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The Argentinian forest sector: opportunities and challenges in supply chain management

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A B S T R A C T

The rise in the worldwide demand of forest products of the last decades predicts an expansion of the forest harvesting industry. In this context, the Argentinian Northeastern Region (NEA) is considered a promising land since the local forest harvesting industry has one of the largest growing rates in the world. Despite its potential, this region faces some challenging obstacles: budget shortage, trade barriers and poor logistic infrastructure. For instance, traditionally the forest products are delivered by truck, which is from three to five times more expensive than other means of transport, like maritime or river transport. This is why in this paper, after a revision of the most recent advances in the worldwide supply chain management practices in the forest industry, recommendations for Argentina in order to overcome its main drawbacks in the forest sector are presented.

1. Introduction

Worldwide, the forest sector contributes with approximately 2-3% of the world gross product, constituting a business that manages U$160,000 million per year. However, the complexity of the "forest sector" has increasingly grown in the last decades, affected by, among other factors, the climate change, energy policies and market changes, like for example the decline of the consumption of communication paper (printing and writing paper and newsprint) in several industrialized countries at the turn of the century for the first time in history (Hurmekoski & Hetemäki, 2013; Latta et al., 2016). In this evolving scenario, traditional leading countries in the sector, such as North American and Western Europe countries, Russia and Japan (FAO, 2014), have been matched by emerging economies like China, Brazil, India, and Indonesia in regards to forest production (Hurmekoski & Hetemäki, 2013).

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It is well-known that many of the traditional leading countries have a highly developed industrial forestry sector. This, in turn, is supported by specific research that provides the basis for enhancing efficiency in forest operations management. For example, for the case of the Scandinavian region, we can find Östlund et al. (1997), who analyze the impact of the forest management of the last century on the Scandinavian forests, and Näyhä et al. (2012), who propose the main guidelines for the installation of forest bio-refineries for in this peninsula. Examples can be found in North America, such as Bergeron et al. (2004), who study the impact of fire frequencies of the last decades on sustainable industrial forest management, or Cyr et al. (2009), who propose an analysis of the ages of the North American forest heritage to predict the future heritage of the forest according to forest management policies. For the case of the forest industry, especially sawmills, important contributions can be found, for example, in the works of Gaudreault et al. (2010), who propose a series of models for the integrated planning of the production of different processing units. Saadatyar (2013) and Sohrabi (2013) propose a management tool based on the generation of "production campaigns" based on raw material, product prices and cutting schemes. These works were preceded by others who started this line of research, such as the cases of Todoroki and Rönnqvist (2002), Faaland and Briggs (1984), Geerts (1984), who sought to determine an optimal production plan taking into account all the components that affect the process of wood transformation.

In 2014 the global production of roundwood was calculated in 1,837 million m^3 (Food and Agriculture Organization of the United Nations, 2014). From this amount, about 90% has been taken from native forests. On the one hand, this situation has attracted the strong criticism of environmental organizations. However, on the other hand, this represents a golden opportunity to continue enhancing forest industry in countries that have high growing rate of planted forest, such as Argentina, Brazil, Chile and Uruguay. Therefore, the objective of this paper is to, based on the experience and surveys carried out by the authors, propose the main guidelines for enhancing the forest sector in Argentina, and others sub-tropical countries in order to take full advantage of its potential. For this, initially we present a revision of the main present practices in forest management and a thorough description of the current state and challenges of the Argentinian forest sector in order to, finally, perform some recommendations for the sector.

This work contributes with the description of the logistic competitiveness of the forestry sector of a specific region, i.e., the Argentinian Northeastern Region (NEA), highlighting its main strengths and weaknesses and a comparison with its neighboring countries, which are its main competitors. Finally, after the description of the sector showed the limit usage of Decision Support Systems (DSS) tools, we revised the application of DSSs in other parts of the globe as a mean to enhancing the sector competitiveness through the optimization of the resources usage.

This paper is structured as follows. In Section 2 the general forest supply chain is described along with several applications of DSS to the strategic, tactical and operational planning levels of the sector. In Section 3 the current state of the Argentinian forest industry is presented. In Section 4 the actions and research lines that should be encouraged for the sake of the Argentinian forest sector are proposed. Finally, in Section 5 the main conclusions of this work are outlined.

