896.5	2694.9	2694.9	2694.9	18180.4	5728.0	2694.9
2l**WT unload (min)**	3-P	1206.0	1500.0	521.0	851.0	1206.0	2191.0	1607.0	7414.0
	FIFO	6084.9	33592.0	319.9	6084.9	6084.9	11697.0	4326.0	6084.9
2l**Loads to lines**	3-P	80	119	48	87	85	72	76	0
	FIFO	0	0	0	0	0	0	0	0
2l**Loads from yard**	3-P	88	49	120	165	139	96	92	168
	FIFO	168	168	168	252	224	168	168	168
2l**Ar.after hours**	3-P	12	14	11	11	12	140	19	17
	FIFO	10	14	10	10	10	140	18	10
2l**Max WT (min)**	3-P	162.0	209.0	199.4	161.0	162.0	636.0	317.0	1153.0
	FIFO	190.1	679.0	63.0	190.1	190.1	731.0	224.0	190.1
2l**AVG WT (min)**	3-P	34.9	31.9	29.2	24.9	34.9	169.1	67.7	96.2
	FIFO	73.2	217.2	25.1	73.2	73.2	279.2	83.8	73.2

pulpwood reception costs. In fact, scenario SCN_7 excluded the lines from the delivery stage resulting on a 154.8% increase on the value of the objective function, therefore surpassing the value reported with the FIFO procedure.

The thorough analysis on the resultant daily delivery schedules provided the reasoning for the variations on the value of the objective function reported for the scenarios.

Specifically, scenario SCN_5 reported the worst objective function values with both solution methods as a result of the highest number of total daily deliveries. The reception cost provided by the 3-phase method considering the 151 trucks deliveries during the day was 13139.6ϵ, while the sum for the all 240 deliveries rose above 15000ϵ. It was the order of magnitude than the total reception cost given by FIFO.

Scenario SCN_6 showed that a 25% increase on the number of truck arriving within the rush hours ([07hr, 09hr[, [11hr, 13hr[and [19hr, 21hr[) increased the total reception costs to 4566.5ϵ. In both scenarios, the trucks spent 91% and 80% of the waiting time at the service queue (total of 22825min for SCN_5 and 6454min for SCN_6). Thus suggesting that an extra service gate could led to better solution results when a large number of deliveries is expected. The truck

maximum and average waiting time rose to 636.0min and 169.1 min on SCN_5 and about half of this value on SCN_6 (317.0min and 67.7min, respectively).

The results of SCN_6 further evidenced that the increment of the reception costs with the 3-Phase method were significantly higher than with the FIFO procedure (41.5% and 12.10% respectively). Both methods reported a significant increase on the costs related with the summed waiting time to complete the reception processes. Yet, the proposed method further reported the increased of the material handling costs due to fewer loads unloaded at the production lines, as well as the increase of the overtime costs due to a larger number of trucks received after hours.

Scenario SCN_1 showed that reducing 2min (28.5%) the length of the time slots at the service gate due to shortening the duration of the service stage operations, enabled a 29% increase of the gate capacity. The number of arriving trucks per time window could be increased from 17 to 24, summing 168 deliveries per day. 119 of the freights could be directly unloaded at the lines, leading to a reduction of about 300ϵ on the material handling cost. Yet, the higher traffic led to congestion and longer waiting times particularly at the unloading locations. The total waiting time to complete the delivery stage rose 19.6%. While the average and maximum waiting time for a truck to complete the reception process could go up to 73.2 and 209min, respectively. The impact of increasing the total waiting time overturn the reduction on the materials handling cost, leading to the final 22% increase of the costs related with the reception process.

Similarly, the high reception costs obtained with the FIFO procedure for this scenario were also a consequence of prolonged waiting time to complete the delivery stage. The average waiting time was 73.2min. Although, in the worst case the wait could go up to 679 min for trucks arriving at rush hours close to the end of the day. Then, the maximum of 9 trucks waiting on the service queue were recorded.

Scenario SCN_2 proved that reducing 5 min the length of the time slots at the warehouse had little impact on the objective function (0.22%). In fact, the positive improvement related with the reduction of the waiting time at the delivery stage (from 1206min to 521min) was balanced by the increase of the pulpwood handling cost due to the reduction of the number of freights directly unloaded at the lines (from 80 to 48). This scenario led to the best value of the objective function obtained with the FIFO procedure (2913.4ϵ), still 8.9% higher than with the 3-Phase method. As expected, the increased unloading capacity at the warehouse reduced the total waiting time to 521min. While the truck maximum and average waiting time recorded also the lowest values of 63.0 and 25.1, respectively.

Both scenarios SCN_3 and SCN_4 reported maximum increases of 9.9% and 2.1% on the value of the objective function due to improvements at the unloading infrastructure available on the production lines (reducing 5min the unloading time at the lines and adding one new production line processing product type B). In the first scenario, the shorter unloading time at the gate was responsible for the 23.7% reduction of the waiting time to complete the delivery stage. The average waiting time for a truck reduced to 24.9min. It further enabled 7 more direct freights to the lines corresponding to at least 68.6ϵ savings on the materials handling cost. Yet, the number of time slots at the lines rose to 252, therefore 77 new freights from the warehouse were needed to assure complete supply to all the time slots at the production lines. This study did not acknowledged the scheduling of the trucks engaged on this internal wood movements, therefore this cost was not considered.

In the second scenario, the 5 new freights directed to the new line processing the assortment type B lead to a 55.3ϵ reduction on the materials handling cost and consequently on the value of the objective function (2615.2ϵ). It did not impacted on the trucks waiting time as there were no delivery queue for this product assortment. This result was a direct consequence of the number and distribution of the product assortments among the arriving trucks. Product type B was delivered by 32 trucks, spread across the delivery day. In the baseline scenario, 6 were unloaded at the warehouse because the trucks arrived before or after the line opening hours and 21 went directly to line 3. This line had a 37.5% occupation on the baseline scenario. The remaining 5 freights that needed to be directed to the warehouse due to lack of available slots at line 3 were those that went to the new processing line considered on SCN_5. If the arrival of these freights was planned to fit on the vacant slots at line 3 then no additional line was needed for this assortment. On the contrary, additional processing lines for the predominant product assortment A (corresponded to 62.5% of the freights) or for the product C not yet accepted in any of the production lines may led to greater improvements on the objective function value.

As expected, the FIFO procedure was not sensitive to the variations introduced by the former two scenarios, since it does not acknowledge direct unloading at the production lines.

The results of the scenario SCN_7 with the 3-Phase method proved that excluding the lines from the delivery stage could rise the total reception cost up to 6805.4ϵ. It was a consequence of the 83% increase of the summed waiting time to complete the delivery stage as well as the 1317.4ϵ related with the material handling cost of all the daily deliveries directed to the warehouse. This was the only scenario were the FIFO procedure performed better than the 3-Phase solution method. The FIFO procedure led to lowest waiting time both at the service stage and at the delivery stage (2694.9 min against 2986.9min and 6084.9min against 7114.0min). This was due to the fact that in this procedure the operations could start as soon as the gate/warehouse become available, while on the 3-Phase method the truck may need to wait some additional minutes in order to start the operation only at the beginning of the fixed time slot at the gate/warehouse.

Consequently, the truck maximum and average waiting time for SCN_7 with FIFO were lower than with the proposed method (190.1min against 1153.0 min and 73.2min against 96.2). Yet, the 3-Phase solution method has the advantage of assuring lowest waiting time for high and medium priority trucks as well as minimum waiting time for on-time trucks. This advantage was not acknowledged on the current cost function. Yet, more sophisticated cost functions with distinct unit costs for waiting time according to the truck segment, may dissolve the performance differences between the methods reported for SCN_7 or even lead to total reception costs with the 3-phase method lower than the FIFO procedure.

The comparison of the truck average, minimum and maximum waiting time among the scenarios confirmed that the performance of the 3-Phase method is better than FIFO when considering the sub-set of the high and medium priority trucks in all of the cases. On the remaining sets, the results with the proposed method were better for all low priority trucks in the scenarios with the exception of SCN_5 and SCN_7 as well as for the very low priority trucks in 5 of scenarios (Figure 5).

This analysis further reveled slight variations for the three indicators in the case of the high and the medium priority trucks (e.g. the truck average waiting time varied between 19-32 min and 11-25min respectively) (Figure 5).

Contrarily, larger fluctuations were reported for these indicators in the case of the low and very low priority trucks. The maximum waiting time for the later could rise above 420min in some scenarios. Yet, on-time arrivals were awarded with reduced waiting periods, despite the truck segment. The correspondent minimum waiting time varied between 0-8min in all cases, with the exception of the very low priority trucks on SCN_5. The increased traffic of trucks from higher segments caused profound delays on the reception of the very low trucks, that wait in this case an average of 361min.
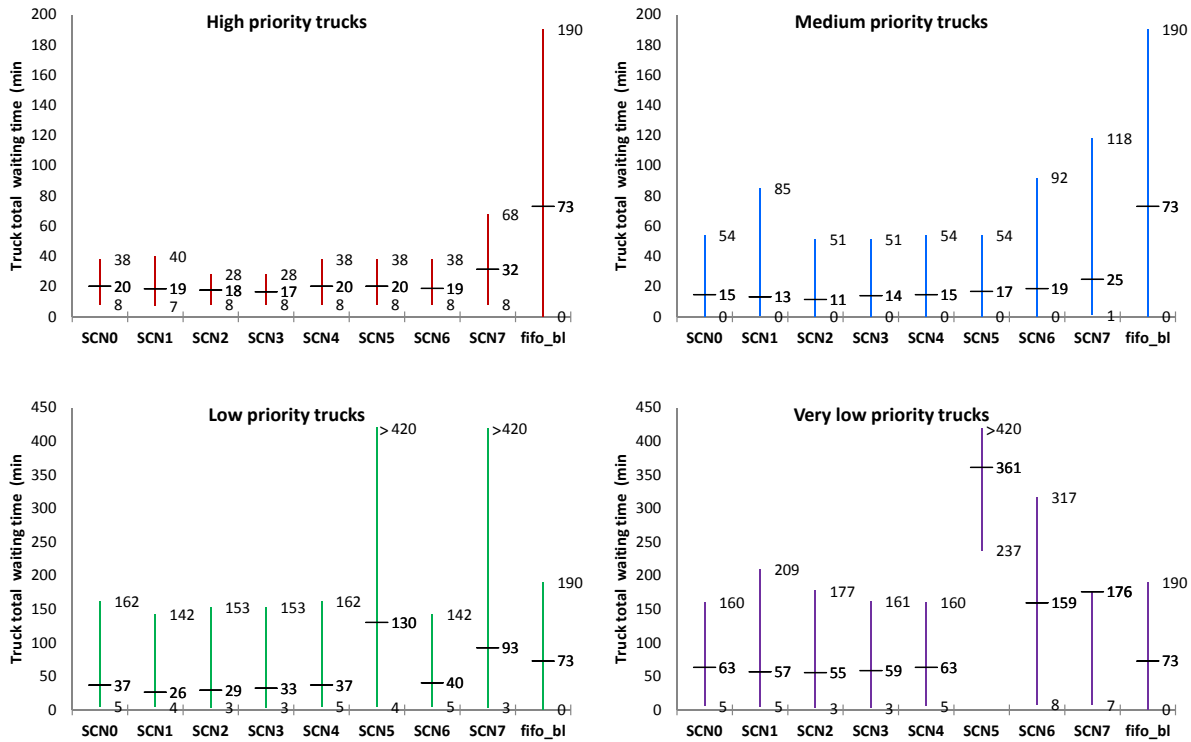
Figure 5: Comparison among the what-if scenarios of the maximum, minimum and average waiting time for a truck to complete the wood reception process, using the 3-Phase method

Real-life implications of the 3-Phase method

The proposed approach for the RMRP based on RM principles proved to enhance significant earnings both for the hauliers and the mill. It has a result of reducing both the cost of having the trucks stationary at the mill waiting to complete the delivery process and the cost of raw materials handling at the warehouse. The thorough analysis of the resultant daily delivery schedules may further provide valuable information for daily reception planning conducted by both players.

Specifically, the haulier may plan in advance the routes to comply with the time slots reserved for their trucks after running phase 1 - Time Slot Planning. It may foresee the increase of the number of trips per day with the possibility of fulfilling other clients besides the mill, avoid drivers working extra-hours or even reducing the fleet size or time needed to conduct the transportation services. These aspects contribute to the higher efficiency on the utilization of its transportation resources and may further provide to the haulier a competitive advantage over the competitors.

The mill may benefit from a more efficient use of the manpower and equipment resources allocated to the service, delivery and line supply stages. On the medium term, it may even experience improvements of the mill layout as a consequence of less space needed for parking the trucks at the mill. The mills stock levels and the warehouse layout may also be revised due to the possibility of direct unloading at the production lines.

Yet, the extent of these benefits that can actually be accomplished on real-life situations relays on the successful implementation of a new fare and transparent reception process adopted by both players. The hauliers should be periodically informed of its priority index and should take part on the time slots reservation negotiation before the delivery day. The advantages of minimum waiting time for on-time arrivals and the consequences of the delays should be clearly stated. Efforts should be done the progressively increase the number of planned trucks engaged on phase 1 - Time Slot Reservation.

During the delivery day, there may be a open communication channel between the driver and the gate to report delays that may eventually led to new time slot reservations. There is a clear advantage on knowing in advance the real arrival time for the planned and unplanned trucks. Therefore, sophisticated truck positioning systems may be foreseen for setting automatically the arrival time and placing the truck at the service queue.

The management of the trucks parked on the service queue may be enhanced by electronic boards for displaying the next truck entering for service as well as the position of the trucks in the queue and the estimative of its entrance time, built on the results of second phase 2 - Time Slot Promising.

When the truck completes the delivery process and exits trough the service gate, an automatic delivery report may be generated, based on the real delivery time and total waiting time provided by phase 3 - Time Slot Allocation.

6. Conclusion remarks

Managing the reception of raw materials at the mill service gate, combined with the accompaniment of the trucks following movements until unloading and exiting the mill are aspects of the inbound logistics processes impacting on the procurement cost. It may avoid trucks congestion and queuing at the service gate as well as greater accession with the pre-established transportation plans, leading to a reduction of the costs and the duration of the transportation services. It may further foster the direct unload of the raw materials at the docks located at the beginning of the processing lines, therefore avoiding the stock movements to and from the

intermediate warehouses. It decreases the overall material handling cost and improves the value chain efficiency.

This paper provided a comprehensive description for the Raw Materials Reception Problem, using as case test the pulpwood reception at a pulp mill. It further presented a novel 3-Phase method anchored on the Revenue Management principles to address this problem. The method relied on carriers/trucks segmentation and booking list computation for progressively assigning the arriving deliveries to the time slots available at the service gate and at the unloading locations.

The 3-Phase method was successfully applied to the pulpwood reception process. Yet, this solution approach may be applied to several activities related with agriculture and management of natural resources, whenever the minimization of the waiting time before unloading the trucks at the transformation centers is of interest.

The results showed a 55% reduction on the total reception costs for this case study, 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 times for the planned deliveries arriving on-time as well as inferior waiting time for the trucks on higher segments.

The information provided by the resultant daily delivery schedules proved to be instrumental for planning the reception process. Furthermore, the method was successfully applied to generate "what-if" scenarios that can effectively evaluate the impact of key parameter values used both on the case simulation and on the solution method over the solution results. Thus, providing valuable information to support decision-making.

Future developments will address the paradigm of time slot discretization. In fact, the use of time slots with the length of the service and unloading operations lead to an increase of the waiting time. Future work will test the use of smaller time slots, specially at the production lines. The delivery could use more than one consecutive slot, depending on the efficiency of the unloading equipment and the truck capacity. Alternatively, the use of larger time slots will also be considered. For example, supplanting the rule of "1 truck/15 min" by the rule "3trucks/45min". This approach may lead to higher flexibility on assigning late-arrivals to new slots. It may further enhance the use of over-booking strategies under the phase 1 - Time Slot Reservation.

The 3-Phase method may further be improved with innovative cost functions, taking into account distinct unit costs per segment. Additionally, new carriers/trucks segmentation strategies may be tested, such as ABC analysis (e.g. [9]). Finally, the trucks assignment to the time slots at the unloading locations during the consecutive phases of the method, may rely on additional criteria related with the evaluation of the freight on the service stage. As an example, the pulpwood with considerable humidity should be obliged to unload at the warehouse. Additionally, balancing the number/weight of the freights unloaded on the production lines processing the same assortment may lead to more efficient use of the unloading equipment.

The work will further pursue with new real-life applications, preferably with other raw materials besides pulpwood. The focus will be the performance of the proposed solution approach as well

as testing new strategies for implementing the new raw material reception process anchored on the RM principles. The deployment the proposed method to final users within newly developed information systems or integrated with existing Advanced Planning and Scheduling Systems (e.g. [3]) will also the attempted.

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ORIGINAL PAPER

An enterprise architecture approach to forest management support systems design: an application to pulpwood supply management in Portugal

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Abstract A key requirement for the success of a forest management information system is that it may effectively address its users' needs. Yet, the development of models and methods to address-specific forest ecosystem management processes has not been matched by architectures that may take into account the human dimension of information systems. This paper presents an approach to pulpwood supply system architecture. Emphasis is on participatory business modeling that may effectively address users' needs and enhance system resilience. An Enterprise Architecture methodology is proposed so that the information systems' functional requirements for pulpwood supply may emerge from business and information architectures in workshops with the stakeholders. Results of its application to a vertically integrated Portuguese pulp and paper company are presented. The case study focuses on processes and business information required to support the pulp mills entire pulpwood supply management. Results show that the proposed approach addressed effectively end-users' involvement in pulpwood supply system design. It provided an architecture that addresses all stakeholders' perspectives and concerns and it

was thus instrumental to develop a Pulp and Paper Supply Chain Process Framework. Results further show that it may effectively identify and integrate information systems' components, ensuring business information integrity.

Keywords Forest management · Supply chain management · Decision support systems · Enterprise systems architecture

Introduction

Forest management has been addressed by a wide variety of computer-based systems. Stimulated by developments in business administration and industry, these systems have been improving the quality and transparency of decision-making in natural resource management (Reynolds et al. 2007). They have evolved to meet increasingly complex problems faced by forest owners and forest managers. The earlier computer-based systems addressed the optimization of a single objective (e.g., net present value) under a context of regulation. They often focused on stand-level decisions and on the improvement of strategic processes. The increasing awareness of the importance of biodiversity, esthetic values, recreation uses, and externalities derived from productive forests prompted the development of a wide array of new-generation decision support systems (DSS) (e.g., Borges et al. 2003; Reynolds et al. 2007; Hetemaki et al. 2005). Typically, they are multicomponent systems, with various combinations of models and optimization techniques, supported by Database Management Systems (DBMS) and accessed by spatial and graphical user interfaces. More recently, the importance of integrating segments of the wood supply chain has further prompted the research of models and decision support

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systems capable of addressing simultaneously production, distribution, and sales concerns (e.g., Weintraub and Romero 2006; Carlsson et al. 2006; Forsberg et al. 2005). Emphasis was on systems with integration, cooperation, and interoperability mechanisms required to support the interactions among all parties involved in wood supply chain (e.g., Palender et al. 2005; D'Amours et al. 2008).