2. Supply chain in the forest sector

The Supply chain consists of all the parts involved directly or indirectly with the satisfaction client's requirements. This involves suppliers, warehouses, production, distribution, retailers and final clients. The management of the supply chain can be defined as the planning and implementation of the activities that enable the satisfaction of the client's demand as well as the monitoring of those activities. Thus, supply chain management comprehends the flow of both freights and information, from the beginning of the chain to the final element: the client. Fig.1 shows a scheme of a forestry supply chain, in which the freights flows correspond to woody products.

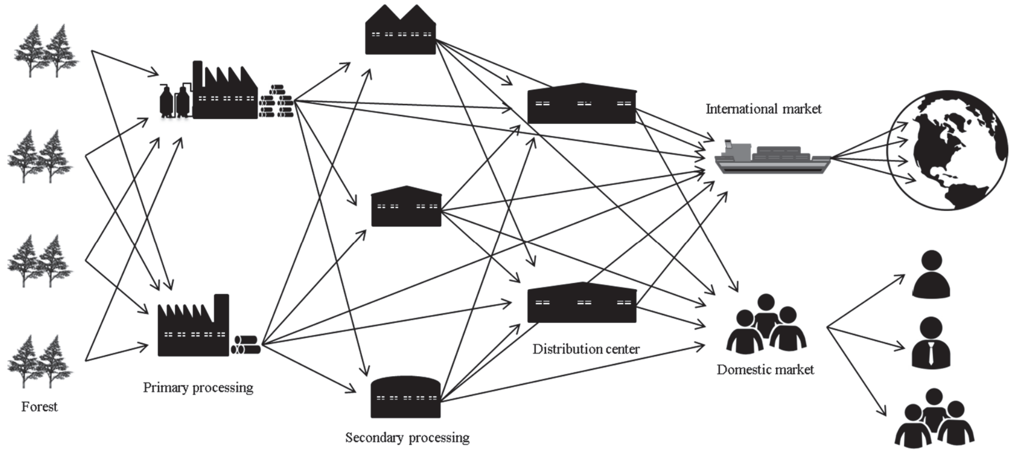

Fig. 1. The supply chain management for forest sector in Argentina

The first component of the supply chain in Fig. 1 is the forest with standing trees. These trees are harvested and bucked according to the type of demand that they may fulfill. These raw forest products are delivered to the so-called "primary processing" industry in which an initial industrialization is performed. From primary processing several products are obtained, e.g., pulp, sawed wood, plywood and boards (Broz, 2015). The destination of these products depends, again, on the specific type of demand. Some of them can be directly sold as exportation freights in order to be processed abroad while others can continue to the so-called "secondary processing" or remanufacturing. The secondary processing adds value to the products through the performance of more specific operations. After this, the final products are delivered to the distribution or exportation centers where they become available for retail customers.

2.1. Support for decision-making and planning levels

One of the main characteristics of forestry systems is the low flexibility in the raw material generation, which is regulated by the period of time it takes a tree to grow until it reaches a proper size for its industrialization. In Argentina, a rotation turn for coniferous takes around 15 years, depending on the economic opportunity to carry out the logging (Milanesi et al., 2013 and Milanesi et al., 2012). However, in general, the rotation turn varies from 13 to 22 years, depending on the variety of tree and the expected output products.

These aspects enhance the importance of planning in the forest industry. For example, an error of over-exploitation due to a weak planning in one year will imply several years of under-exploitation due to the large period of time that it takes a tree to grow, affecting the economic performance of the system in the long run. Therefore, forestry supply chain activities must be rigorously assessed and planned. Therefore, it is almost impossible to address this type of management without tools that helps and support managers. Operations Research has generated a great number of tools to support the decision-making processes for the most varied scenarios and systems (Hillier and Lieberman, 2010). Forestry systems is an active field of study for Operations Research (Weintraub et al., 1996; Martell et al., 1998; D'Amours et al., 2008; Rönnqvist et al., 2015). With this aim, forestry management community considers that a proper method for planning starts with the establishment of a hierarchy of the different decisions that must be taken according to the planning horizon they affect. Normally the hierarchy of decisions is categorized in three levels: strategic, tactical and operational. We present literature review of some recent and remarkable contributions of the Operations Research to forestry supply chain management, taking into account this three planning levels.

2.2.1. Strategic level

In the strategic planning, the time horizon is at least a turn of forest rotation, what in Argentina is in general 18 years (Broz et al., 2016). However, in others ecosystems the strategic time horizon is larger than 80 years (D'Amours et al., 2008). For strategic planning, long run forecasts about economic, social and ecological consequences of the activities are taken into account. Traditionally, the strategic forestry planning focuses on the interaction between decision-making process and the sustainability of the wood supply and economic viability of the forest in the long run. However, in the last years social and environmental issues are becoming more relevant at this planning stage. In general, the strategic planning involves decision related to the large scale production, land use and plantations management (Bettinger et al., 2009), as well as the construction of industrial plants, e.g., sawmills, long-term investment flows (Milanesi et al., 2014), product design and stock management (D'Amours et al., 2008). Also, government legislation about biodiversity and land use must be contemplated at this planning level.

As mentioned, this level can vary significantly considering the geographical region analyzed. When the turns are short, the time horizon of this level can include several rotations turns. Conversely when they are too long, it can include only a portion of the rotation turn (Broz, 2015). Then, determining the horizon length is a critical issue. In this sense, Broz et al. (2014) and Milanesi et al. (2013) propose a real options approach as a financial-economic tool to define the optimal turn. It considers stochastic average sell prices for the products, considering that the prices follow a Brownian geometric stochastic process, a discrete time representation and the use of binomials grids based on the model's parameters. This approach provides the optimal turn for each stand, but it does not enable the integral management of the whole system. For overcoming this barrier, linear programming models are more suitable (Broz, 2015).

Concerning more specific forest planning problems, Díaz-Balteiro and Romero (2003), studied a planning problem which considers a time horizon of 100 years, dividing it in periods of 10 years. The planning process accounts several criteria of performance among them, the maximization of Net Present Value (NPV), the carbon balance between the carbon released by forestry activities and the carbon sequestered by the trees growth. The problem was represented as a goal programming model and solved by LINGO. They used real data from Spanish forests. Another case is Gunnarsson et al. (2007), where the entire supply chain is modeled with mathematical programming. The model provides optimal plans for transportation of raw materials from forest to pulp mills, for the production mix at pulp mills, for delivering pulp products to customers and for the selection of potential client orders. Chauhan et al. (2009) optimize a two-echelon timber supply system where the first echelon considers the harvesting stands and the second echelon considers a group of mills. The objective function is to minimize costs (harvesting and transportation) while meeting demand constraints. For large instances the authors developed a branch-and-price algorithm that performs correctly. Shabani and Sowlati (2013) and Shabani et al. (2014) address problems of energy generation from wood biomass. The supply chain is presented in mixed integer non-linear programming model and solved with an approximation algorithm. The objective considered is improving cost competitiveness. Milanesi et al. (2014) study forestry systems under variables scenarios from an investment perspective. For this, fuzzy logic methods are applied for weighting possible scenarios and assess ROV (Real Options Value) for each case. The forestry system studied is the Argentinean Northeast with a planning horizon of 20 years. Paradis et al. (2015) tackle the wood supply for industrial consumers. The authors present a two-level formulation for this NP-hard, non-linear and non-convex problem. They decompose the problem into convex sub-problems, which also provide a global optimum. The obtained solution shows a low risk of wood supply failure (Paradis et al., 2013 and Paradis et al., 2015). In Troncoso et al. (2015), a vertical integrated supply chain is presented. The supply chain is modeled through mathematic programming with the aim of supporting decisions from harvesting to primary and secondary wood processing. Decisions are influenced by production and transport costs, and the best solution is evaluated according to its NPV. A special feature of this work is the joint consideration of strategic and tactical planning levels. First the strategic performs the plan and then suitable tactical decisions are taken for that plan. In Broz et al. 2016, a strategic multi-objective planning problem for Argentinean forestry sector is addressed. In this problem, the supply of the primary processing industries is modeled. The objectives considered are the maximization of NPV and maintaining a certain balance between the carbon release-sequestration, the harvested volume balance and the distance covered of each year in the planning horizon. The relative importance (weights) of each objective is determine through a survey that collected the opinion of several experts and is used as an input for an extended goal programming model. The problem was solved with CPLEX.