Yet, Information and Communication Technology design for forest management and wood supply has often overlooked and underestimated the human dimension of information systems. In a review, some of the more important and most recent developments of DSS in forest management, including examples from North America, Europe, and Asia, Reynolds et al. (2007) emphasized the need for a clear focus on the target users. Addressing the human dimension of information systems may be the key to successful information systems development. The adoption of adequate system design methodologies may be instrumental for that purpose. These should emphasize transparency, maintenance, and scalability and be based upon stakeholders' involvement and proper testing. Enterprise Architecture (EA) may provide a suitable framework for system design. It relies on business processes' modeling and on information characterization (Schekkerman 2009). It identifies system requirements to support business processes, ensuring the alignment between the business requirements and the Information Technology (IT) function (Sousa and Pereira 2005). The EA framework was developed within the IT domain to promote an integrated and global view of the entire IT function, namely of its relationship with business processes. Nevertheless, EA captures and represents knowledge about the organization decision-making dynamics. Accordingly, this approach has been applied to support Information Systems design in several organizations worldwide, e.g., governmental organizations (e.g., Martin et al. 2004; Hjort-Madsen 2006), retail industry (Stecher 1993; Vasconcelos et al. 2003) and furniture manufacturing (Xu et al. 2007). (Shunk et al. 2003) further uses an EA approach to analyze the process interactions and to establish the supply chain process integration in the defense electronics industry. (Ribeiro et al. 2005) demonstrated its potential for specifying the Integrated Forest Management System strategic module for a major pulp and paper industry in Portugal (Grupo Portucel Soporcel).

In this article, we propose and test an extension of the four-stage EA methodology presented by Spewak and Hill (1992) to actively incorporate forest practitioners and decision makers in forest management systems design. The first stage—Process Architecture—focuses on current and future business processes. Business modeling encompasses the characterization of both the information needed and the information produced by business activities. It further identifies the players responsible for each process as a whole as well as for conducting each activity within the process. The second stage—Information Architecture—aggregates the information flows into high-level information entities that may underlie the future database structure. The third stage—Application Architecture—identifies the future system modules and its functional requirements. The last stage—Technological Architecture—characterizes the technological requirements and produces the system development guidelines. The proposed approach extends the research presented by Ribeiro et al. 2005 by including interactive workshops and other complementary participatory techniques (e.g., Kangas et al. 2008) to explicit and document stakeholders' knowledge, concerns, and requirements, thus improving their involvement in the future system design. In fact, forest practitioners and decision makers' representatives are active members of the EA team, thus collaborating in all EA stages execution and validating all the outputs. The proposed approach was tested on the development of a wood supply management system for a Portuguese pulp and paper company. As the business processes are likely to be similar across pulp and paper companies, the Enterprise Architecture, first stage, was further instrumental to demonstrating how stronger user involvement in system's design may help define a Pulp and Paper Supply Chain Processes Framework.

Materials and methods

The case study

Eucalypt (*Eucalyptus globulus* Labill) is the most important pulpwood producing species in Portugal. Eucalyptus plantations extend over 647×103 ha—about 20.6% of the total forest area in Portugal with a total yield of about 5.75 million m^3 per year (NFI 2005). Eucalyptus pulpwood is the key raw material of the pulp and paper industry. This industry includes 5 pulp production companies operating on 7 industrial units spread across northern and central Portugal. The industry transforms about 6,4 million m^3 of round wood (83% is eucalyptus) and manages over 180×10^3 ha. The pulp industry is thus both the largest forest owner and the biggest forest products consumer in Portugal. Currently, the majority of its forest areas have the Forest Stewardship Council certificate for sustainable management. Furthermore, they provide about 4,000 direct jobs and contribute to 0.8% of Portuguese Gross National Product. They take the sixth and the fifteenth positions in the European and world pulp production rankings, respectively (Celpa 2007).

The case study addressed the needs of Celbi's (currently Altri's) industrial unit in Figueira da Foz. This unit

produces about 600×10^3 tons of eucalyptus bleached sulfate pulp, and it consumes pulpwood either harvested from Altri SGPS SA eucalypt plantations (circa 65×10^3 ha) or bought in the Portuguese market (Celbi 2007). The proposed approach thus focused on processes and business information required to support forest management and wood supply under an integrated wood supply management approach. Specifically, the project aimed at specifying a computerized system to support pulpwood supply business processes (e.g., strategic and operational forest management planning, forest operations follow-up and accounting, forestland classification, and forest inventory) and pulpwood supply (e.g., market acquisitions). Logistic activities associated with transportation planning and follow-up, wood yard management, and wood reception at the industrial unit entrance were also addressed. Information flows and interdependencies with remaining supply chain activities (pulp and paper production, distribution and sales) were also considered.

Methods

Both Celbi's business experts and IT managers were actively involved during the entire Enterprise Architecture project. Their role and responsibilities were clarified and accepted in kickoff meetings with the commitment of the Administration. Specifically, they participated in workshops to characterize business processes and they validated the outputs of all four stages of the EA approach, according to the guidelines defined in the Zachman Framework (Mykityshyn and Rouse 2007). The first stage—Process Architecture—focused on the business processes representation. It considered a three-level hierarchical top-down structure for representation purposes. It further considered integrity rules (e.g., all information flows in upper levels have correspondence with processes' data flows) in order to avoid inconsistency. These representations were built over the meeting room walls in ten 4-h interactive workshops, involving an average of ten stakeholders, e.g., forest and plant supply planners, operations planners, IT managers, and forest certification experts. Participants were asked to identify the entities, activities, and data flows using different color Post-It notes and to display it in the correspondent schemas. The results of the Post-It technique are easily perceived by all participants. The technique further facilitates the discussion and rearrangement of the business representations (Kangas et al. 2008). The top representation level consisted of a context diagram. This organization-centric diagram presented Celbi's department's relationships with outside entities. The circular objects in the diagram represented internal and external entities/roles. These are displayed closer or farther from the center according to its business

relevance. The connectors in the diagram corresponded to the information flows among entities. The intermediate representation level, i.e., the business model, identified the company's business processes that handle information flows with external entities, grouped according to its physical location. It further identified relevant internal processes e.g., periodic planning processes. This representation level provided an integrated vision of all ongoing processes to enhance the support of decision makers and the company's administration. The bottom-level representation consisted of a flowchart detailing the activities and information flows within each business process. Both activities and information flows are sequenced according to its temporal execution and followed the Business Processes Management Notation (BPMN). All activities and information flows are further defined in the correspondent dictionaries (Table 1).

The intermediate representation level, i.e., the business model might, have been driven in this case study from existing higher level process framework standards such as the Supply Chain Operations Reference-model (SCOR 2006) and the Process Classification Framework (APQC 2006). These generic standards developed by "Open Groups" propose a common and unambiguous baseline to promote communication and interoperability between cross-industry organizations, enhancing collaborative, and horizontally integrated approaches. Yet, their generic scope does not address the forest production and wood management specificities of a vertically integrated pulp and paper company. The newly developed Pulp–Paper Supply Chain Processes Framework, built from this case study business model, took advantage of both former standards and the specificity of the this industry. Moreover, our purpose was to test an approach where user involvement should play a key role in the business process representation.

The second stage—Information Architecture—was instrumental to identify the core information entities. For that purpose, the industry's experts met in brainstorm meetings to analyze business processes' input/output information flows. In the course of these meetings, more than 100 entities were identified that might be useful for further database structuring. They were grouped into higher level information entities to meet the information architecture target of a maximum of 25 Information Entities per project in order to facilitate the forthcoming Applications Architecture stage. Each information entity should have a business responsible for its management and for performing operations such as acquisition, classification, quality control, presentation, distribution, and assessment. It was characterized by one identifier, defined from a business perspective, one description, and one set of attributes (Table 1).

Table 1 Characterization of the Enterprise Architecture artifacts

| EA artifact	Properties
Role	Identifier, name, and description
	Organization
	Physical location
Process	Identifier, name, and description
	Category (business or support)
	Objectives
	Physical location
	Frequency (daily, monthly, triggered by client, other)
	[Activities]
	[Responsible role and participant roles]
	[Input and output information]
	[Relationship with other processes]
Activity (and activity dictionary)	Identifier, name, and description
	[Associated processes]
Information flow (and information dictionary)	Identifier, name, and description
	Support type (paper, electronic flow, oral communication…)
	[Associated processes]
Information entity	Identifier, name, and description
	Objective
	[Associated information flows]
	Key-identifier
	[Associated attributes]
	[Relationship with other information entities]
	[Relationship with the processes, based on CRUD matrix]
Attribute	Abbreviator, name
	Units
	Source
	Optional (yes/no)
	Data type: check box, value list, text (char number), date, integer, decimal, logic (V, F)
	Table name and field name on the data model
Information system	Identifier, name, and description
	Objective
	[Supported processes, based on CRUD matrix]
	[Supported information entities, based on CRUD matrix]
	[Supported activities]
	Interfaces (GUI, with external systems and with other internal modules)
	Migration and integration requirements
	Technological requirements
Application module	Identifier, name, and description
	Interfaces
	Functional requirements

The third stage—Applications Architecture—started with a tabular display of business processes and information entities. The former were represented as rows and the latter as columns in the table. Then, the processes flow-charts (bottom-level representations from the Process Architecture stage) were revisited in order to identify the relationships (Create, Read, Update, Delete) between each process and each information entity thus building a CRUD matrix. Afterward, the rows and columns of the CRUD matrix were reorganized and grouped. Proper system consistency and business-IT alignment rules were applied to identify the future system functional modular components (Sousa et al. 2005) (Table 1). Accordingly, each process should only be supported in one module and each information entity should only be CRUD in one module. The modules were further described according to its data repositories, graphical user interfaces, and interfaces with other existing or foreseen systems. The impact analysis of the proposed modules on the existing systems was based on its prior characterization in IT surveys conducted with the IT managers.

Finally, the Technological Architecture stage specified the technological requirements and development guidelines of an information system that might efficiently and effectively support pulpwood supply management. It was based Celbi's on Information Technology strategy and Information Systems development best-practices. An implementation plan was further produced. The sequential development of application modules was planned according to the industry's Information Systems deployment strategy (Fig. 1).

Stakeholders' were responsible for the validation of Celbi's Enterprise Architecture reports (Madrinha et al. 2003) at the end of each stage, which may trigger new workshops and documents update. The final meeting was instrumental for suggesting initiatives to overcome potential obstacles to the architecture implementation plan and for foreseeing the management of the Enterprise Architecture initiative. The Microsoft Vision tool, a very common tool for Enterprise Architecture modeling (Schekkerman 2007), was adopted to support all the representations and enable its deployment in the Celbi's internal Web sites.

Results

The entity responsible for the pulpwood supply management was the industry's Forest Management Department (FMD) structured into one major central office and six regional offices. The Process Architecture stage provided a three-level process structure for the pulpwood supply management activities performed by FMD. The top-level
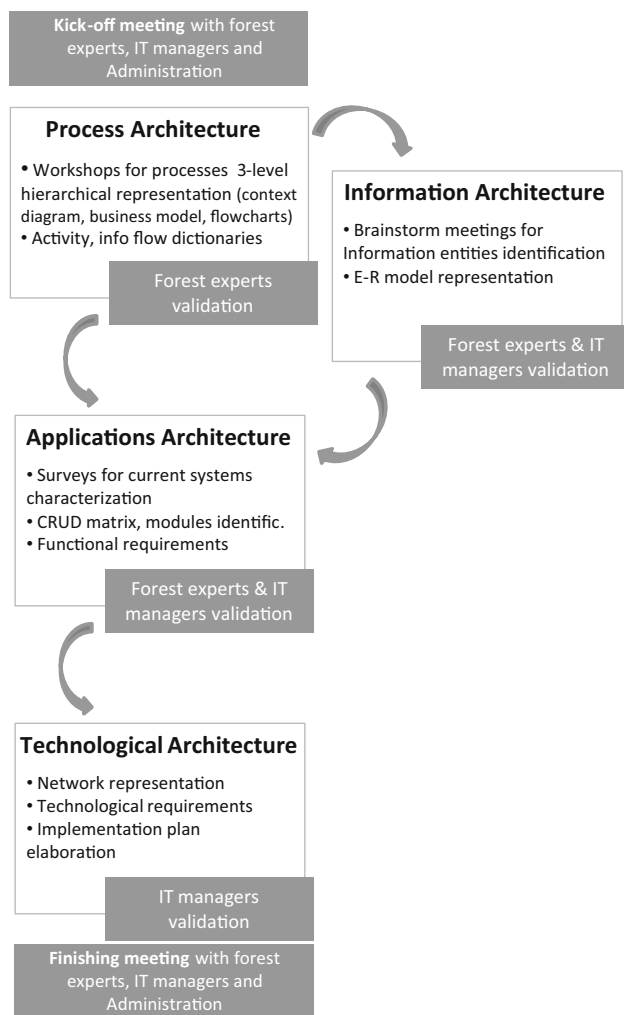
Fig. 1 Four-stage Enterprise Architecture methodology

FMD-centric context diagram identified four other Celbi's departments involved as well as thirteen external entities, and all the information flows among them (Fig. 2). For example, internal electronic communication channeled to FMD information regarding the company's forest strategy, and the suppliers' payments coming out of the companies' administration, and the financial department, respectively. The pulpwood supply volumes from Celbi's properties were accorded with the plant supply department based on the forest strategy. It further supported a bidirectional information flow between the FMD and the plant reception department. The former sent transportation documents to be checked by the latter. Forest owners that rent their properties to Celbi' and forest operations' providers (including transportation) were also classified into the internal sphere (Fig. 2), as its interaction with the FMD is very frequent. The external sphere involves several private and public entities that communicated mostly by regular (paper) mail. Local communities were informed by the FMD when forest operations were going to take place in their territory or nearby. The Portuguese Forest Service and Municipalities are responsible for authorizing plantations by the industry. Afocelca and the Portuguese Protection Service must have access to the firm's forest patrimony characterization to provide adequate fire protection.

The intermediate representation level—the Celbi's Forest Production and Wood Logistics Future Business Model—identified the processes that handled the information flows with the external entities listed in the context diagram as well as relevant internal processes (Fig. 3). A preliminary version of the Pulp–Paper Supply Chain Processes Framework (Fig. 4) was also obtained based on the case study business model, incorporating the expertise of the EA architects gained in similar companies and the concepts of other well-known process frameworks (e.g., SCOR 2006; APQC 2006). It classifies business processes according to its supply scope and temporal scale. Thus, processes were classified according to forest production, wood logistics, pulp and paper (P&P) production, P&P logistics, and P&P sales, scopes and strategic, tactical, operational planning or operational, and subsequent financial follow-up decision focus. It further addresses the transversal support processes, such as Human Resources Management, Environmental impact management, Working Hygiene and Security Management, Financial Management, and IT management. Specifically for Celbi's case study, Forest Production processes included Forestland management (P1), Forest management planning (P2), Transportation and forest operations suppliers' qualification (P3), and Equipment management (P4). The Forestland management process, conducted on the FMD central office, characterized the forest properties under Celbi's administration (self-owned or self-rented). Namely, it classified the properties into geographically contiguous homogeneous management units and it described events and forest operations that took place on them. It further addressed the operations costs' historical records (P1.1) and forest inventory data (P1.2). The Forest management planning process (P2) was classified into 6 sub-processes. Forest strategic management planning (P2.1) selected the harvesting units required to fulfill self-supply pulpwood target levels defined by the Global Wood Supply Management process (P6). Tactical forest planning (P2.2) took the strategic solution for the first 2 years as the decision space and further included spatial constraints to define harvest monthly schedules. Each Forest Region operational plan (P2.3) presented its monthly schedule of harvest and regeneration operations and the corresponding budgeting. It further included the description, prioritization, and budgeting of required maintenance operations. These were assigned according to auditing site surveys conducted by forest experts in each Forest Region (P2.4). The operational budget was negotiated among FMD regional and