2.2.2. Tactical level

Once the long-term strategy is defined, a lower planning level is addressed: tactical level or mid-term planning. On this level, the planning horizon varies from 1 to 5 years. The tactical plan uses accurate information about spatial and growing characteristic of the stands, in order to have a detailed panorama of the living stock. Basically, it disaggregates into the different stands the strategic lineaments stated for the gross forest (Bettinger et al., 2009). To define which stand must be harvested is necessary to specify which demand (primary processing) is going to be satisfied. Distribution and production features are also considered as well as the stock policy in the different phases of the supply chain (D'Amours et al., 2008). Therefore, the tactical plan works as a concrete linkage between the long-term strategies and short-term operations that will impact directly in the supply chain activity.

On tactical level, operations are programmed defining areas in a shorter time scale (Martell et al., 1998). As well as the strategic planning, the planning horizons for tactical level vary depending on geographic conditions and company's organization policies. It can go from 2 to 20 years. For the Argentinean case the planning horizon for this level does not go beyond 5 years.

Díaz-Balteiro and Romero (1998) present a multi-objective model for a tactical harvesting plan. The goals studied are NPV maximization, inter-annual harvested volume balance and obtaining desired characteristics in terms of tree ages and volume at the end of the planning horizon. The authors developed a method based on Analytical Hierarchy Process (AHP) for including goals preferences. In Andalaft et al. (2003), a Chilean forestry system is analyzed from a tactical perspective. The decisions involved in this work are to define when (and in what manner) each stand should be harvested in order to satisfy each client demand and when (and with which quality) roads should be built regarding the planned flow. The objective optimized is NPV and the entire system is presented as a mixed integer programming (MIP) formulation. For solving the problem formulation strengthening and langragean relaxation are implemented. In Ferreira et al. (2011) uncertainty is incorporated into a tactical planning. The kind of uncertainty considered in this paper is about fire happening on *Pinus pinaster* Ait and *Eucalyptus globulus Labill* for Portuguese forests and the objective is to maximize the economic value of the forest. In Nguyen (2012) a stochastic forestry management problem is tackled, where, again, the stochastic process assessed is fire occurrence. The proposed approach starts with the deterministic formulation of the problem and then, the expansion to stochastic programming through the method Sample Average Approximation (SAA from Bevers, 2007). The problem modeled in Andalaft et al. (2003) is revisited with the difference of including market uncertainties and natural variations in future growth and yields. For this, a stochastic programming formulation is presented and for solving a scenario -based approach is used. The scenario-based method used for tackling the problem is the progressive hedging algorithm (Watson and Woodruff, 2010), which solves integer problems heuristically. Bouchard et al. (2016) present an integrated –strategic and tactic– planning model to support forest planning on the long term with anticipation of the impacts of the economic and logistic activities in the forest value chain on a shorter term. They propose a novel optimization approach that includes acceleration strategies to efficiently solve large-scale practical instances of this integrated planning problem.

2.2.3. Operative Level

In the short-term horizon, planning turns operative and the actual activities that will allow to meet the objectives of the supply chain are particularized. This time horizon can be from a period of days to week or months. What operational planning pursues, is to indicate what and where must be done and individualize who is the person in charge of the activity. The tricky part of this level is the overwhelming amount of detailed information that this type of planning can have, which, if it is incorrectly managed, can make it intractable. Some of the typical activities that correspond to this planning for the primary links of the chain are: optimal bucked of harvested logs, location of harvesting and transport equipment, and the transport to the following chain links. In the production shop floor, many of the decisions are related to scheduling problems, plus the supply of the different plants. It is well known the high complexity of these decision processes, this decision process must be done professionally and consistently.

At operative level the tactical plan execution is organized, thus, short-term operations are programmed with more details. For Epstein et al. (2007) and Mcdill (2014) decisions involved at this level should indicates which stands to harvest, the bucking strategy, harvesting equipment location, road building and maintenance and production delivering. The operative planning horizon, once more depends on the geographical regions, and generally, varies from 1 to 5 years, being 1 year a proper planning horizon for Argentinean forestry supply chain (Broz, 2015).

In Karlsson et al. (2004) an annual planning problem is presented considering Swedish firms. The problem includes restrictions that considers the different climatic conditions throughout the year, the mix of products and transport logistic infrastructure issues. The harvesting costs are described for each stand and forest roads are defined considering groups and hierarchies over stands. The goal optimized is to minimize global operational costs. Beaudoin et al. (2007) presents a MIP model that maximizes revenues from selling wood and wood-chips of five different tree species. This model is extended to a stochastic version by applying a Monte Carlo process and a method that allows to consider transport costs. The stochastic version of the problem outperforms the deterministic one. In López et al. (2008), an operative plan is performed for pulp supply chain in order to minimize operational costs through Mixed-integer Programming (MIP) formulation. From a base case, several different scenarios are generated and evaluated. The results show that the stand area is a critical parameter in the performance of the operative plan. Yu et al. (2014) expose a model for the energetic supply chain considering three levels. At the upmost level there are the stands, then the pre-treatment stations and finally the power plants. The objective involved is the overall cost minimization, which includes harvesting operations, transport, pre-treatment of biomass and stocking. The model is presented as a MIP formulation. Rix et al. (2014) define a model for the annual harvesting operations where the objective is to minimize transport and stock costs. As a special feature, authors implement a penalization for products out of specification and for unsatisfied demand. The problem is modelled through a MIP formulation and it is solved with a branch and price algorithm.

3. The Argentinian forest sector

In this section an analysis of the advantages, challenges and obstacles of the sector is carried out with the objective of showing the existing scenario, and thus, to contribute in the generation of tools that help in the decision making process that improve the efficiency of the forestry sector in Argentina.

Despite not been among the main worldwide forest producers, Argentina has about 33,000,000 hectares of native forest and 1,128,411 hectares of planted forest. Although that in some regions the sustainable management of native forest is under heavy debate (Gasparri & Grau, 2009; Carabelli et al., 2007), the planted forest in Argentina has a growing rate of 40,000 hectares per year. For some particular tree species, the production rate is highly competitive; in the case of *Pinus spp.* and *Eucalyptus spp.* this value is about 35 and 45 m^3 per hectare per year respectively, which is a rate from six to ten times higher than those that can be obtained in North-America or Europe (Prosperi, 2013). This is due to favorable climatic and soil conditions, especially in NEA region. In Fig. 2, information about growing rates of different countries is presented. Table 1 shows the yields and rotations age of the main planted species in Argentina.

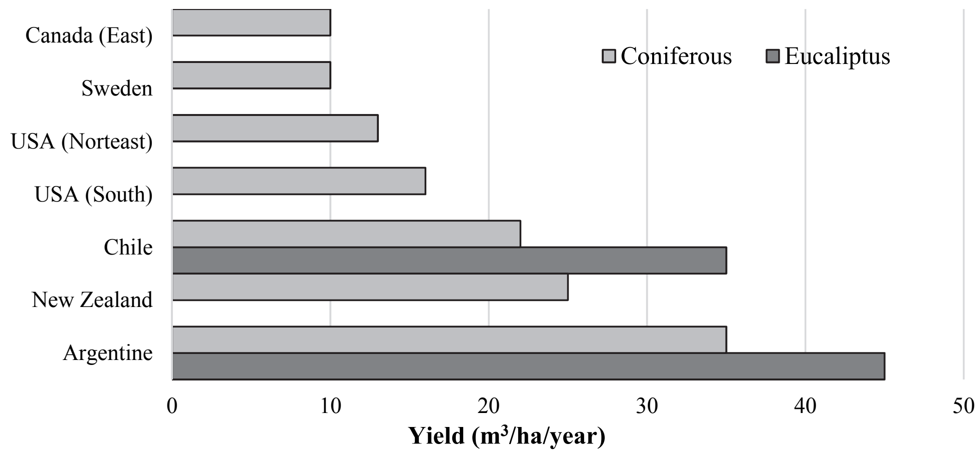

Fig. 2. Comparison between the growing rates for different wood-producer countries (Institute of Studies on the Argentine and Latin American Reality, 2011).