Fig. 2 Context diagram for the Forest Management Department (*top-level* representation obtained at the process architecture stage), identifying the internal and external players involved in pulpwood supply as well as the information flows among them

central offices. The latter was also responsible for grouping accepted forest operations schedules into work-orders, according to the type of forest operation, its monthly schedule, and its location (P2.5). Afterward, qualified forest operations' providers were invited to present a proposal for each work-order. The proposals were evaluated and adjudicated by the FMD. The fulfillment of each work-order was controlled in each region by the Forest Operations Follow-up sub-process (P2.6). It included prior work starting date definition, on-site workers training, on-site auditing, forest operations' provider evaluation, wood production costs estimation, and self-supply wood appraisal. It further provided the transportation data documents needed to control pulpwood flows from the forest to the industrial unit entrance (P9.1). The work-order was closed with the full payment of the forest operations' provider. The forest regions' experts were responsible for establishing rental and acquisition agreements for new forest-lands to either harvest or regenerate (P3), as foreseen in the strategic management plan. Regional offices were further responsible for the maintenance of local forestry equipment (harvesters, soil mobilization devices) (P5). The wood

logistics processes addressed the management of all pulpwood logistic network components, according to the following processes: global wood supply and transportation management at the Central Plant Supply Department (CPSD) (P6, P7), wood yard management (P8), and wood reception at the pulp and paper industrial unit (P9). The global wood supply management sub-process received information about the industrial units' monthly pulpwood demand and defined both the pulpwood volume market acquisition and the pulpwood self-supply volume needed to meet the demand targets. Market acquisitions were based on pulpwood deliveries agreements (P6.1). Pulpwood quality at industrial unit entrance became a parameter for assessing the pulpwood supplier (P6.3). Pulpwood self-supply volume was defined in cooperation with the FMD. The latter checks the availability of self-supply volume within the strategic management planning process (P2.1). At tactical transportation planning level, the self-supply levels were fulfilled with qualified wood (e.g., specific pulpwood products) flows from a group of harvest areas (P6.2) over adequate transportation routes (P7.1). The required transportation fleet and truck scheduling at each
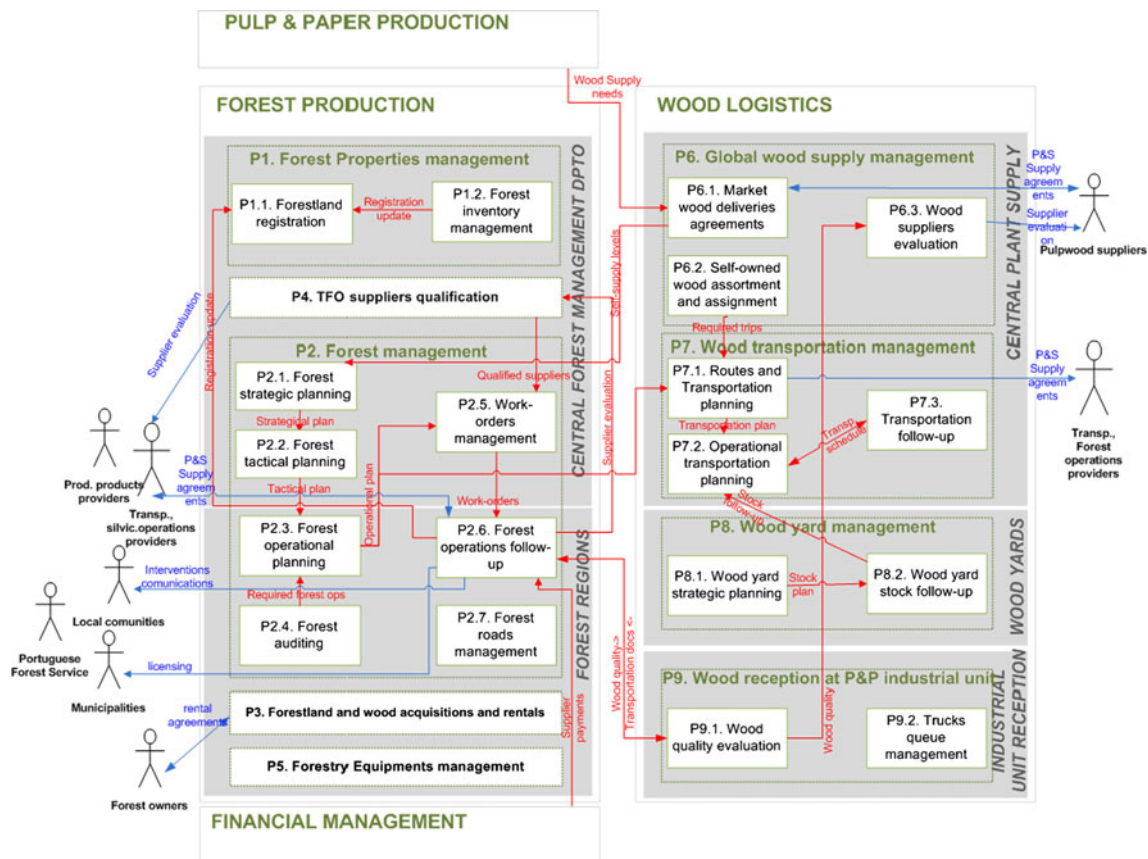
Fig. 3 Celbi's forest production and wood logistics business model (*intermediate-level* representation obtained at the Process Architecture stage) listing the company business processes related to forest production, and wood logistics displayed according to their physical execution location. Includes the information flows among processes and with the external entities

origin and destination were foreseen by the operational transportation planning sub-process (P7.2). The pulpwood flows' destinations included intermediate wood yards, whose storing capacity could not be exceeded (P8.1), or the industrial unit, where the pulpwood quality was assessed (P9.1). The wood trucks real-time location and updated wood yard stocks were permanently monitored, enabling transportation rescheduling (P7.3 and P8.2). Finally, the truck queue management process (P9.3) established the trucks unload sequence and destination in order to mini-mize its nonworking time and enable multiple service trips per day.

The bottom-level representation included all business processes BPMN flowcharts. As an example, the forest areas registration process (Fig. 5) created, deleted, and updated records in the list of forest properties under Celbi's management. A property consisted of a geographically delimited area under the same rental or acquisition agreement. It might include several heterogeneous management units. New forest properties were added to the list after successful acquisition or rental agreements (P3). Restruc-turation requests triggered by forest fires might also lead to

editing of the properties' list. Inventory by FMD regional offices provided the properties, physiographical and eco-logical data. These data were used by the FMD central office to classify the land into management units according to criteria, such as stand composition, stand age, hydro-logical or road networks delimitations, and maximum and minimum size. The biometrical data collected in forest inventories and the history of forest operations were reported at this level.

The brainstorm meetings conducted in the second stage—Information Architecture—identified 120 informa-tion types that were grouped into 25 Information Entities. The Information Entities-Relationship model identified its main attributes as well as the type of relationship among them (Fig. 6). For example, the "management unit" information entity included all its characteristics, biometric data collected in inventory plots, type of ownership, and the historic of forest operations. Each unit had at least one species and if this specie was eucalyptus it produced at least two forest products (eucalyptus pulpwood and bio-mass residues). It was annually audited in order to plan forest operations required by the operational forest plan
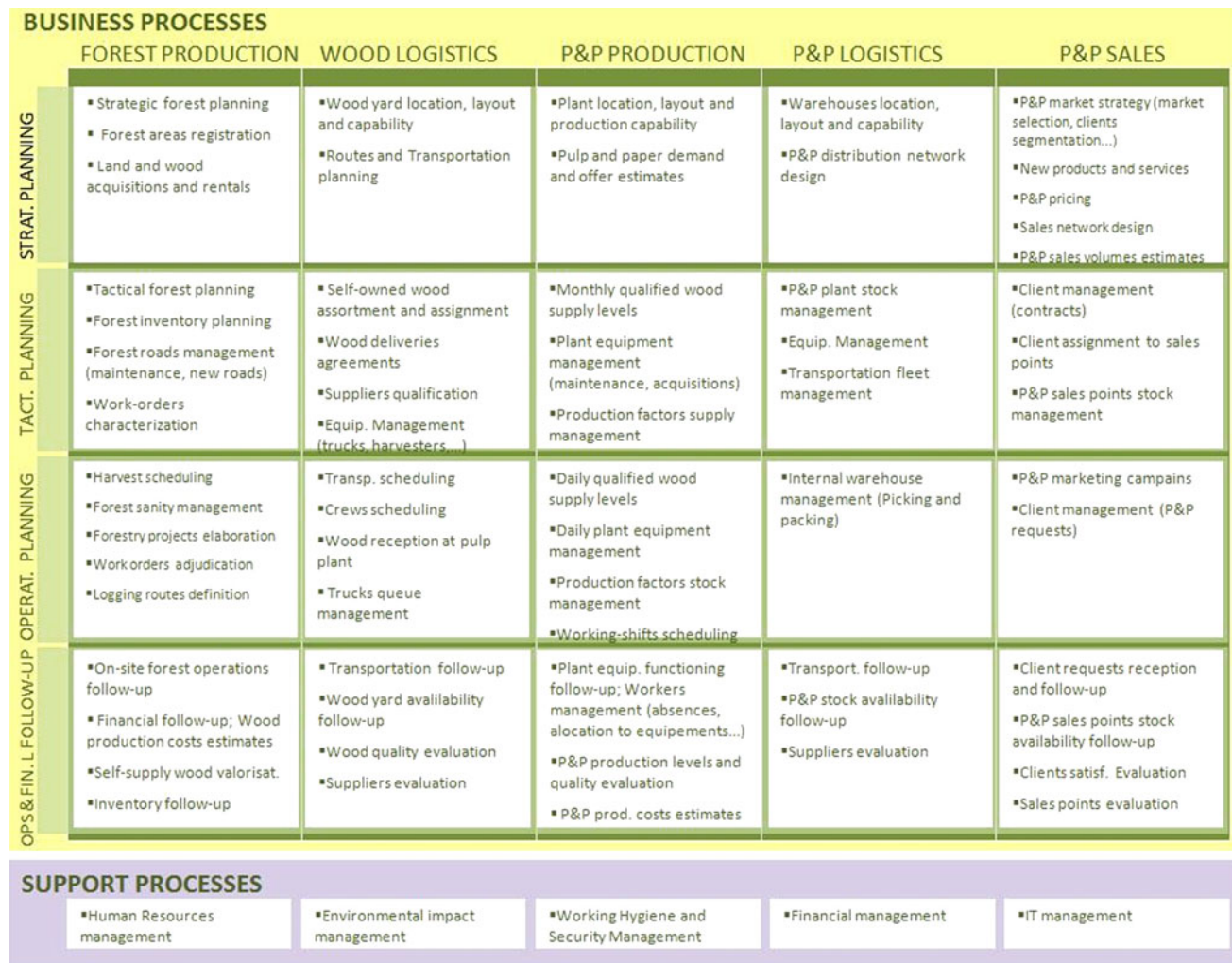
Fig. 4 Preliminary version of the Pulp–Paper Supply Chain Process Framework, based on the case study forest production and wood logistics business model

and tactical transportation plan (e.g., harvest, regeneration, and transportation).

Under the third stage—Applications Architecture—the relationships (Create, Read, Update, Delete) between each business process and each information entity as well as the CRUD matrix manipulation (Fig. 7) enabled the identification of seven pulpwood supply information system (PSis) modules or sub-systems (Fig. 8). Each sub-system managed ("CRUD") an independent sub-set of information entities and had specific functional requirements. Specifically, the Forest Patrimony Management sub-system (FPMss) handled forest properties management in the context of processes such as forestland registration and wood acquisitions and rentals. Forest roads management and annual auditing activities were also included. The Forest Planning sub-system (FPss) encompassed strategic, tactical and operational forest planning, forest equipment management, as well as remote Forest Operations Follow-up for updating biometrical data, events, and forest

operations historical records. The third sub-system, Wood Supply Management sub-system (SMss), addressed the definition of pulpwood market volumes and self-supply volumes to fulfill the industrial unit pulpwood demand target levels. It would further support the assessment of forest operations' suppliers based on information provided by the forest operations follow-up. The Work-orders Management sub-system (WOMss) created and controlled the execution of work-orders for budgeted forest operations, road management activities, and transportation requests. The Wood Logistics sub-system (WLss) addressed wood transportation and storage planning and follow-up. Planning activities are related with the establishment of monthly transportation flows between the forest, the industrial units, and wood yards, as well as to the daily scheduling of trucks and crews. The Wood Reception sub-system (WRss) managed wood loads quantification and qualification at the industrial unit entrance. It also planned trucks unload sequence and internal destination (e.g., wood
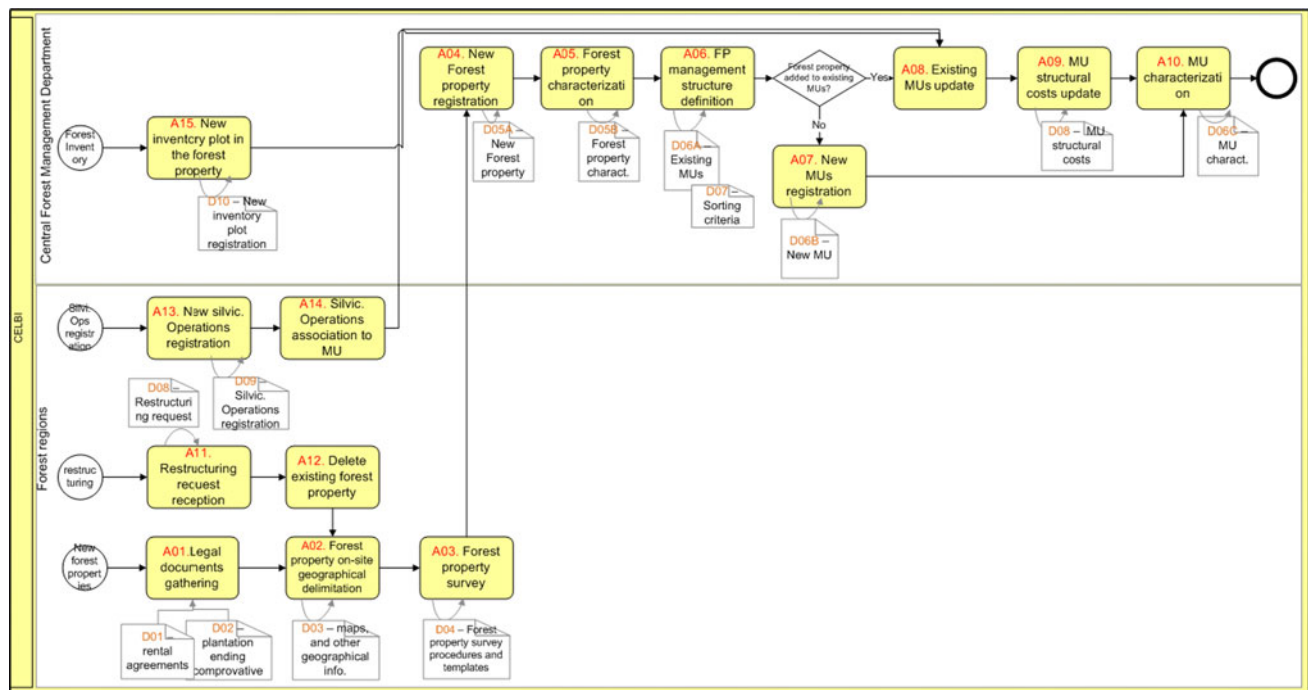
Fig. 5 Forestland registration process (P1.1) example of the *bottom-level* representation obtained in the Process Architecture stage—it sequences the activities performed at the forest region and at the central forest management department as well as the associated input and output information flows

yards, truck park, or directly into the wood digesters). Finally, the Forest Inventory sub-system (FIss) allowed forest inventory planning (logistics, procedures, and plots location) inventory data management.

Sub-systems' internal and external integration requirements were clearly defined from the data interfaces provided by the CRUD matrix. As an example, the forest auditing module of the FMss required reading access ("R") to all existing equipment managed ("CRUD") within the FPss. The future system accessed the Forest Regions' descriptions supported in an external Information System. Both the functional integrity and the independency of the proposed modular structure contributed to eliminate data redundancy and the need for complex data synchronization processes. It further provided the basis for the PSis scalability and evolution capabilities.

The Technological Architecture developed in the fourth stage engaged several principles and recommendations for developing the future system, namely the network infrastructure, Servers structure, Database Management System, Geographical Information System, Middleware, Decision Support Systems, and Security Server. As an example, the local area network implementation should follow six principles, such as the adoption of Open Standards; account for future traffic and servers expansion; adopt a network management platform to detect and solve network failures; collect and manage network maintenance data; include servers redundancy and other network failures tolerance

mechanisms; and central and integrated management of all network infrastructure. The related recommendations pointed up to the use of TCP/IP as transportation protocol and the adoption of Ethernet (100 Mbs or 1 Gbps). Regarding the server structure, the main principle was the adoption of a three-layer schema, encompassing users' workstations, sub-systems applications servers, and web servers for applications frontend. It included the development servers for configuration management and applications testing.

The future sub-systems implementation sequence was scheduled to occur over a period of 2 years. The FPMss would be addressed in the first 6 months of implementation project as they provide information for the remaining sub-systems. The development of the main planning systems (FPss and WLss) was estimated to take 10 months. The remaining 6 months would focus on the SMss, WOMss, and WRss. The FIss development was considered independent and might start at the beginning of the project. A Change Management Project would run parallel to all development activities focusing on users training and system promotion across the entire organization.

Discussion

The proposed approach to Information and Communication Technology design for forest management did address experts' concerns with the human organizational
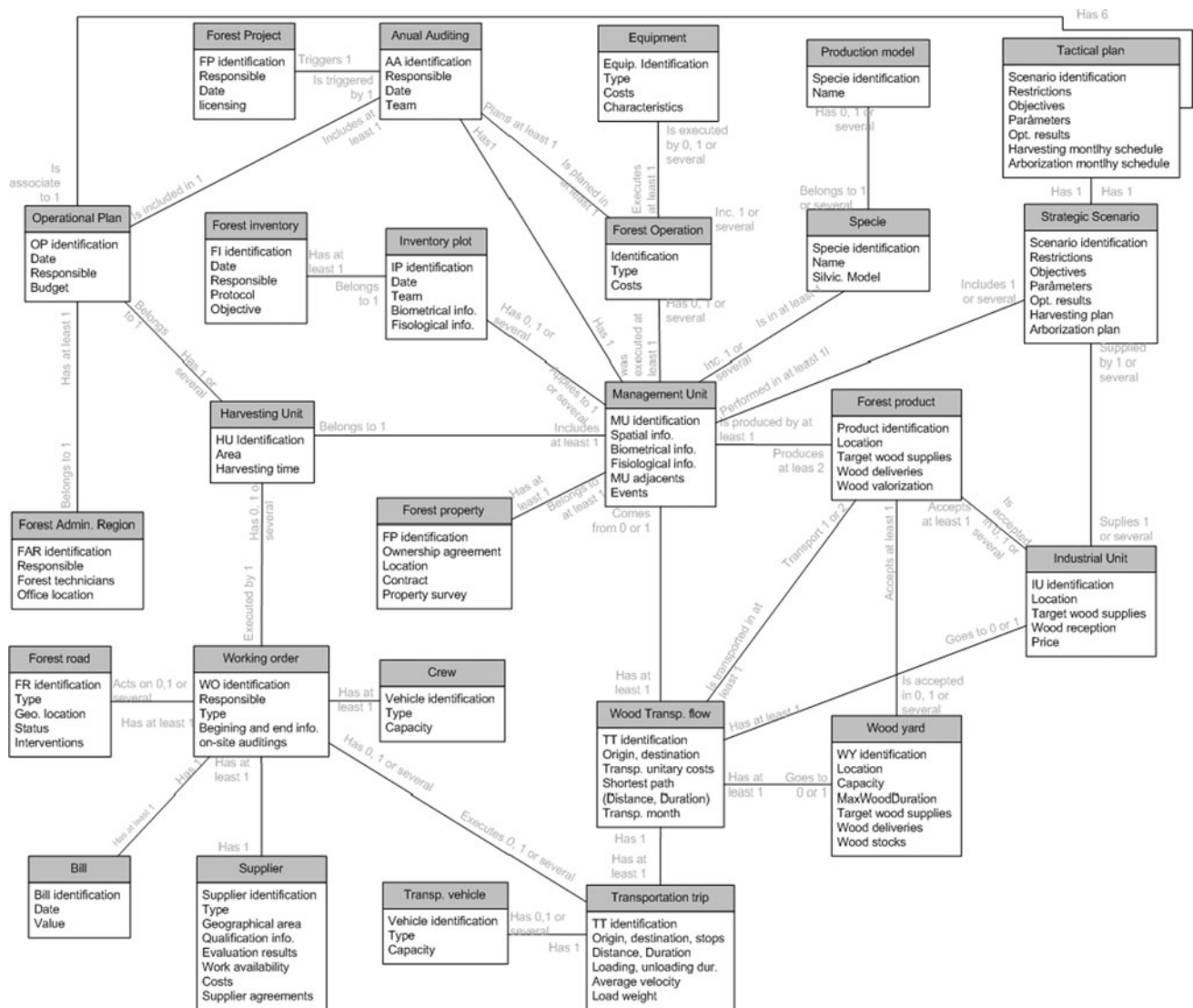
Fig. 6 Information Entities-Relationship model obtained at the Information Architecture stage. It displays all the information entities and its main attributes as well as the nature of the relationships among them

dimensions of information systems (Reynolds et al. 2007). Systems functional requirements were defined according to stakeholders' know-how and expertise. The proposed architecture approach further promoted stakeholder's involvement in all stages of system design taking advantage of participatory methods that are deemed critical to the success of decision support systems (Kangas et al. 2008). Stakeholders' participation through the proposed architecture is instrumental to develop a system that might address effectively the business specificities (Sousa and Pereira 2005). This is a critical success factor for decision support systems (Arnott and Dodson 2008). Stakeholder's involvement in the design of changes to current business processes further facilitates later system deployment and operation.

Nevertheless, forest business experts' successful involvement requires stakeholder's time availability and prior EA

nomenclature training. Additionally, the EA workshops presuppose the ability to develop multidepartment and multirole interactions over abstract drawings and representations. This is even more important when the integration of processes across the whole supply is at stake. These multidisciplinary discussion forums are uncommon in many forest-based companies. Consequently, the initial workshops meetings can be quite time demanding. Further, the EA workshops mediation becomes key for supporting the participation of all stakeholders and ensuring that everyone gets familiar to resultant business concepts and representations. Thoughtful architecture requires expertise to develop the role of change agents (Kendall and Kendall 2008) and to ensure that DSS features such as system restrictiveness and decisional guidance are addressed (Silver 2008).

Fig. 7 CRUD matrix obtained at the Applications Architecture stage. It defines the relationships ("Create", "Read", "Update", "Delete") between the business processes and the information entities, displayed in rows and columns, respectively. Its reorganization leads to the identification of the future system functional modules

Yet, these new collaborative working practices should have positive effects on the forest-based companies' dynamics. Namely, it will facilitate the change that is needed to integrate business process over the whole pulpwood supply. The proposed approach may thus contribute to address concerns with the lack of integration of forestry business processes (Weintraub and Romero 2006) and with the gap between forestry and other industrial sectors' information systems (Carlsson and Ronnqvist 2005, Carlsson et al. 2006). The economic evaluation of the PSis impacts may be completed when the system is implemented. Nevertheless, significant savings can be expected from the automation of the process activities and the management of the business information. Business process models further contribute to increase both the efficiency and the effectiveness of management planning (e.g., lower employee training costs, higher decision-making transparency).

Moreover, EA artifacts serve organization's purposes other than successful information systems design. The proposed approach, namely its Process Architecture, may support process-based certification schemas (e.g., ISO 9000; ISO 14000). It can also be instrumental for the implementation of future forest certification initiatives (e.g., the Forest Stewardship Council certification and PEFC that requires complete documentation of the company's processes and information flows). Nevertheless, a new transversal forest certification process could be added. Its activities should address the specific documentation elaboration, periodic internal and external auditing, and nonconformities follow-up.

The Technological Architecture can guide the design of integrated Information and Communication Technologies (ICT) platforms that may help share business information with other ICT components, like RFID systems or GPS trucking devices thus enhancing supply chain management (Boston 2005). The proposed approach also triggers organizational changes to support enhanced decision-making processes, new information dissemination, and communication policies. Additionally, the EA artifacts update and the resultant knowledge repository may promote insight about the supply chain, and thus facilitate the solution to transversal problems. This is instrumental for improving the efficiency and the effectiveness of supply chain management.

Intercompany collaboration can also be achieved by adopting identical business concepts and business process structures. For example, open standard representations, such as BPMN, enable cross-industry artifacts sharing and comparative analysis. Accordingly, the proposed Pulp–Paper Supply Chain Process Framework may provide a common high-level process structure applied to all vertically integrated pulp and paper industries, based on standard Process Frameworks (e.g., SCOR 2006; APQC 2006). It addresses
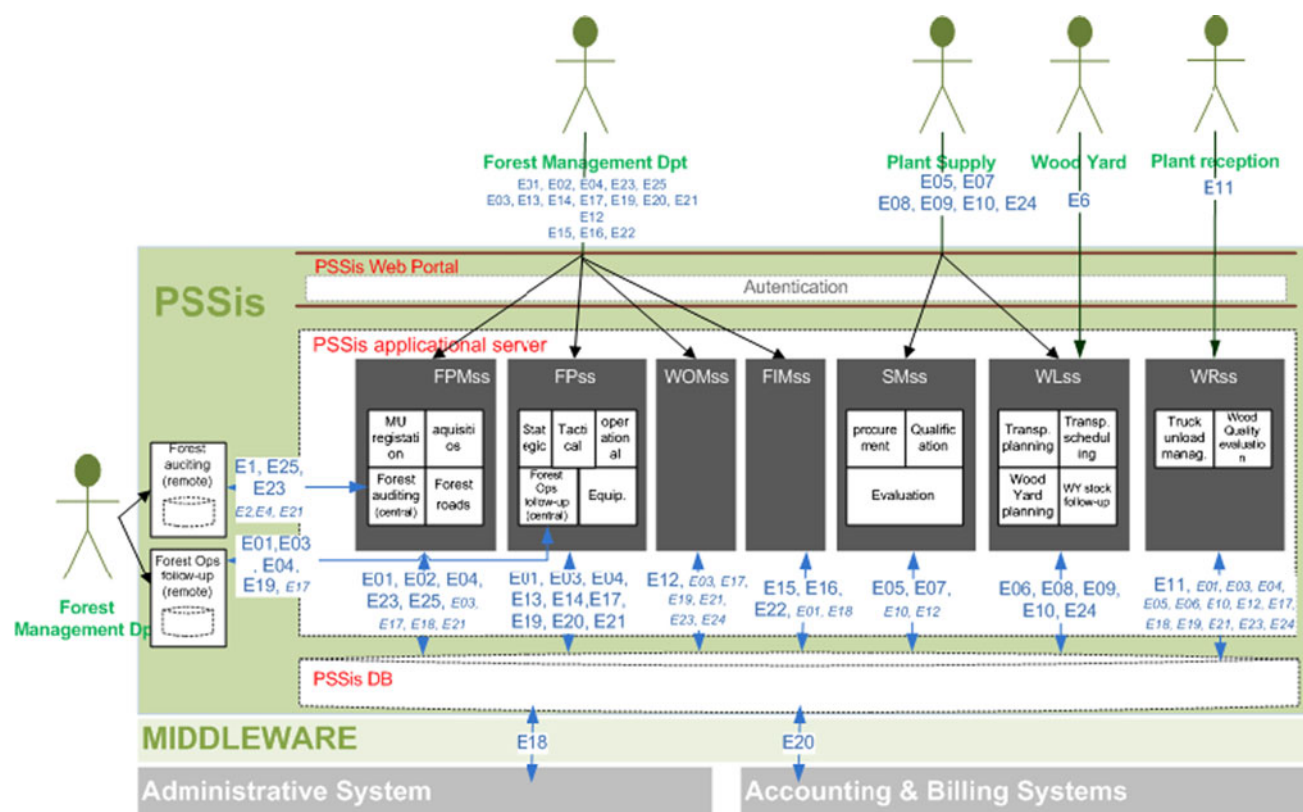
Fig. 8 The proposed pulpwood supply information system (PSis) interfaces-application-information three-layer schema, obtained at the Applications Architecture stage, represents the 7 proposed sub-systems, namely: Forest Patrimony Management sub-system (FPMss), Forest Planning sub-system (FPss), Wood Supply Management sub-system (SMss), Work-orders Management sub-system (WOMss), Wood Logistics sub-system (WLss), Wood Reception sub-system (WRss), and Forest Inventory sub-system (FIss). It also identifies their main user and the information entities handled, such as

Management Unit (E1), Forest Property (E2), Harvesting Unit (E3), Silvicultural Operation (E4), Industrial Unit (E5), Wood Yard (E6), Forest Product (E7), Transp. Flow (E8), Transp. Trip (E9), Transportation Vehicle (E10), Supplier (E11), Work-order (E12), Strategic Scenario (E13), Silvicultural Model (E14), Forest Inventory (E15), Inventory plot (E16), Operational Plan (E17), Forest Administrative Region (E18), Forest project (E19), Bill (E20), Equipment (E21), Production Model (E22), Forest road (E23), Crew (E24), and Auditing (E25)

forest production processes jointly with other supply chain processes (e.g., logistics and sales processes). The proposed framework is tied to the case study and to its EA architects perspective. Nevertheless, it may provide support to efforts of multidisciplinary stakeholders, committed to a common international initiative aiming at developing a Pulp–Paper Supply Chain Process Framework.

Conclusions

In Portugal, there was considerable experience of developing computer-based tools to enhance the efficiency and the effectiveness of forest management planning and scenario analysis (e.g., Borges et al. 2003, 2008, 2009; Ribeiro et al. 2004; Falcão and Borges 2005; Falcão et al. 2006). Yet, these systems focused mostly on strategic and tactical management planning processes. Further, stakeholder's involvement in system's design and development was

limited to the identification of management planning or scenario analysis problems and to the validation of solution reporting. (Ribeiro et al. 2005) described an architecture approach to develop an integrated forest planning system but did not address the whole pulpwood supply chain.

This research was built on this experience. The proposed architecture approach did contribute successfully to address concerns with the integration of the human dimension in forestry information systems. The participatory techniques involved business process and information representation workshops and did capture successfully stakeholders' know-how and expertise in order to define systems functional requirements. Stakeholders' involvement in all four stages of the proposed approach and the architects' expertise provided an adequate representation of the pulpwood supply chain processes and core information. It further enabled the specification of the correspondent supply chain management system ensuring business information integrity. Specifically, the Process Architecture encompassed a

hierarchical top-down process structure that addressed all stakeholders' requirements and concerns. The Information Architecture identified the key pulpwood supply information entities. The Application Architecture specified the pulpwood supply information system (PSis) modular components, in alignment with the processes and core information entities. Finally, the Technological Architecture provided adequate technological requirements and implementation guidelines.

The proposed architecture approach was further successful in integrating business processes currently dispersed over the pulpwood supply chain. Namely, it demonstrated how to integrate forest production and wood logistics processes. The integrated vision, provided by the Celbi's Forest Production and Wood Logistics Future Business Model, was instrumental for establishing interoperability platforms between traditionally independent components of the vertically integrated pulpwood company. The EA artifacts further helped to develop a Pulp and Paper Supply Chain Process Framework proposal. It provides a common high-level process structure that may be generalized to all vertically integrated pulp and paper industries. The cross-industry generalization of business concepts and processes promotes collaborative approaches and the development of common ICT interoperability platforms.

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A participatory approach to design a toolbox to support forest management planning at regional level

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Abstract

Forest management planning in a region typically involves multiple stakeholders. Decisions processes are idiosyncratic, driven by individual goals and supported by segmented forest-based information. Nevertheless, stakeholders' decisions do impact one another leading to complex interaction networks where communication, cooperation and negotiation play a key role. This research addresses the need to develop decision tools to support these roles. Emphasis is on the integration of participatory planning tools and techniques in the architecture of a regional decision support toolbox. Specifically, this research proposes an Enterprise Architecture methodological approach to design a toolbox that may both address distinct stakeholders' interests and decision processes and support communication, cooperation, negotiation and information sharing, facilitating the regional interactions network. Results of its application to Chamusca county in Central Portugal are presented. This regional interaction network involves decision processes and information shared by 22 entities clustered into 13 stakeholders groups, including forestland companies and private forestland owners - acting individually or grouped into associations and federations -, national and regional offices of the forest authority, forest services providers, non-governmental organizations and research centers. Results suggest that the proposed approach may provide a toolbox that may effectively address stakeholders' decision processes and goals and support the regional interaction network.

Keywords: forest management, multiple stakeholders, decision support systems, enterprise architecture, participatory process

1. Introduction

Forest resources management in a region is typically conducted by individual stakeholders acting mostly independently. Decisions are thus idiosyncratic. They are framed by individual economic, ecological and/or social objectives within specific institutional arrangements and organizational structures (e.g. private forestland owners, associations, private companies or public administration). The decision-makers organizational context further dictates the spatial-temporal scales used for forest planning. Sophisticated models and tools are available to support individual decision-making and help address current as well as emergent forest management planning problems (e.g. Borges et al. 1999, Falcão and Borges 2002 and 2006, Palahi and Pukkala, 2003, Nieuwenhuis & Tiernan 2005, Dias-Balteiro and Romero 2008, Constantino et al. 2008, Toth and McDill, 2008, Vainio et al. 2009, Pukkala et al. 2009, Costa et al. 2010, Forsell et al. 2009, Ferreira et al. 2011, Garcia-Gonzalo et al. 2011).

However, stakeholders' decisions do impact one another leading to complex interaction networks where communication, cooperation and negotiation play a key role. Forest resource management in a region is conducted mostly by individuals and institutions acting independently. Yet the plans are the result of interactions that these tools can hardly acknowledge, if used within unilateral frameworks. Individual stakeholder's decisions reflect unilateral perceptions of the regional forest sector, often based on imperfect, outdated and un-shared information. Yet they condition and are conditioned by the decisions of other forest supply chain agents. For example, the selection of forest species by a NIPF will impact later in time the availability of raw material to neighboring transformation centers as well as the fulfillment of goals set in regional forest plans by the public administration. Similarly, NIPF harvesting decisions are impacted by demand requirements and will in turn affect the regional availability of harvest equipments, regional employment and landscape configuration. Conversely, the lack of equipments or unfavorable prices may lead NIPF to postpone harvesting decisions. Further, the social and ecological impacts of these decisions may be considered unacceptable to local communities. The lack of acknowledgement of these interdependences within the management planning framework may lead to unnecessary conflicts and sub-optimal resources utilization (Grimble, R. and K. Wellard 1997, Martins and Borges 2007).

The development of regional toolboxes that may integrate models and tools currently available to support individual decision-making as well as facilitate communication, cooperation, negotiation and information sharing techniques between stakeholders thus emerges as a pertinent research problem. To our knowledge, no such regional toolboxes (RgTbx) have been developed. Our RgTbx concept has similarities with group decision support systems (GDSS). The latter, rely on collaborative technologies and enable distributed meetings and group work. Korpela et al (2001) applied a GDSS-based approach to the analysis of the strategy of forest industries. The RgTbx concept extends these functionalities.

The number of agents involved suggests the need to use participatory planning techniques to strengthen stakeholders' involvement in the toolbox design. This will be influential for adequate

representation of communication and cooperation processes to be supported by the toolbox. In fact, participatory planning techniques have been successfully used for problem structuring, strategy definition and collective decision-making when objectives are fuzzy or the information is scarce (e.g. Martins and Borges 2007, Ananda and Herath 2003, Kurtilla and Pukkala 2003; Purnomo et al 2005, Kangas et al 2008, Hjortsoe et al. 2005, Christensen et al. 2008). Soft-OR methods have also been discussed to help support the solution to such ill- structured problems (Hjorts 2004, Ackermann and Eden 2009). Participatory planning techniques may further be used within a multi-criteria decision analysis framework to help assess strategies and plans (e.g. Diaz-Balteiro et al. 2009, de Steiguer et al. 2003, Sheppard and Meitner, 2005, Tecle et al 1998, Schmoldt et al 2001, Nordström et al. 2009). Finally, and of specific interest to this research, these techniques may be very helpful for information systems design, e.g. within an Enterprise Architecture (EA) approach. Ribeiro et al. 2005 and Marques et al 2010a applied EA approaches to design corporative forest management decision support systems, combining several technical profiles of two Portuguese pulp and paper companies. This methodology was further used to support interoperability between information systems (e.g. between decision support systems for forest planning and mobile devices' information systems for real-time operations follow-up) used by wood supply chain agents (Marques et al 2010b, Marques et al 2011a).

In this research we propose a regional toolbox (RgTbx) to fully address the individual forest planning problems and to provide a record of the management actions on a daily basis. It further addresses the information exchange and communication mechanisms required to support the interactions networks. We further propose an EA methodological approach to engage the stakeholders in the design of the RgTbx so that it may support individual decision making processes while acknowledging regional interactions networks. Emphasis is on the adaptation of participatory planning techniques to develop a toolbox that may also address the need to automate data exchange processes and communication mechanisms.

The proposed EA approach is an extension of the methodology firstly presented by (Spewak, 1992) and applied in forestry contexts by Ribeiro et al. 2005, Marques et al 2010a. Accordingly, participatory planning techniques are applied to explicit and document stakeholders' knowledge, concerns and requirements. No a priori assumptions are made about individual decision processes and network interactions so that the toolbox may effectively address stakeholders' needs and successfully accommodate the human dimension into its development. Specifically, the approach relies on modeling information, forest decision processes and interactions networks in the framework of Process Architecture workshops with the stakeholders. The process architecture (PA) thus aims at providing a collective and consensual vision representing both the individual decision processes and the interactions networks. Furthermore, it aims at providing the baseline for RgTbx components identification, including the decision support tools and the data elements handled by the stakeholders. A complete specification of the RgTbx is influential for the alignment between the forest management decision processes and the IT function (Sousa and Pereira 2005, Sousa et al 2005). The proposed EA methodology was tested on Chamusca County, located in Central Portugal. The set of stakeholders included forestland companies and private forestland owners acting individually or grouped into associations and

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federations. It further included national and regional offices of the forest authority, responsible for managing public forests as well as providing regulatory frameworks for forest management planning. Representatives of forest services providers, forest industries, forest investment funds, non-governmental organizations and research centers were also involved.

2. Materials and Methods

2.1. The Chamusca county case study

The Chamusca county is a rural and low population density municipality, extending over 74,599ha in the Central Portugal. Forests extend over 51% of the county territory. Eucalypt and maritime pine plantations extend over 62% of the county forest area while cork and holm oak multi-functional forests occupy 25% of this area. The remaining 3% corresponds to protection areas. The forestland is predominantly private. Pulp and paper companies and a few large-scale non-industrial private forestland owners (NIPF) are responsible for managing 73% of the area while the remaining area is held by more than 2,200 NIPF, some with holdings with less than 1ha. These stakeholders can act individually or grouped into forest associations and federations. Typically, NIPF sell stumpage and cork to local trade entrepreneurs. Often, the latter own the harvesting equipment and rely on local workers hired for the harvest season. The transportation of forest products is typically outsourced to logistic operators or individual haulers. Forest operations are regulated by the regional office of the forest authority according to regional plans and forestry policies. The regional office is also responsible for managing the public forests in the county. Recently and as a response to the 2003 wildfires that burned 20x103ha of the county's territory, the local municipality also plays a key role in developing and supervising forest wildfires prevention plans as well as in coordinating the forest wildfires suppression efforts. Other stakeholders include forest investment funds, non-governmental organizations, local communities and forest research agencies.