Table 1
Yields and rotations of the main planted species in Argentina. Source: Ministry of Agroindustry of Argentina (2015b)

Species	Rotation (years)	Yield (m^3/ha/year)
Eucalyptus grandis	8-15	35-50
Araucaria angustifolia	25-30	15-18
Pinus elliottii	18-20	20-25
Pinus taeda	16-20	20-40
Pinus ponderosa	35-45	14-25
Prosopis alba	20-25	
Paulowina sp.	10-15	18-22
Melia azedarach	12-15	
Salix sp.	10-12	20
Populus sp.	10-12	23
P. elliottii × *P. caribaea var. hondurensis* (Hibrid)	12-16	30-40

Fig. 3. Distribution of industrial forest plantation in Argentina (green areas). Source: Ministry of Agroindustry (2017)

Furthermore, according to Prosperi (2013) Argentinian potential surface for planted forest can be extended up to 40,000 million hectares, what makes Argentina a potential highly competitive country in the forestry sector. Fig. 3 depicts the distribution of industrial forest plantations in Argentina and Fig. 4 shows the evolution of roundwood production between years 2000 and 2014.

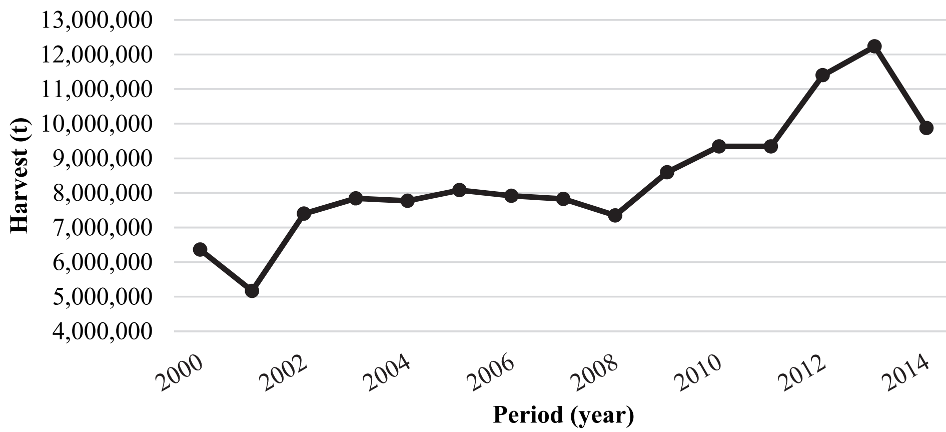

Fig. 4. Argentinian roundwood production from planted forest per year (in miles of tons). Source: Ministry of Agroindustry of Argentina (2015a).

The main cultivated species in terms of the percentage of Argentinian wood production are pines, mainly *Pinus elliottii* and *Pinus taeda* but also *Araucaria angustifolia*, *Pinus ponderosa* and *Pseudotzuga menziesii*, about 64% of the total wood production; Eucalyptus about 23% of the wood production, mainly *Eucalyptus grandis* and *Eucalyptus saligna* but also *Eucalyptus camandulensis*, *Eucalyptus tereticornis*, *Eucalyptus viminalis* and others; Salix and Populous about 9% of the wood production, where *Populus deltoides* and *Populus* × *euroamericana* are the most cultivated species among Populus. *Salix babilónica* var. sacramenta, *Salix nigra*, *Salix babilónica* × *Salix alba* and *Salix matsudana* × *Salix alba* are the Salix species most cultivated; and the last 4% is composed by other less important species, such as *Grevillea spp*., *Paulownia spp*., *Melia spp*., *Robinia spp*., *Prosopis spp*. and *Toona spp*. (Prosperi, 2013). Among the twenty-four Argentinian administrative divisions (so-called provinces), the three main provinces of the NEA region, i.e., Misiones, Corrientes and Entre Ríos, concentrate almost the 78% of the forest plantations of the country. According to the Ministry of Agroindustry of Argentina (2015b), about 85% of the Argentinian production is concentrated in the NEA. From the 300,927 new hectares that have been planted in Argentina in the last decade, 67% were settled in Corrientes and Misiones. This increment in the planted area have led to a rise of planted wood production that is supported by the presence of about 1,000 industrial factories, which are mainly (about 98%) small and medium enterprises (SME).

Table 2
Production level and number of industries in Misiones province according to industry size. Source: SIFIP (2012)

Sawmill classification	Wood production (foot^2/month)	Amount of industries
Small	0- 21,200	521
	21,200-31,300	44
	31,300-63,600	74
	63,600-127,200	41
	127,201-254,000	21
Medium	254,001-305,000	23
Medium to large	305,001-1,484,000	4
Large	>1,484,001	3
	Total	731

Table 2 shows the production level and number of industries in Misiones province according to the classification proposed by SIFIP (2012). This explains the large number of direct and indirect jobs produced by the forest sector in Argentina. According to a recent report (Schwarz et al., 2015) the forest industry employs about 69,000 people directly and indirectly. Therefore, the forest industry represents the main economic activity for several families of the NEA's territory (Schwarz et al., 2015). However, several of this people are employed in low quality jobs. In Table 3 the forest plantations distribution classified by tree variety and province are shown.

Table 3
Forest plantations distribution in Argentina. Source: Ministry of Agroindustry of Argentina (2015b).

Province	Area by tree species (hectares)				Total (hectares)
	Coniferous	Eucalyptus	Salix-Populus	Others	
Misiones	306,592	10,557		35,243	352,392
Corrientes	263,268	108,985		1,016	373,269
Entre Ríos	20,174	106,281	26,967	577	153,999
Buenos Aires (Delta)	27	29	57,539	78	57,673
Mendoza			7,900		7,900
San Juan			457		457
San Luis	46		75	29	150
Neuquén	60,721		1,522	727	62,970
Rio Negro	5,235		1,145	248	6,628
Rest of the country	71,197	29,151	2,288	10,337	112,973
Total country	727,260	255,003	97,893	48,255	1,128,411

Moreover, Argentina has a remarkable potential to expand its cultivated area without interfering with agriculture, which is one of the most important economic activities of the country (De Renolfi, 2005; Prosperi, 2013). Additionally, the price of the land for agricultural use is one of the lowest in the world (Prosperi, 2013; SAGPYA, 2001).

3.1. Forest-industrial chain of value in Argentina

The forest-industrial chain of value in Argentina starts in the logs extraction of roundwood and has two major processing stages. Fig. 5 gives a general scheme of this chain of value with the different intermediate and final products. Synthetically, the raw material, e.g., roundwood, undergoes a first industrial processing that can consist in either a mechanical transformation or a chemical transformation. The chemical transformation produces pulp that will go directly to the second processing stage to produce paper and cardboard. The mechanical transformation is slightly more complex having intermediate products, i.e., chips, laminated wood and sawnwood, and final products, i.e., particle board, fiberboard, plywood, and edged and measure wood. The residues and part of the chips are used to generate energy. These final products of the first industrial stage are used as inputs for the second processing phase, where they are destined to other industries (paper, cardboard, plywood, edged and measured wood) or to final consumption (construction and flooring).