2.2. Methods

The stakeholders' engagement plan aimed at identifying the RgTbx components. It encompassed four stages for interactive design of the Forest Management Processes Architecture (PA), as suggested by the enterprise architecture methodology (Figure 1). The first stage of this participatory process involved the selection of stakeholders. The research team met with a key stakeholder, the local forestland owners association ACHAR, in order to get the information needed for the identification of relevant entities i.e. forest stakeholders in the county. These entities were clustered into groups and functional categories to be addressed in separate process architecture workshops. Afterwards, at least one representative designated by each entity took part in the kick-off meeting. One forest practitioner from ACHAR was further included in the project team in order to strengthen the contacts with the stakeholders and provide technical support to the moderator during the workshops. The PA workshops were instrumental for the second stage of the

proposed engagement plan, aiming at the identification of individual decision processes within prevalent management planning problems. The workshops relied on a post-It method for hierarchical top-down process interactive design, over two consecutive half-day sessions. During the first session, participants were asked to identify, in Post-It notes, the entities they interacted with and to display them in the organization-centric context diagram, closer or farther from the center according to their business relevance (Marques et al 2010a). The information flows among entities were further identified in this first level of processes' representation, differentiating paper and electronic carriers. The identification of the information flows was influential for highlighting the interactions' network among the stakeholders involved in forest management in the region. It further provided the basis for developing the second level processes' representation - the Business Model - for each group of stakeholders.

The design of the Business Models emphasized the business processes conducted by each stakeholder group. Only the processes directly related to forest management activities were further detailed into flowcharts - the third level processes' representation. The latter depicted the sequence of activities performed by each stakeholder as well as the information used and produced by each forest management activity. These third level representations were interactively built during the second session with each stakeholder group, using the Business Process Modeling Notation. The outcome of the individual PA workshops was displayed on a HTML data repository in order to enable dynamic navigation throughout the representations as well as to provide easy access to objects descriptions and semi-automatic reporting.

The outcomes of the PA workshops were validated by all stakeholder groups. At the time of validation, stakeholders further answered a questionnaire addressing current and future perspectives about their role within the regional forest management planning framework. This was characterized by 21 elements classified into to five main groups e.g. the forest management planning setting, the resources allocation, the implementation of forest operations, the usage of computerized-tools, models and information to support decision-making and the context elements (Table 2). The three first groups encompass management planning activities. The fourth addresses the way these activities are automated and supported by computerized tools while the fifth includes specific regional network elements. The answers to the questionnaires, other than providing valuable information to characterize the management planning problems that were prevalent in the region thus further highlighted the roles and the activities conducted by each stakeholder group to tackle them.

The answers to the questionnaires and the outcomes of earlier PA workshops provided the input for the integrated stakeholders' analysis in the third stage of the engagement plan. Individual context diagrams were merged into a complex integrated context diagram. This was influential to develop the Regional Forest Management Planning (RFMP) Framework as well as to identify the roles played in it by each stakeholder at Chamusca region. The four-level integrated diagram displayed the main decision-makers at the center. The stakeholders involved in consultation, regulation or implementation of the decision, were displayed at the next level. The stakeholders that are just informed about the decisions were represented next. All other entities were

represented at the level farther from the center. The characterization of roles played by each stakeholder in the RFMP Framework was based on the generic responsibility assignment matrix (e.g. PMI, 2010), as well as on the answers to the individual questionnaires by each stakeholder group (Table 2).

The results of the third stage of the engagement plan were influential to locate individual decision processes in the overall framework of forest management planning in the Chamusca county. They further provided information to develop the communication and cooperation mechanisms needed to support the regional interactions networks, thus contributing to enhance data sharing among the entities engaged in forest planning in the region. Moreover, they further supported the identification of the RgTbx components to be addressed by the last stage of the engagement plan.

This stage encompassed the detailed listing of data and decision support tools used or required by the stakeholders groups. Additionally, a data ownership matrix was developed to highlight how each stakeholder group handled each data and information element, (e.g. create, read, update and delete). This matrix was driven from the individual decision processes and helped identify the actual data and information needs by each stakeholder group. It further suggested techniques for enhancing communication, cooperation, information sharing and exchange within an adequately regulated access to the RgTbx. The results were subjected to validation by the representatives of the stakeholders groups and further discussed on the project final meeting.

3. Results

The first stage of the stakeholders' engagement plan led to the selection of 22 entities that were classified into 13 stakeholders groups and 4 functional categories. They represented about 900 people with direct interests in the Chamusca county forest sector. The entities included both active and passive stakeholders, i.e. those who affect/determine a decision or action and those that are affected by it (Grimble and Wellard 1997, Martins and Borges 2007) (Table 1). Most representatives took part on the kick-off meeting. Nevertheless, smaller-scale owners did not participate in this meeting. They usually do not rely on technical forestry support thus their contacts were not available at ACHAR at that moment. Yet they did participate in subsequent PA workshops. The private sector category aggregated industrial and non-industrial forestland owners (NIPF) as well as their forest associations and federations. It further included forest-based industries, forest service providers and the forest investment fund. The public sector category encompassed the Chamusca municipality, one parish representing local communities and the forest authority (both national and regional offices). Finally, one non-governmental organization and one forest research center were also selected. The forest holding structure as well as the management objectives and practices motivated the definition of 4 sub-groups of NIPF. Accordingly, the large-scale intensive sub-group included owners with forestry as their main economic activity (e.g. timber and/or cork and pine nut production) and, typically, with holdings with more than 500 ha. The owners in the medium-scale intensive sub-group considered forestry as their secondary

economic activity and their holdings had an area between 100 and 500 ha. Nevertheless they conducted regularly management operations according to their forest management plan (PGF). The owners of the small-scale sub-group (<100ha) considered forestry as a residual activity and usually did not conduct any forest operations. Lastly, the multifunctional sub-group included owners that focused mostly on other non-wood products and market services, such as mushrooms production, apiculture, hunting and tourism. Each sub group was further characterized according to planning constraints and regulations (e.g. wildfire protection and wildlife conservation frameworks) to the management of their holding, landowner age, academic degree and technical competences.

The identification of individual decision processes within prevalent management planning problems during the second stage of the engagement plan underlined the contribution of each stakeholder group to the overall forest management planning framework in the Chamusca County. Forestland owners play a key role in forest management planning in the region. The PA workshops confirmed that the sophistication of the planning process tends to increase with the holding size. In fact, both the industry and large-scale NIPF usually develop strategic (long term) plans at forest level. Typically, these plans are developed by a single decision-maker, target multiple objectives and include both wood, non-wood productions and services. The decision-maker is most often supported by skilled forest practitioners that configure the plan to meet the requirements of the legally binding forest management plan (PGF). The first years of the strategic plan provide the input for the operational plan aiming to provide actual resources allocation, budgeting and detailed specifications for the forest operations implementation. The operations are further clustered into work-orders, implemented with outsourced resources and controlled by the owner. The management planning processes are frequently supported by computerized-tools with adequate growth & yield models powered by updated forest inventory data. Optimization techniques embedded on decision support systems to help search for the most profitable plan have also start been used, mostly by the industrial owners (e.g. Borges et al 1999, Marques et al. 2011b).

The medium-scale NIPF, the managers of public forests and the other forestland owners technically supported by Forest Associations address similar strategic problems. The forest public administration is further responsible for the development of regional forest plans (PROFs). These encompass a participatory planning process aiming at the development of strategic regional forest sector goals. The goals are tied to the territory through the definition of sub-regions that are homogeneous according to dominant forest functions (e.g. production, conservation). PROFs further suggest management goals, species selection and prescriptions to be adopted by individual management plans (PGF).

Small-scale NIPF usually conduct long-term planning at stand level and target wood or cork production. Both small-scale NIPF and the managers of public forests confirmed concerns with other non-wood products and services with an increasing importance on the region, such as fruits (e.g. pine nuts), mushrooms, fishing and hunting. Yet multiple productions are often not addressed fully by the planning process as few production functions are available. Decisions regarding the supply of these products and services are unstructured and supported mostly by

empirical insights and traditional silviculture models. No computerized-tools other than geographical systems, databases or spreadsheets are used to support those activities. Tactical and operational planning is often absent as the implementation of forest operations is usually outsourced to service providers.

The role of the recently created forest investment fund was further highlighted. The fund buys or rents forest properties, acting like both the owner and the manager of forest properties just like in the case of the industry. The problems faced the fund are mainly related to the acquisition of new properties. After acquisition the fund properties face management planning problems that are thus similar to the large-scale NIPF owners and the industry problems.

The identification of individual decision processes further underlined the role of the local forest association, ACHAR. It provides consultancy and technical support to help NIPF develop their plans. Moreover, it often provides the resources needed to implement the individual plans. ACHAR may further impact the regional forest management planning framework as it represents the landowners' interests on national and regional forestry forums.

These actors - industry, NIPF owners, forest investment fund, forest association and managers of public forests – develop individual decision processes to address forest management problems. Yet these processes are impacted by a large number of stakeholders within a vast interaction network.

This research developed context diagrams, business models as well as a detailed characterization of individual processes for all stakeholder groups. Yet for conciseness we will illustrate results focusing mostly on ACHAR. Its context diagram (Figure 2) displayed the regular contacts of the Forest Association with 13 other entities. For example, the regional office of the forest authority is responsible for checking whether the individual management plans (PGF) developed by ACHAR for his associates meet the regional forest plan (PROF) guidelines. Additionally, ACHAR interacts frequently with the Chamusca municipality to support the implementation of regional wildfire prevention activities as well the local wildfire suppression platform during the wildfire season. Moreover, both ACHAR and the forestland owners have regular contacts with forest service providers as they often outsource harvesting and cork and timber transportation operations. These small-scale enterprises play a key role in the regional forest logistics and operational planning. Nevertheless, they seldom use computer-based tools to address their management planning problems. The information flows between ACHAR and other stakeholders are supported mostly by oral communications and paper requests rather than by the use of templates or numbered documents on an electronic format.

The PA workshops underlined that the participation of stakeholders such as ACHAR in the RFMP Framework extends beyond the support to forestland owners decision-making. In the case of ACHAR, only two business processes in its business model (Figure 3) were directly related with providing management planning services to the forest owners (P1) or with providing support to their forest products commercialization (P4). The first process included the development of forest management plans (P1.1), forest resources inventory (P1.2), cartography (P1.3), forest operations follow-up (P1.4), forest products evaluation (P1.5), sanitary control (P1.6) and forest

investment projects formatted for application to public subsidies to forest activities (P1.7). Other business processes by ACHAR included the support to the regional wildfire prevention infra-structure (P6) and non-commercial activities, such as outreach activities (P2), associates' representation activities (P3), research and development activities (P5), cooperation for local development (P7) and administrative management (P8).

Lastly, the analysis underlined the sequence of activities usually conducted in the framework of each process. For example, the development of the forest management plan, according to existing forestry regulations, encompasses a number of activities carried out by the ACHAR forest technicians at the request of an associate (P1.1.) (Figure 4). According to the sub-process flowchart (third level representation) it starts with an expedite site characterization based on data publically available (e.g. at the forest authority offices) such as forest cover maps and PROF guidelines and recommendations for the zone where the property or set of properties is located. If needed, it may include visits to the forest site to collect forest inventory data. Afterwards, the property is classified into homogenous management units. The identification of management goals generally takes place in a meeting with the owner. Typically they address revenue concerns and they thus focus on the supply of the most important market products (timber and cork). Yet, the ACHAR technicians may highlight the economical benefits of new prescription models, alternative species and other non-wood productions and services. Environmental and social concerns are typically met through the compliance with PROF guidelines. In the end, the management plan (PGF) suggests one prescription for each stand and it provides a rough estimate of the operations/investment costs.

The integrated stakeholders' analysis conducted under the third stage of the engagement plan provided an overall interpretation of the contribution of all the stakeholders in the RFMP Framework. In fact, 42 distinct entities were represented in the integrated context diagram. Over 85 information flows were reported to be exchanged among entities. The complexity of this diagram made it unreadable outside the dynamic HTML repository. It reinforced the key role of the industry and the NIPF as the main decision-makers, represented at the center of the diagram. Other decision-makers included the forest investment fund and the managers of public forests.

The simplified version of the overall RFMP Framework (Figure 5) combined the information from both the integrated context diagram and the individual business models and highlighted the main individual decision processes addressed by the key decision-makers (industry, NIPF, forest investment fund and regional office of the forest authority). There are few explicit interactions between the first-level stakeholders. They are more prone to happen in the interface between NIPF and the forest fund in the case of properties that are included in the fund. Yet, implicit interactions were reported among NIPF, namely regarding the setting of prices in forest products selling agreements.

At some extent, all first-level stakeholders were influenced by the stakeholders at the second level of the RFMP Framework. Specifically, the industry owners relied on wood supply levels agreed with the forest-based industries, while the harvesting decisions of the NIPF were conditioned by the negotiations with cork and timber trade entrepreneurs and forest service

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providers. The wood harvested impacted the demand requirements of the neighboring transformation centers. Additionally, both forest owners and the forest investment fund interact with the Chamusca municipality for licensing their forest operations according to regional and national regulations (e.g. deriving from PROF). The forest authority can support the forestry regulations application by the municipality and usually also intervenes on some PGFs approval. This is, for example, the case when the property is part of a collectively managed area (such as the ZIF) or when the manager is applying for public funding. These interactions are often expressed as verbal contacts and oral agreements although document exchange may also occur. Electronic information exchanges were rare, while data sharing and exchange through integration of information systems owned by distinct stakeholders were inexistent.

The third level of the RFMP Framework includes passive stakeholders (e.g. local communities, forest research centers, non-governmental organizations, forest federations, industry associations and hunting associations). These entities do not interact so frequently with the first-level stakeholders and yet they provide information and support to enhance forest management planning at the Chamusca County. For example, the forest owners' federations and the forest research centers conduct regularly outreach activities (e.g. training courses, experimental development and demonstration of novel computerized-tools to support forest planning) to address first-level stakeholders interests and requests. The stakeholders groups involved on the PA workshops further reported 20 other national and international entities (e.g. police department and international sectorial associations) indirectly engaged in forest management planning in Chamusca. These are represented at the fourth level of the integrated context diagram.

The integrated stakeholder analysis further focused on the roles of the stakeholders within the RFMP Framework (Table 2). Results highlighted that each activity involved an average of 7.4 stakeholders. As an example, the definition of management planning constraints involved up to 10 stakeholders. This set included 4 first-level stakeholders groups (decision-makers), 2 second-level stakeholders groups (responsible for the setting up of constraints within national and regional planning) and 2 additional groups to be consulted about this issue (e.g. forest associations). At another extreme were the activities that involve only one stakeholder group e.g. the selection of service providers that are exclusively undertaken by the forest owners. The analysis further highlighted the contribution of the forest research centre to enhance decision-making processes over all RFMP Framework problems and activities. Moreover, the results reported in the role matrix underlined as expected the importance of first-level stakeholders, which are directly involved in 90-95% of the RFMP Framework problems and activities. The Chamusca municipality and the forest authority are the only stakeholders that address the RFMP Framework activities through an approval role. The forest research centre and non-governmental organizations address these problems and activities through a consultancy role while the forest association may play several roles (e.g. decision-maker, implementation and consultancy).

The stakeholder groups' replies to the questionnaire handled during the last stage of the engagement plan led to the listing of 20 tools needed to support their current and future individual decision processes within the forests management planning problems prevalent in the region (first

part of Table 3). This was influential to define the RgTbx components. Only 21% of the tools listed are already in use. Specifically, the growth and yield models (Q2) and the harvest planning models (Q6) are often embedded in the information systems used by industrial owners, large-scale NIPF and forest associations. The prescription models (q1) and forest management standard procedures (q3) are also used by most first-level stakeholders. Most stakeholders pointed out to the lack of updated data and information about forest product prices. In fact, the forest authority out-dated web information service storing reference prices was considered very useful. The forest association most pressing requirement was the availability of adequate forest productivity zoning maps and regional forest production models. According to ACHAR, this would help save forest inventory costs thus reducing the forest management plans production costs. It would further provide information needed to project forest products supply over the planning horizon. Logistics optimization models were not directly requested by first-level stakeholders as they focus mostly on strategic forest-level planning and outsource forest operations to second-level stakeholders. Yet according to the forest research centre, the use of these models might contribute to reduce operations costs and increase revenues especially in the case of integrated supply chain management. The forest service providers could also benefit from these models but their small-scale operation may preclude the investment in the development of these tools. Additionally, new procedures and manuals were required by most stakeholders groups in order to address issues like biodiversity management and conservation, forest operations best-practices, procedures for product certification and management models for conservation areas. These tools should address the specificity of the management planning problems prevalent in the region. Proper training and the availability of technical bibliography were also a major requirement.

Still in stage 4, the core information needed by individual processes and further exchanged within the regional interactions network was classified into 25 data and information elements to be address by the RgTbx (second part of Table 3). 48% of the data elements were already being used, namely by first-level stakeholders. These included mostly thematic Geographical Information System (GIS)-files (e.g. the geographical limits of main land uses at the county level (i1), the protected areas, meteorology data, and forest cover type areas (i2), hunting areas (i3), forest intervention zones (i4), burned areas (i5), PROF sub-regions (i6), hydrology (i19), forest wildfire prevention plans (i20) and forest roads (i21)). ACHAR, the forest investment fund and the industry owners also used tailored information systems to manage forest inventory data (i7), forest properties and record forest operations implementation (i13). The handling of data and information elements by stakeholders (Table 3) further highlighted the relative importance of stakeholders' groups in the RFMP Framework. As expected, the first-level stakeholders handled most data and information elements (e.g. ACHAR accessed 23 data and information elements, 14 of them with editing permissions). The forest research center can access - on a read-only basis – the elements related with its research interests while local communities and non-governmental organizations cannot edit any of the elements to be supported by the RgTbx.

The current data and information handling scheme by the stakeholders' network may lead to redundancy and inconsistency. In fact, each data and information element is handled by an average of 7.8 stakeholder groups. Further, 75% of the elements may be created and updated by

more than 1 group. As an example, the general information about forest products and markets (i10), conservation values (i18) and forest properties (including management units, management plans and forest operations historic records) (i13) are used by 10 stakeholders' groups. Yet, currently the information is not shared among stakeholders. Each stakeholder follows independent procedures for acquiring data and producing information that are kept and used by several entities. This scheme contributes to increase the overall data production costs and leads to redundancy and potential inconsistency. For example, the same forest property boundary (i13) may be delimited by a wide range of entities for distinct purposes, e.g. by individual forestland owners to support forest planning, by the forest investment fund to support property acquisition negotiations and by the regional office of the forest authority for taxing purposes. This contributes to controversies over the actual boundaries and the property official area. The same applies to forest inventory data (i7). Forest associations conduct forest inventory to support the development of PGF, while the forest research centre collect inventory data to support experimental research and demonstration projects (e.g. development or adjustment of growth and yield models). Additionally, the forest authority conducts a periodic national forest inventory evaluation. The inventory protocols are often different and the results are not promptly shared by stakeholders. The data and information redundancy problem is further compounded by the way each stakeholder accesses the information managed by another. Access privileges and procedures vary and this leads to significant differences in the quality and quantity of information used to conduct activities in the individual processes. As a consequence the outcomes of similar management planning processes may be different thus complicating in turn the comparison between distinct planning exercises.

Therefore, communication, cooperation, information sharing and exchange techniques to be added to the RgTbx will be instrumental for supporting the regional FMD interactions network. The development of these techniques was based on the way each stakeholder handles each data and information element. For example, proper system integration interfaces were suggested for importing the data and information elements produced by external entities (e.g. protected areas maps, meteorological data and forest cover type maps produced by the public administration (i2)). The latter were to be accessed as "read-only" by the toolbox users. Similar integration interfaces were designed for accessing data and information elements managed by external proprietary information systems owned by users of the RgTbx.

Providing external systems with easy access to the data and information elements managed within the RgTbx was also a major concern. Therefore, this research produced initial guidelines for the development of a Service Oriented Architecture for the RgTbx. Accordingly, the information services provided by the RgTbx modular components should be the basis for all information exchanges. These services should be directly mapped to the data elements. They should rely on general transaction standards for the forestry sector (e.g. Papinet 2010). Their technical documentation should be easily accessible by the developers of other external systems. It further produced security policies to ensure that each stakeholder has full control over the access to his information, thus preserving data confidentiality. Specific access control modules were suggested to parameterize the access permissions of all other users after a new data input by a stakeholder. Stakeholders may only access instances of information when both its owners provide

explicit access permission and the information element itself is relevant to his individual decision processes. This security architecture was key to sustain the confidence of stakeholders on the toolbox and thus to contribute to its use to support their planning processes namely the implementation and the record of the management outcomes.

Furthermore, special attention was given to the data and information elements editable by more than one stakeholder group. As an example, both ACHAR and the forest service providers needed to Create, Update, Delete new equipment or equipment characteristics (i23). The future data and information governance models should include the identification of a unique stakeholder group responsible for each data element, thus contributing to information consistency. It further identified the potential users of each data element according to the integrated stakeholder analysis. In the case of data and information elements managed by more than one stakeholder group, automatic workflow procedures were recommended to ensure both that the data instance could not be simultaneously changed by different stakeholders and that any input or update is validated by all the stakeholders involved before it became effective. For example, when the boundaries of a forest property are being updated, the system should trigger a procedure to prevent other stakeholders from editing these boundaries. Afterwards, the proposed boundaries update should be accepted by other relevant stakeholders so that, for example, it does not conflict with other existing boundaries. Lastly, data consolidation mechanisms were suggested to enhance cooperation among stakeholders. As an example, the information about forest intervention zones (i4) kept by ACHAR could be aggregated into macro indicators (such as total forest area covered by ZIFs). This will be help support forest strategy and regulation processes conducted by the national forest authority with the participation of the forest federations.

4. Discussion

The proposed approach for developing a regional forest management planning toolbox (RgTbx) addressed the need to acknowledge both the forest management decision processes by individual stakeholders and the complex regional interactions network. The RgTbx resulting from the application of this approach may enhance the development of individual decision processes by providing access to innovative decision support tools (e.g. models, methods and procedures). It may further support the stakeholders' regional interaction network with adequate communication, cooperation, negotiation and information sharing procedures and techniques. It will thus be influential for improving forest management planning at regional level.

The engagement of stakeholders in the design of the RgTbx was a major concern of this research. Therefore, participatory planning techniques were applied, particularly during the process architecture workshops, according to the enterprise architecture methodological approach. This approach has been used in Portugal for designing individual decision support systems, especially for forest-based industries (e.g. Marques et al 2010a,b) as well as for addressing interoperability between systems used to support the pulp and paper supply chain (Marques et al 2010b, Marques et al 2011a). Yet, this research extended the EA methodology to the architecture

of a regional toolbox to be used in a multiple stakeholders' context. The research challenges posed encompassed the development of an approach to both ensure the representativeness of the stakeholders involved in the process and consolidate the results of the individual process workshops in an integrated stakeholders' analysis.

Thus, the proposed four-stage stakeholders' engagement plan encompassed stakeholders' selection, workshops involving the stakeholders groups for individual decision processes design, integrated stakeholders analysis, and the identification of the RgTbx components. Special attention was given to the stakeholders' selection stage in order to ensure representativeness and transparency. This stage is often a bottleneck to the development of the participatory planning processes. In order to overcome it, the project team must identify the relevant players and promote their active involvement in the workshops. The cooperation with a key regional stakeholder (ACHAR) was instrumental for the success of the engagement plan by this research. ACHAR promoted the project locally, made the contacts with the other relevant stakeholders and provided support to the research team moderator during the workshops. The forest owners association was also the main promoter of the project outcomes and may contribute decisively to the implementation of the RgTbx. The 13 stakeholders groups and the 22 entities directly involved proved to be representative of the regional forest planning context. They included the forestland companies, the private forestland owners, their association and federations, the national and regional offices of the forest authority, the forest investment fund, the Chamusca municipality, the forest services providers, the non-governmental environmental organizations and a research centre. The lack of involvement of the small-scale NIPF group was carefully considered as it could pose as a limitation to the representativeness of the results. Yet, recent studies on the behavior of forest owners in Portugal (e.g. Batista and Santos 2005, Novais and Canadas 2010) provided the adequate rationale for their individual decision processes. The project team representations were validated afterwards with the forest association and the local communities. Nevertheless, the research dissemination results could be enhanced by the active involvement of these forest owners.

The PA workshops were instrumental for documenting the stakeholders' current decision processes as well as for identifying their concerns and expectations. They further provided the opportunity to discuss with the forestland owners the rationale of traditional and out-dated management practices and emphasize the advantages of the adoption of new processes and new computerized-tools to support them. The outcome of such interactive meetings was highly dependent on the moderator ability to clearly define the meeting objectives, establish a solid trust relationship and frame their participation in the workshop. The experience with Chamusca county proved that these PA workshops should start with a brief project presentation, emphasizing its objectives and the expected outcomes (specifying what is and what it is not expected) to avoid misleading the participants and raising false expectations. This presentation should further provide a clear description of the method to be used during the sessions, including a reference to the terminology as well as to the graphical representations to be obtained. These representations were built by the moderator on a paper board according to the answers of the stakeholders to the research questions. They were complemented by notes taken by the remaining members of the project team. Alternatively, classical interview methods were used whenever there was evidence of

lack of abstraction capacity by stakeholders. Yet these approaches did not encourage such an active involvement of the participants. The results of all the sessions were documented on a modeling tool (MS VISIO). The tool was not used during the workshops since it could interfere negatively with the meeting dynamics. This tool was also used to automate the generation of reports to be delivered afterwards to the participants for content validation. The workshop with each stakeholder group encompassed at least two sessions. The first focused on the context diagram while the second addressed the individual decision processes, based on a draft proposed by the team after the first session. In some cases, additional sessions were conducted for validating the reports since most stakeholders did not reply when non-face-to-face methods were tried.

The individual and the integrated context diagrams provided a good representation of the complexity of the regional interaction network. The analysis of these diagrams further raised issues that can be properly addressed by forthcoming projects. The first issue was related to the quantity, quality and the format of the RgTbx information to be accessed by the first-level stakeholders. The content of current information flows should be screened during the development of the RgTbx data model to avoid superfluousness and low quality. The second issue was the reported scarce use of computerized-tools by some stakeholders groups. Lack of training, small business size and specific business requirements not easily met by commercial systems were among the explanations provided. Yet other factors may be behind the potential resistance to computerized-tools utilization, such as ineffective dissemination or inadequate forest extension services. The acknowledgement of these factors may be instrumental for promoting the use of the RgTbx. The ongoing projects involving industrial owners, forest owners associations, National Forest Authority and the forest research centre aiming at the development of forest management decision support systems may suggest potential collaborative approaches. Furthermore, the list of required computerized-tools highlights future research opportunities. The third issue was the lack of cooperation practices within the interaction network between stakeholders belonging to each group as well as between stakeholders at the same level in the context diagram. The implementation of the RgTbx should involve periodic meetings and discussion forums to enhance communication and cooperation between stakeholders.

An additional concern to be addressed by the RgTbx implementation is the need to reflect on the toolbox the changes of stakeholders' roles that result from ongoing initiatives for reorganizing the forestry sector. The integrated stakeholder analysis highlighted the prominent role of forestland owners in forest management planning in the region. However, this scenario is likely to evolve. The importance of other stakeholders groups is prone to increase in order to address emergent regional and forest wide concerns (e.g. with wildfires). In this context, in the future forest associations may play a more active role in forest management planning as they will become directly responsible for managing the newly created intervention forest zones. The latter may also lead to a more active role in the development of commercialization strategies and circuits. Recently, local communities and NGO have acquired technical skills to participate and lead forest certification schemas. This may contribute to increase their influence on management planning decisions as well as on national and regional forest regulations.

The use of the RgTbx will trigger significant changes to the Chamusca forest planning context. The use of the toolbox components will enhance the decision processes by individual stakeholders. The optimization methods for evaluating alternative options and for comparing the practices with other innovative solutions will contribute to increase the efficiency and the effectiveness of forest management planning. These models will address other non-wood productions and forest services as well as the economical and social sustainability of the regional forestry sector. Additionally, the toolbox will facilitate the communication, cooperation and information sharing between the stakeholders, through the adoption of adequate system integration, data access control and exchange mechanisms. This will be influential for the efficiency and the effectiveness of the regional interaction network.

This research also underlined the need for rules governing the procedures and tools to support the network. Specifically, it suggested the development of an adequate organizational structure that could promote the discussion about data governance models with the stakeholders. This new entity would be directly responsible for maintaining and updating the RgTbx and for providing training and support to the users. Its governance board should include representatives of the stakeholders groups and the decision process within this board should reflect the relative contribution of each stakeholder. Namely it should reflect the amount and relevance of data and information elements kept by the stakeholder but accessible by other users. This aspect is of particular relevance since the RgTbx implementation should include a schema for financing the production of certain information elements.

5. Conclusions

In this article, a regional toolbox was designed to address both the individual decision processes and the complex interactions networks between stakeholders involved in forest management planning in a region. To the best of our knowledge, such a regional toolbox has not been suggested in the forestry literature. The stakeholders were actively involved in the toolbox design. The proposed stakeholders engagement plan extended the enterprise architecture methodological approach of Marques et al 2010a,b to apply participatory planning tools and techniques during interactive workshops to elicit decision processes within forest management planning problems prevalent in a region. The identification of the RgTbx components was built upon these processes representations. Specifically, it included a set of decision support tools (e.g. models, methods and procedures) already used or else that were required to address the stakeholders' individual decision processes, It further included a list of data and information elements needed to support decision-making. The RgTbx further included communication, cooperation, information sharing and exchange techniques aiming at supporting the regional interactions network.

The proposed stakeholders' engagement plan for designing the regional toolbox was tested in the Chamusca county, located in Central Portugal. The set of stakeholders included 22 entities, divided among 13 stakeholders groups, representing more than 900 people with direct

interests in the region. The results show that the proposed methodology may be used to provide representations of the individual decision processes. The representation of the information elements exchanged and shared among stakeholders did provide a clear vision on the complex regional interactions networks. Complementary, the integrated stakeholders' analysis highlighted the key role of the forest owners, forest investment funds and regional offices of the forest authority in the forest management planning framework in the region.

Interactions and data exchange among these stakeholders were rare. Yet, all first level stakeholders were influenced by the other stakeholders groups (e.g. the forest service providers, forest associations, forest based-industries, Chamusca municipality and the national office of the forest authority), acting mainly as consultants or regulators. More than 20 other passive stakeholders groups were indirectly engaged in forest management planning in Chamusca, including forest research centers, local communities, sectorial associations and NGO. These results were instrumental for identifying 20 decision support tools and 25 data and information elements to be included on the RgTbx. 21% of these tools and 48% of the data elements were already used by the stakeholders. The potential problem of data redundancy and inconsistency was characterized. This was influential for the suggestion of the communication, cooperation, information sharing and exchange techniques to be added to the RgTbx. These techniques included system integration interfaces and Service Oriented Architecture features to regulate communication between the RgTbx and other external systems. Both data governance models and access policies were further suggested for managing the data and information elements within the RgTbx in order to avoid redundancy, inconsistency and preserving data confidentiality. Additionally, data consolidation mechanisms were suggested to enhance cooperation among stakeholders.

Future research will divide the RgTbx into functional sub-systems and provide their detailed functional specifications. It will follow the enterprise architecture approach where these specifications emerge from the confrontment between the presented Process Architecture and the subsequent Information Architecture, therefore assuring the alignment between the decision processes and the IT function.

Acknowledgements

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Figures

Stakeholders selection	Individual decison processes	Integrated stakeholders analysis	Regional Toolbox components
1st meeting (stakeholders groups identification)	Modelling tool	1st meeting (integrated context diagram)	Decison-support tools
Stakholders clustering into categories	1st PA session (context diagram)	2nd meeting (overall RFMP framework)	Data elements
Contacts with stakeholders	2nd PA session (decision processes)	Matrix with questionaire consolidation	Data ownership matrix
Kick-off meeting	Questionaire		Components validation by stakeholders
	Data Repository & report		Final meeting
	Report validation by stakeholders		

Figure 1 – Forest stakeholders' engagement plan for designing the regional forest management toolbox
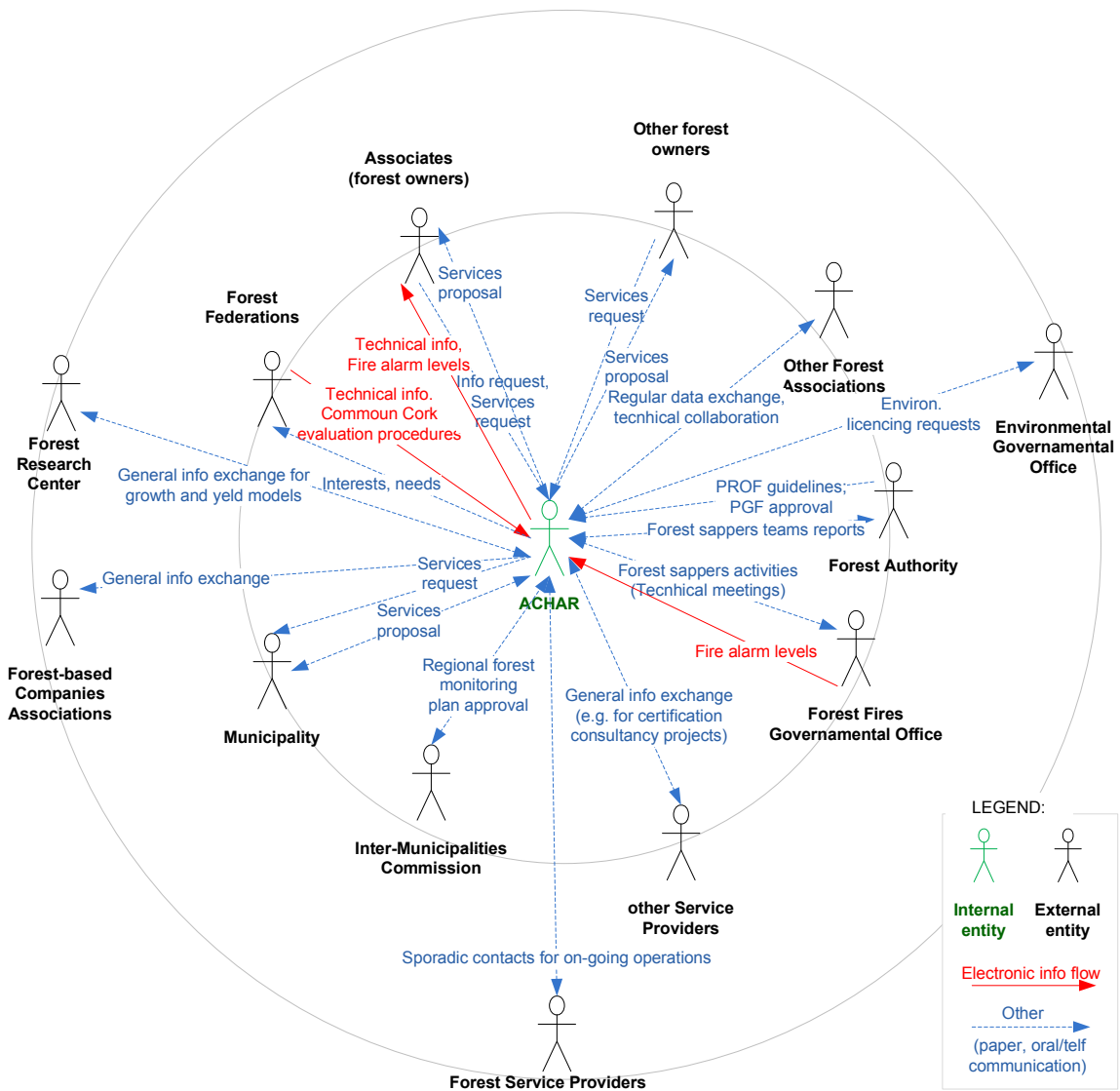
Figure 2 – ACHAR context diagram
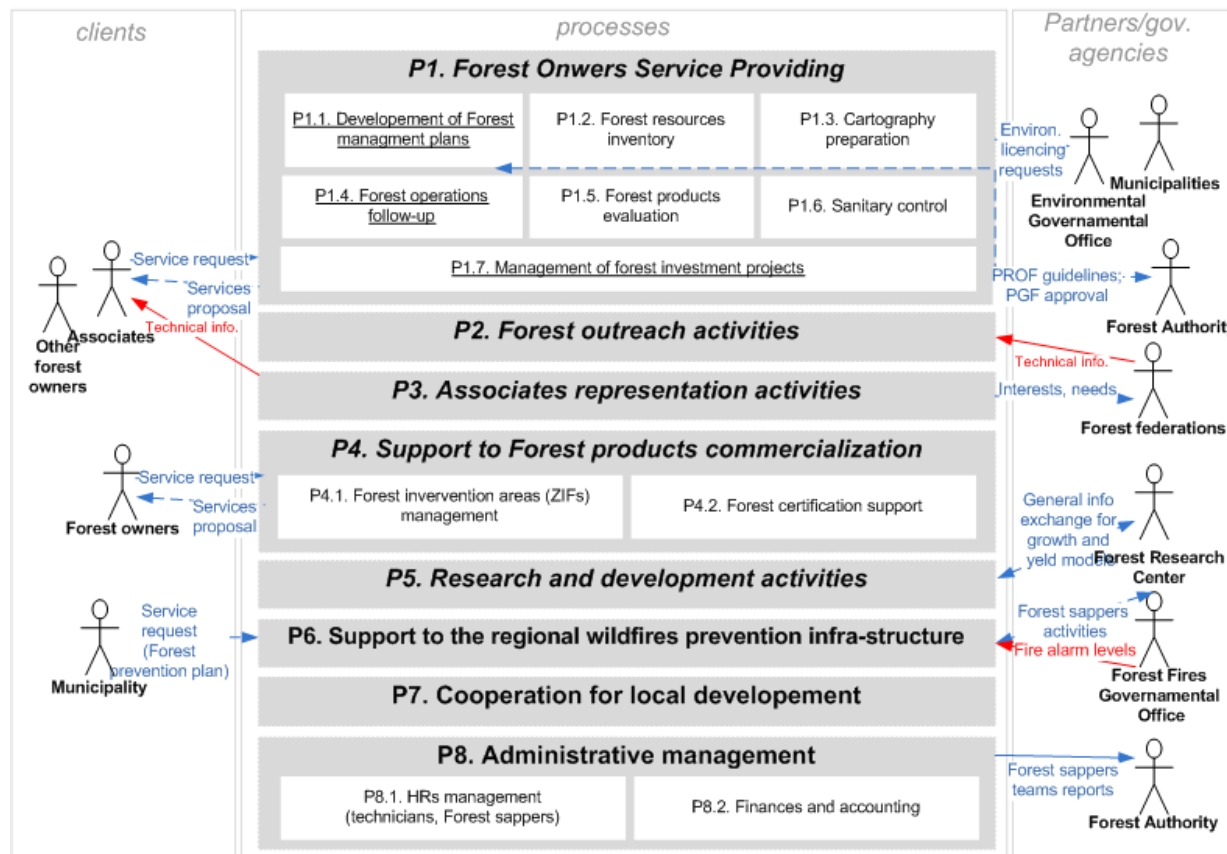
Figure 3 – ACHAR business model
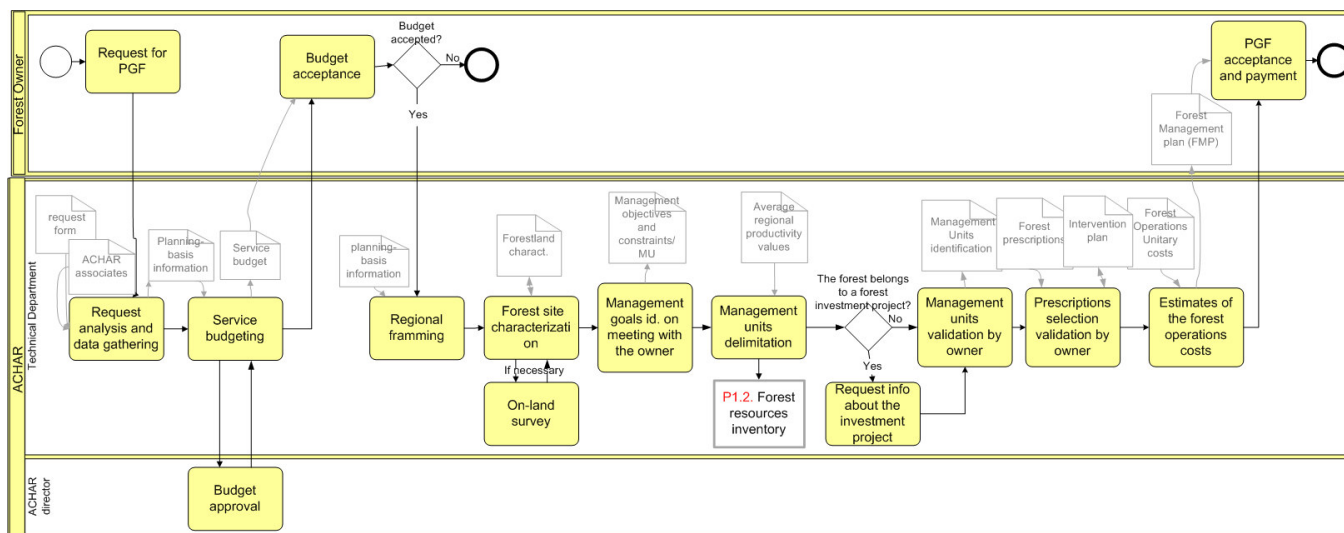
Figure 4 – Process of preparing the Forest management plan (P1.1) by ACHAR after forestland owner request

3rd level

Forest Research Center

Forest research and dissemination

Training

Forest federations

Forest markets and policies follow-up

Associates representation and service providing

Training and education

Forest research

Local communities

Representing the communities interests

Sectorial associations

Representing the associates interests

NGO

Management of forest certification initiatives

2nd level

Forest Service Provider

Forest Operations implementation

Equipment and crews management

Wood trade negotiations

Forest Associations

Forest Owners service providing

Support to forest products commercialization

Forest-based industries

Wood supply planning

Municipality

Licensing forest operations

Processing claims and offenses in forest areas

Forest fire prevention infra-structure planning

Forest Authority (National Office)

Regional forest planning, PGF approval

Forest regulations

Forest investment support

ZIFs management

1st level

Small-scale NIPF

Strategic stand level planning (new plantations, maintenance, harvesting and cork stripping)

Wood trade negotiations

Industry owner large-scale NIPF

Strategic forest level planning (fulfill wood demand)

Operational planning (resource allocation & budget)

Work-order management

Operations control

Forest Investment Fund

New properties acquisition

Strategic forest level planning

Operational planning

Operations control

Forest Authority (Regional Office)

Strategic, forest level planning of public areas

Operations control

Wood auctioning

Figure 5 – Simplified version of the Regional Forest Management Planning Framework, including the main individual decision processes of the stakeholders groups engaged in forest management planning in the Chamusca county

Tables

Table 1 – Stakeholders categories and groups

Category	Group	Entity	Nº representatives	Workshops
Private Sector	Non-industrial private forestland owner (NIPF)	Large-scale intensive	4	WS1
		Medium scale	2	WS2
		Small-scale	1	
		Multifunctional	1	WS2
	Forest associations (FA)	ACHAR – Associação dos Agricultores da Charneca	3	WS3
	Forest federations (FF)	Forúm Florestal	1	WS4
		UNAC - União da Floresta Mediterranica	1	WS4
	Industrial private forestland owner (IPF)	Silvicaima	2	WS5
	Forest-based industry (I)	Grupo Portucel-Soporcel	1	WS6
	Forest Services Provider (FSP)	BETA	1	WS7
	Forest Investment Fund (FIF)	Floresta Atlântica	2	WS8
Public Sector	Chamusca Municipality (M)	Forest technical office	1	WS9
		Civil Protection	1	WS9
	Forest Authority	DRFLVT - Regional Office (FAn)	1	WS10
		AFN - National Office (FAr)	4	WS11
	Local communities (LC)	Junta de Freguesia da Chamusca	3	WS12
Non-Governmental organization	Non-Governmental Organization (NGO)	WWF Mediterranean Programme Office	1	WS13
Research Agencies	Forest Research Centre (FRC)	CEF – Centro de Estudos Florestais	2	WS14
Total	**13**	**22**	**32**	**14**

Table 2 – Matrix identifying the role of each stakeholder group in the regional forest management planning framework. It lists the roles using the categories: Responsible for developing the activity (R), Approves/regulates activities (A), Implements activities (E), Informed about activities (I) and Consulted/provides guidelines for activities (C). The stakeholders groups were: Non-industrial private forestland owner (NIPF), industrial owner (IPF), Forest Investment Fund (FIF), Forest Authority regional office (FAr), Forest Service Provider (FSP), Forest Association (FA), Forest-based industry (I), Municipality (M), Forest Authority national office (FAn), Forest Research Center (FRC), Forest Federation (FF), Local community (LC) and Non-Governmental Organization (NGO)

Forest management planning framework	Stakeholders groups													Total
	NIPF	IPF	FIF	FAr	FSP	FA	I	M	FAn	FRC	FF	LC	NGO	
Forest management setting:														
A1. Defining Management Units	R	R	R	R		E			C	C				7
A2. Defining Production Objectives	R	R	R	R		C	C		C	C	C			9
A3. Defining Other Management Objectives	R	R	R	R		C			C	C	C			8
A4. Defining Management Constraints	R	R	R	R		E		A	A	C	C		C	10
A5. Defining Conservation Actions	R	R	R	R		C				C	C			7
A6. Defining Erosion prevention actions, forest diseases, forest fire prevention	R	R	R	R		E		E	A	C	C			9
A7. Defining Infra-structure maintenance	R	R	R	R		E			A	C	C			8
Resources allocation:														
B1. Forest species selection	E/R	R	R	R		R/E		A	A	C	C			9
B2. Forest prescriptions selection	E/R	R	R	R		R/E			R	C	C			8
B3. Equipment and operations protocol selection	E/R	R	R	R	R/E	0		C		C	C			8
B4. Service providers selection	R	R	R							C				4
B5. Forest products usage and commercialization	R	R	R	R		0	C	C	C	C			C	10
Forest operations implementation:														
C1. Timing of maintenance operations	R	R	R	R		0			I	C				6
C2. Timing of harvesting operations	R	R	R	R		0		R	I	C				7
C3. Timing of cork-stripping operations	R	R	R	R		C			I	C				7
C4. Timing of forest inventory activities	I	R	R	R		R/E			R	C				7
Usage of computerized tools:														
D1. FM optimization	E/R	R	R	R		R/E				C				6
D2. FM tools	E/R	R	R	R		R/E				C	R			7
D3. Risks and climate change simulator	R	R	R	R		C			C	C				7
Context elements:														
E1. Local communities interaction	R	R	R	R	C	0			I		C	R		8
E2. Forest policies and strategies def.		C				C			R/E	C	C			5
Total	20	21	20	19	3	15	2	7	15	21	11	1	2	
%	95%	100%	95%	90%	14%	71%	10%	33%	71%	100%	52%	5%	10%	

Table 3 – Components of the forest management planning RgTbx. It includes the tools needed to support both individual decision processes and the regional interaction network. It further includes the data ownership matrix, presenting how each stakeholder group handled each data and information element(e.g. Create (C), Read (R), Update (U); Delete (D). (*: GIS-based information); The stakeholders groups were: Non-industrial private forestland owner (NIPF), industrial owner (IPF), Forest Investment Fund (FIF), Forest Authority regional and national offices (FAr, FAn), Forest Service Provider (FSP), Forest Association (FA), Forest-based industry (I), Municipality (M), Forest Research Center (FRC), Forest Federation (FF), Local community (LC) and Non-Governmental Organization (NGO)

Decision Support tools	Stakeholders groups													
	NIPF	IPF	FIF	FAr	FSP	FA	I	M	FAn	FRC	FF	LC	NGO	Total
Models/methods:														
Q1. Forest productivity zoning	x	x	x			x	x		x	x				6
Q2. Regional growth and yield models	x	x	x	x		x				x				6
Q3. Fruit production estimation model	x	x	x	x		x			x	x				7
Q4. Cork quality & quantity prediction models	x	x	x	x		x				x				6
Q5. Harvesting/stripping opt. Models	x	x	x	x		x				x				6
Q6. Impacts of fertilization into production	x	x	x	x		x				x				6
Q7. Forest market evolution models	x	x	x	x		x	x		x	x	x		x	9
Q8. Product distribution, routing, storing, etc.		x	x	x		x	x			x				5
Q9. Optimal equipment allocation models		x	x	x		x	x			x				5
Q10. Risk prediction models		x	x	x						x				4
Procedures/documents:														
q1. New forest prescriptions for market goods	x	x	x	x		x			x	x				7
q2. Prescriptions for non-market goods, services	x	x	x	x		x			x	x				7
q3. Forest Management standard procedures	x	x	x	x	x	x			x	x	x			10
q4. Prescriptions for conservation areas	x	x	x	x		x			x	x	x			8
q5. Participatory tools for public forest and ZIFs	x			x		x		x	x	x	x		x	8
Other tools:														
t1. Training courses on planning tools	x	x	x	x	x	x	x		x	x	x			10
t2. Support on non-wood products and services	x			x		x				x	x			5
t3. Collective forest equip. owning/renting	x					x	x			x	x			5
t4. Portable devices for forest surveys	x	x	x	x	x	x	x		x	x	x			10
t5. Online Forum	x	x			x	x		x	x	x	x	x	x	10
Data and information elements														
i1. Municipallity Management Plan*	R	R	R	R		R		CRUD		R				8
i2. Protected Areas*, meteo.*, land uses*	R	R	R	R		R	R		R	R				8
i3. Hunting areas*	R	R	R	R		R			CRUD	R				7
i4. Forest Intervention Zones (ZIF)*	R	R	R	R		CRUD		R	RU	R				8
i5. Historic record of the area burned annually	R	R	R	R		R		R	CRUD	R				8
i6. Regional Forest Management Plan*	R	R	R	R		R	R		CRUD	R				8
i7. BD Regional forest inventory data*	R	CRU	CRU	CRU		CRUD			CRU	R				7
i8. BD product prices	RU	R	R	R	R	CRUD	R		R	R			R	10
i9. BD forest operations costs	RU	R	RU	R	RU	CRUD			R	R			R	9
i10. General info. on forest product markets	R	R	R	RU	R	R	R		CRUD	R	CRU		R	11
i11. BD Service providers characterization	RU		RU			R	CRUD	R		R	R			7
i12. Technical forest bibliography				RU		R	R			CRUD	RU			5
i13. BD Properties and forest operations*	CRUD	CRUD	CRUD	CRUD	R	CRUD		R	RU	R	R			10
i14. BD forest investment support	R	CRUD			R	CRUD			CRUD	R	R			7
i15. Legislation analysis	R	R	R			R	R	R	CRUD	R	CRUD	R		10
i16. Forest sectorial statistics				R			R		CRUD	R		R		5
i17. BD ownership structure	R	R	R			CRUD		RU	R	R	R	R		9
i18. BD conservation interests	RU	CRUD	CRUD	CRUD		CRUD		RU	RU	R	R		R	10
i19. Watercourses and water repositories*	RU	RU	RU	RU		CRUD			R	R	R			8
i20. Forest fires prevention plans*	R	R	R	R		R		CRUD	R	R	R			9
i21. Forest roads*	R	RU	RU	RU		CRUD		R	R	R	R			9
i22. BD Administrative info.	CRUD	R	R	R	CRUD	CRUD					CRUD			7
i23. BD equipments	R	R	R	CRUD	R	CRUD	R			R	R			9
i24. BD licensing requests & Infractions	R	R	R	R		CRUD		CRUD	CRUD			R		8
i25. Wood demand estimates	R	R	R	R	R		CRUD							6

Applying Enterprise Architecture to the Design of the Integrated Forest Products Supply Chain Management System

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Abstract. The forest products supply chains encompass a multitude of agents with independent business processes and information systems. The network of interrelationships and information flows among the agents is often neglected when designing information systems. Common procedures and automatic data exchanges can enhance collaboration as well as improve IT alignment with business needs across multiple organizations in the supply chain. This article proposes an Enterprise Architecture methodological approach for designing an integrated modular Forest Products Supply Chain Management System. Individual system requirements and data flows are driven from the Process Architecture Framework. Results of its application to the forest production, wood logistics and plant supply processes within Portuguese pulpwood, biomass and lumber-based supply chains are presented. Results show that this approach can effectively specify individual systems requirements driven from the processes representations built in collaboration with the agents. It further shows that a data service-oriented architecture can be derived, ensuring business information integrity and systems integration.

Keywords: enterprise architecture, processes, integration, forest management.

1 Introduction

The forest products supply chains (FPSC) can be seen as large networks of activities and agents throughout which the tree products are gradually transformed into consumer products. Forest owners and forest practitioners perform long-term forest operations planning in order to grow mature trees suitable for different utilizations. Yet they have also to either plan short-term harvesting and transportation operations, targeting specific transformation centers, or outsource these activities to entrepreneurs, sawmills or pulp and paper companies as part of forestland rental or harvesting agreements. The latter perform wood procurement medium-term planning in order to fulfill their monthly production plans. The subsequent stage involves a serious of

transformation activities (e.g. bucking, sawing, pressing, and drying) whose by-products are also exchanged among the transformation facilities and sold in intermediate markets. The consumer products are traded by merchants and distributed to specific markets. The distribution and transportation activities are usually conducted by independent service providers. The concurrent supply chain agents (involved in the same activities) usually do not interact, contrary to the frequent data exchanges and process triggering among different-staged agents. Recent integrated supply chain approaches did model the pulpwood flows and the information exchange (D'Amours, Ronnqvist et al. 2008)). Yet fragmented activity modeling approaches and information systems prevail (Ronnqvist, 2003). (Reynolds, Twery et al. 2007) presented an overview of Forest Management Decision Support Systems in use in North America, Europe, and Asia and underlined the importance of end-user involvement and integration for successful development of these systems. Often systems were tailored to meet single agents' business requirements or were developed in the context of research projects that did not need to take into account robustness and scalability for continuous use.

Enterprise Architecture (EA) methodology approaches have been successfully applied to design scalable information systems and integrated multi-activity forest-based systems. It is based on processes' modeling and information characterization (Schekkerman 2009) conducted in Process Architecture workshops with end-users (or supply chain agents). These workshops are instrumental for identifying system requirements to support business processes, ensuring the alignment between business requirements and the Information Technology (IT) function (Sousa and Pereira 2005). (Ribeiro, Borges et al. 2005) demonstrated the EA potential for specifying the Integrated Forest Management System strategic module for a major pulp and paper industry in Portugal (Grupo Portucel Soporcel). (Marques, Borges et al. 2009)) extended this approach to develop an information system for the entire pulpwood supply chain, also in the context of an integrated Portuguese pulp and paper company.

In this article we propose and test an extension of the EA methodology (Spewak and Hill 1992) to involve several agents in the specification of the information system needed to support each supply chain activity. The collaboration between supply chain agents that are involved in different chain segments enables the identification of data exchanges, interoperability and integration requirements of an integrated FPSC Management System. The first component of the proposed approach - Process Architecture (PA) focuses on forest production, logistics, and plant supply processes as well as on the business information of the Portuguese pulpwood, biomass and lumber-based supply chains. It further takes into account the SCOR - Supply Chain Operations Reference Model, proposed by the Supply Chain Council (The Supply Chain Council 2008), in order to develop Process Architecture Framework. Implementation guidelines, best practices and correspondent optimization models are identified for each process. The business information is structured into information entities in the course of the Information Architecture (IA). The third EA component, Application Architecture (AA) is built from previous EA artifacts (Marques, Borges et al. 2009). Namely, it identifies single supply chain activities sub-systems requirements, their data services and the overall interoperability and integration requirements. The fourth EA component, the Technological Architecture (TA) proposes the most adequate

technologies to support each supply chain activity. The proposed approach extends the research conducted by (Ribeiro, Borges et al. 2005) and (Marques, Borges et al. 2009) as it simultaneously addresses the needs of several agents of the three major Portuguese forest products supply chains – pulpwood, biomass and lumber-based products. The common Process Architecture Framework and FPSC Management System requirements were validated by the agents involved in the case study.

2 Material and Methods

2.1 The Case Study

The pulp & paper and lumber & derivates production, with annual sales of 1623×10^3€ and 1131×10^3€ respectively, are key economic sub-sectors of the forest cluster and represent 14% of the GNP, 12% of exports and 9% of the industrial employment (INE, 2007).The seven existing operating units consume annually 5593×10^3m^3 of pulpwood (mainly from *Eucalyptus globulus* Labill) to produce $1833,2\times10^3$m^3 of eucalyptus pulp. Two of these units also consume about 731×10^3m^3 of *Pinus pinaster*Ait. to produce $188,5 \times10^3$m^3 of pulp (CELPA, 2008). Most pulp production targets the European market, although about 45% is internally consumed in two integrated paper production units. These units also absorb the total recycled fiber pulp production ($327,9 \times10^3$ton). The industry is highly concentrated into two major economical groups, with self-owned forestland, thus controlling all the supply chain activities. Together, they are the major Portuguese private forest owners. The harvesting and transportation operations in self-owned of rented forestland are conducted by small-scale service providers. Alternatively, the industry relies on market wood delivery contracts established with local wood suppliers, who independently handle wood procurement, exploitation and transportation. International market supplies, usually carried by boat to the port nearest to the industrial units, allow the industry to overcome national wood shortages.

Contrary, there is a proliferation of traditional, small-scaled, disintegrated lumber transformation units, consisting of more than 250 sawmills and 12 panels production units, distributed mainly in the Center and North regions. These primary transformation units consume mainly *Pinus pinaster*, *Populus sp., Eucalyptus sp.* and other residual softwoods, provided exclusively by local wood suppliers (entrepreneurs). These are crucial business intermediates as they establish multiple contracts with small-scaled private forest owners, conduct harvesting and transportation operations and deliver pre-defined monthly qualified amounts at the transformation units. There is little if any direct contact between the mills and the forest owners. These entrepreneurs also sustain the woodchips (sawmills by-products) supply to the panels units. Wood importation, negotiated directly by the individual transformation units, is gaining importance, especially from Spain, Brazil and USA. The lumber and panels support more than 4500 carpentry and furniture small-scale units, responsible for secondary transformation and consumer products commercialization (AIMMP, 2007).

The recent increase of the biomass sub-sector economical importance justifies its inclusion in this study. In fact, there are currently 6 biomass centrals operating in Portugal, and 4 new units planned until the end of 2010. The majority is located at

pulp and paper facilities. Together they produce 133,6MW from about $1,4x10^6$ton of forestry residues with origin in self-owned forestlands or internal market, usually chipped at the harvesting sites (Celpa, 2009). Up to now, the forest residues were managed independently in small-scale and trail operations conducted mainly by the pulp and paper industries. Its increasing demand fosters the systematic forest residues collection and chipping, preferably integrated with the traditional harvesting operations.

2.2 Methods

The EA approach aims at modeling the three main FPSC, namely their common forest production, logistics and plant supply processes. The nuclear EA team includes forest practitioners, logistic experts and IT technicians. They work in straight collaboration with a consultants committee, consisting of forest production experts and representants of each of FPSC and service providers. An average of 8 experts met in three half-day interactive process architecture workshops. The forest products procurement network was firstly characterized. It identified all product sources and destinations and possible product flows among them. Secondly, the hierarchical Process Architecture Framework was progressively defined, as the EA team and consultant experts designed to common, innovative processes. The process element was the elementary object. Similar to SCOR Supply Chain Operations Reference Model (The Supply Chain Council 2008), the first and second levels grouped the process elements into process types and categories, respectively. The FPSC overall model represented the process elements, their higher level types and categories and the main information flows among them. Each process element was divided into tasks (fourth level), whose input and output information were characterized. These are generic and referential tasks, upon which recommendations, guidelines and system requirements were driven. This level of detail does not allow a flowchart representation. It is suitable up to the fifth process level, were the task is detailed into organization-specific activities and sub-activities.

The process elements input and output information are instrumental for identifying the 22 information entities (IE) of the Information Architecture, in the course of EA team brainstorm meetings. Each IE should have a business responsible for its management and for performing operations such as acquisition, classification, quality control, presentation, distribution and assessment. It was characterized by a single identifier defined from a business perspective, description and a set of attributes (Marques, Borges et al. 2009).

Both process elements and IE were analyzed according to alignment rules (Sousa, Pereira et al. 2005) within a CRUD matrix (Create, Read, Update, Delete). The CRUD matrix manipulation enables FPSC management system modular components identification (sub-systems). Its functional requirements, data repositories, graphical user interfaces and data services were also described by the EA team in the Applications Architecture report. It further included the overall system integration requirements driven from the sub-systems data services and the supply chain agents' interoperability schemas. The FPSC management system technological requirements and development guidelines were discussed in the Technological Architecture report. All EA reports were validated by the consultants committee.

3   Results and Discussion

There are significant differences in production and logistics of eucalypt, pine logs and forest residues emerging from the forest products procurement network (Fig. 1). Both species can came from importation or national market. Currently, the self-owned forests are mainly for eucalypt supply and forest residues. All the products are transported by truck from the forest areas to the destinations. The forest residues transportation requires closed-trailer trucks. The eucalyptus logs railway transportation is frequent from the terminals to the pulp and paper production units.
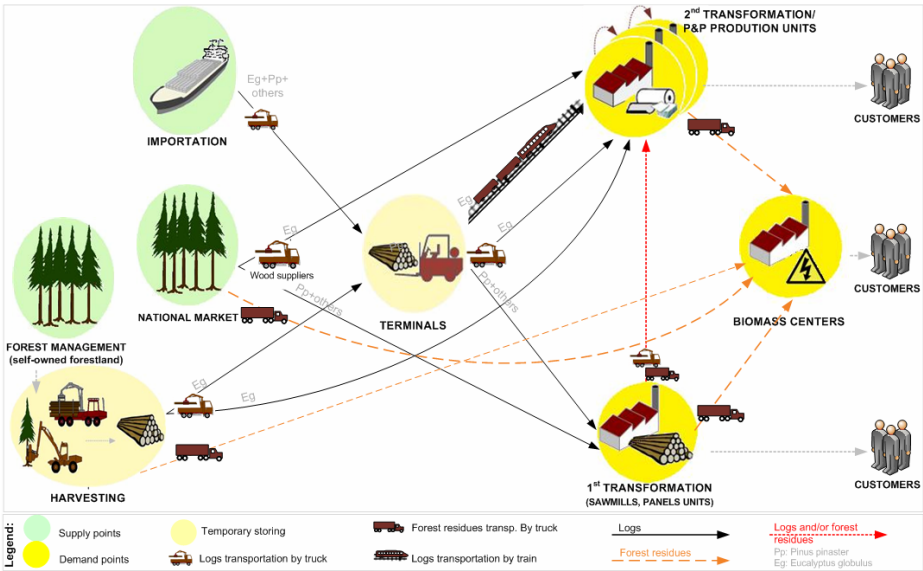
Fig. 1. The Forest products procurement network represents the supply, demand, temporary storing locations, and transportation flows for *Eucalyptus globulus*, *Pinus pinaster* logs and forest residues, considering the forest production, wood logistics and plant supply processes of the pulp & paper, lumber & derivates and biomass supply chains

The forest management (self-owned forestland) supply point is addressed by the process elements included in the Forest Production process type (FPSC Process Architecture Framework, Fig. 2). The forestland management category (1.1.) includes Forest properties registration (1.1.1.), forestland monitoring and protection against biotic and abiotic hazards (1.1.2.), forest inventory periodic inventory (1.1.3.) and new forestland properties acquisition or rental (1.1.4). The forest operations hierarchical planning process elements are included in Forest planning (1.2.). The operations follow-up and annual properties surveys by the forest owners or forest practitioners are grouped into the On-land operations management (1.3.). Specifically for integrated pulp and paper companies, this type includes the internal forest roads management (1.4.), which schedules the roads maintenance operations regarding foreseen harvest operations.
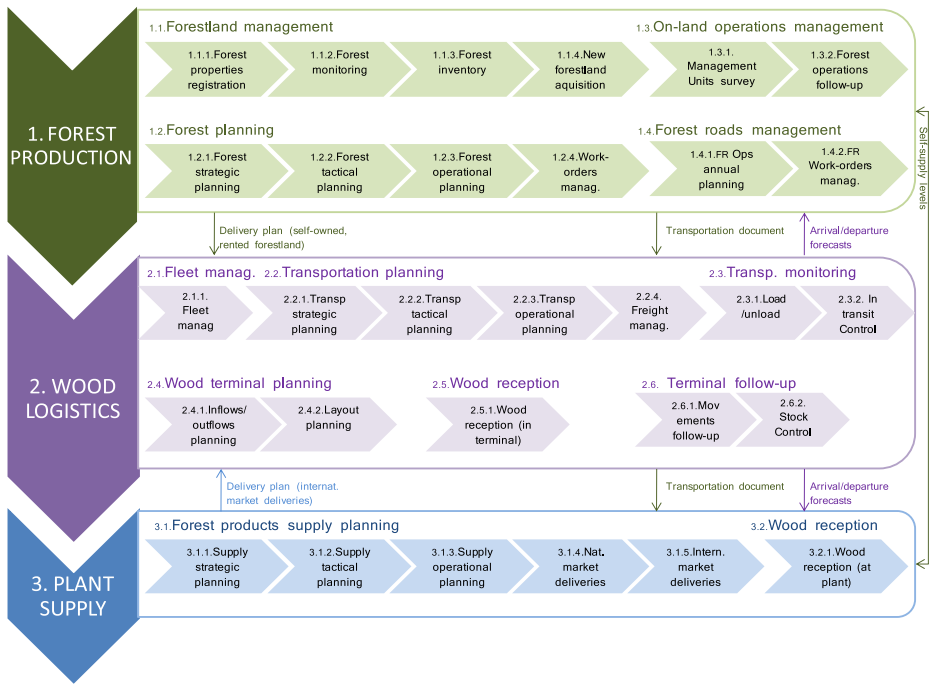
Fig. 2. The FPSC Process Architecture Framework groups the process elements into process categories, displayed into 3 main process types: 1. Forest production, 2. Wood logistics and 3. Plant Supply

The terminal temporary storing, truck and railway transportation flows correspond to the 2. Wood Logistics process type, mainly performed by the service providers, although the terminals usually belong to the transformation industries. Specifically, the fleet management (2.1.), transportation planning (2.2.) and transportation monitoring (2.3.) aim the transversal transportation management, while wood terminal planning (2.4.), wood reception (2.5.) and terminal follow-up (2.6.) control terminals functioning.

The product supply (logs, forest residues) at the transformation units and biomass centrals is commonly addressed by the third Process Type. Thus, the process category Forest products supply planning (3.1.) includes the overall supply hierarchical planning and the logs deliveries from the national (wood suppliers) and international markets. The plant wood reception (3.2.1.) presents similarities with the 2.5.1. process element. Its related tasks, identified in the process description (Table 1), perform trucks unloading and load evaluation based on the anticipation of the next incoming truck, estimated from the arrivals/departures forecasts available from the In-transit control (2.3.2.) process.

All the input and output information flows associated to the Forest Production process elements was grouped into 15 information entities (IEs), namely: Forest Property (E2), Management Unit (E1), Harvesting Unit (E3), Forest road (E15), Forest inventory (E20), Forest hazard (E19), Forest Operation (E4), Forest Plan (E21),

Table 1. Description of the Plant wood reception (3.2.1.) process element

Input information	Task	Output information
▪ *Arrival/departure estimates* ▪ *Transportation document*	3.2.1.1. Anticipate next incoming truck ▪ Estimate arrival date ▪ Provide destination ▪ Notify unloading team and equipment (if needed) ▪ If there is a delay,	▪ *Unloading notification*
	3.2.1.2. Verify truck load ▪ Load quality evaluation ▪ Wood weight	▪ *Load entrance registration*
	3.2.1.3. Truck unload	
▪ *Truck daily schedule*	3.2.1.4. Record truck exiting ▪ Truck exiting date ▪ Update next trip origin (if needed)	▪ *Load entrance registration update*
▪ *Trucks queue at plant entrance*	3.2.1.5. Manage truck queuing ▪ Prioritize and display truck entrance sequence	▪ *Next entering truck*

Work order (E12), Service Provider (E13), Equipment (E14), Crew (E16), Forest Product (E7) and Wood pile (E17). The Management Unit and Forest Operation are manipulated ("Read") by all of these processes. The first is managed ("Create", "Read", "Update", "Delete") by the Forest properties Registration process (1.1.1.) whenever a new property is acquired or a forest hazard, like a forest fire, obliges to new forestland segmentation. Each management unit, usually with a geographical representation, is homogeneous in terms of its characterization and foreseen and executed forest operations, although it can include many different forest properties. The forest operations are planned by management unit (within the forest plans), according to the silviculture models adopted. The on-land operations management processes (1.3.) "Create", "Update" and "Delete" the executed Forest Operations, and associate it to a Management Unit. Some of these IEs are also "Read" by the subsequent supply chain processes. Nevertheless, Logistics processes manage the Transportation Vehicle (E10), Logistic Plan (E22), Freight (E9), Terminal (E6) and Wood load (E18). The freight is the main IE of the transportation monitoring process (2.3.). It is "Created" at the origin (harvest unit or terminal), when a new transportation document is issued and "Deleted" (or sent to historic records) when the truck is unloaded. It includes the time estimates in each origin and destination, which can be periodically updated based on the vehicle real-time positioning. Finally, the Supply Plans (E8) and Wood Supplier (E11) are managed by Plant Supply processes. The Industrial Units are handled by these processes but its information is managed by external systems.

The confrontment between the process elements and EIs within the CRUD matrix and the application of IT alignment rules suggested FPSC management system partitioning into 12 modular components (Fig. 3). The Forest Patrimony Management (S2) and Forest Inventory (S4) sub-systems, adequate for forest owners and forest

practitioners, foresee remote equipments for properties delimitation and on-land data collection. The vast area coverage of the Forest monitoring mobile devices (S3) and the required Operations Central justifies its adoption only by large-scale forest owners (such as the integrated pulp and paper companies) or forest-owners associations. These are also the main users of the Forest planning and operations management sub-systems (S1) and (S5). Forest plans can be integrated with supply plans (S12), in the case of integrated pulp and paper companies, although the simplified versions of the small-scaled forest owners usually do not account for market demands. The transportation planning sub-system (S6) includes the freights and service providers' selection and adjudication, conducted by the Pulp and Paper production units and individual wood providers, as well as the detailed truck scheduling performed by the service provider. The later manages a self-owned or associated vehicle fleet (S7). Similarly, the Transportation follow-up sub-system (S9) provide information on vehicle positioning, which is used for monitoring purposes by the service provider and for load reception anticipation in the terminals and production units. The wood stock control sub-system (S8), encompassing truck load/unload, wood reception and stock control at the terminals, assures wood flows quantitative control across the logistic network, according to integrated pulp and paper companies requirements. The transformation units, including sawmills and biomass centers, perform annual supply planning, based on the targeting production estimates (S12). This is the input for the Wood Supply management Sub-system (S11) responsible for all national and international wood market acquisition activities. The wood load verifications at the plant entrance are similar to terminal reception, which justifies a common module for both processes. Although the terminals, owned by integrated companies, are usually managed independently (S10).
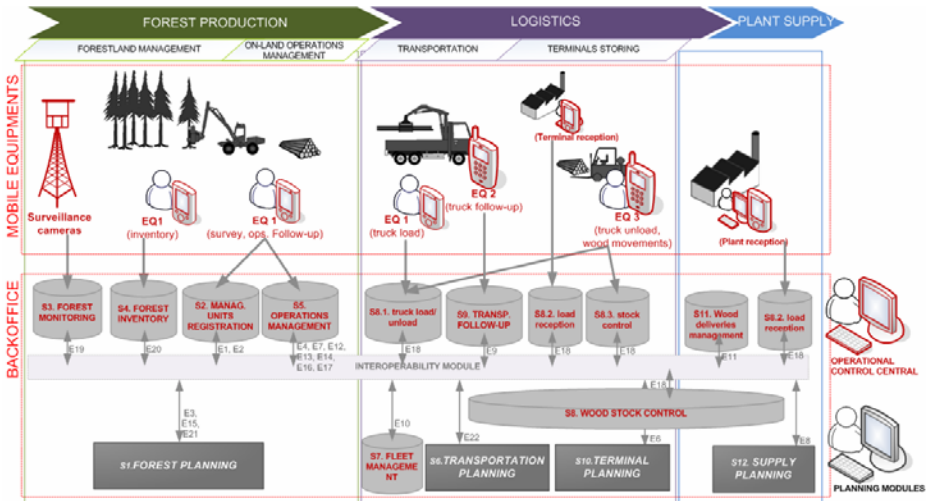
Fig. 3. FPSC management system application architecture diagram, representing the 12 modular components (sub-systems) identified from the CRUD matrix analysis

4 Final Remarks

The EA approach emphasized the overall FPSC management system integration requirements. Preliminary results show the possibility of normalizing macro-scale business processes for several FPSC agents. The proposed Process Architecture Framework constitutes a best-practices reference guide, leading to individual agent efficiency improvements and enhancing its collaboration with the other supply chain counterparts. It can be mapped into individual agent specific procedures. Data services provided by each sub-system were clearly identified. Detailed sub-system functional specifications have been produced and validated by the agents. This enables easier and contextualized system developments, thus reducing the overall IT costs.

Acknowledgements

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