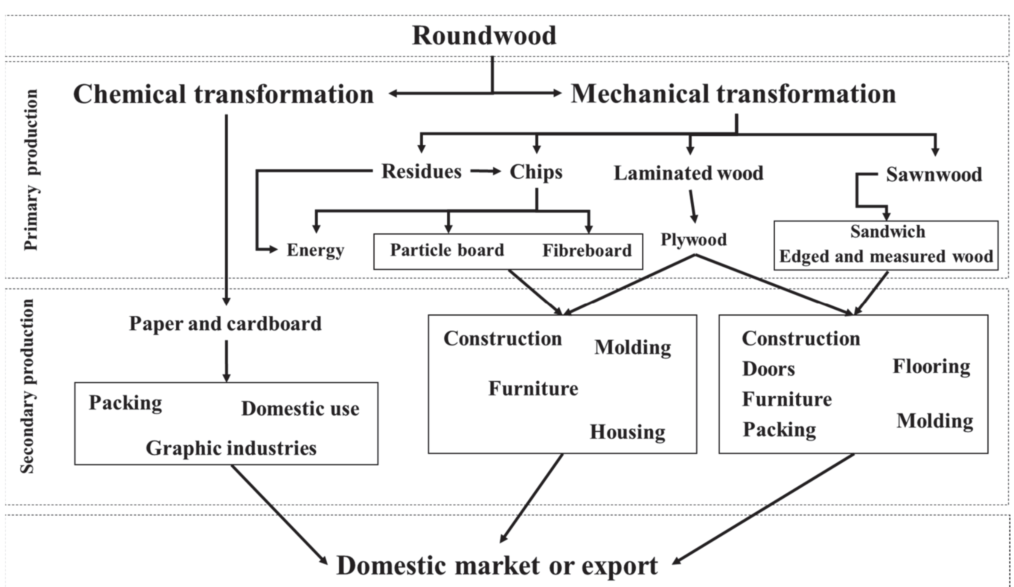

Fig. 5. Forest-industrial chain of value scheme in Argentina

Although all these favorable aspects, the lack of investments, either in industrial production or in management technologies, and the extremely high logistic cost are huge drawbacks of the NEA's forest sector and affect competitiveness of the products for domestic consumption and exportation.

3.2. What is the situation in the neighborhood? The forest sector in other South-American countries

South-American countries share several cultural, social and political characteristics. This is why we consider that a comparison between Argentina and is neighboring countries is fairer than a comparison to other world forest producers from distant regions. In this sense, it is important the contribution of Mac Donagh et al. (2017) that made a thorough description of the characteristics of three South-American countries (Brazil, Argentina and Uruguay). Jones et al. (2017) made an analysis of the forest sector sustainability in South America making some important recommendations for the sake of the sector.

Brazil is one of the major forest producers worldwide, having more 7,800,000 cultivated hectares. The main tree species are the *Pinus spp* and *Eucalyptus spp* and the wood is mainly used for pulp, sawnwood, energy, charcoal and rubber production (IBA, 2016). According to ICyP (2012) the Brazilian cellulose industry and the paper industry represent the 7.6% and the 2.5% of global production respectively. Both industries explain around the 4% of the Brazilian GDP. Even though this impressive panorama, Brazil also experiments several logistics problems (Garcia-Escribano et al. 2015; Espach, 2006), some of them similar to the Argentinian case, such as poor infrastructure and high transport costs that have not been completely sorted out yet despite the government efforts.

Chile has a planted area of 2,300,000 hectares, which are mainly composed by *Eucalyptus spp* and *Pino radiate* (Mc-Manus, 2012). According to Mc-Manus (2012), the forest sector explains the 5.3% of Chilean GDP, being one of the main exports and employment creation sector. Chile, in opposition to its neighbors, has a competitive logistic cost based mainly on its developed infrastructure and beneficial geography (González et al. 2008). However, the country has experienced some problems that affect the sustainability of the sector. On the one hand, environmental impact due to the massive reforestation with exotic species and, on the other hand, social impact due to the competition for the land used with aboriginal communities (CONAF, 2015).

With around 1,000,000 de hectares, Uruguay is the last country in the area to initiate a large scale promotion of industrial forests (Morales & Siry, 2009). The forest industrial sector of Uruguay, that is mainly composed by huge vertically integrated companies (for example, UPM, Montes del Plata and Weyerhaeuser), explains the 2.6% of the Uruguayan GDP, being responsible of more than 15,000 direct jobs (Uruguay XXI, 2016). The main tricky issues that this country experiment are the lack of adequate infrastructure and sustainable territorial management policies (Silveira et al., 2016; Six et al., 2014).

3.3. Logistic problems in Argentina

According to González et al. (2008) the logistic cost, that is composed mainly by transport and stock expenses, in Argentina represents about 27% of the Gross Domestic Product (GDP), in Brazil 26%, in Colombia 23%, in Chile 18%, in USA 9.5% and in the Organization for Economic Co-operation and Development (OECD) 9%. Similarly, the calculates logistic cost in Argentina represents 30% of the Free on Board's value (FOB), 17% in Uruguay, 9% in Brazil and 7% in Chile; i.e. exporting a container of wood from Misiones (Argentina) is about three or four times more expensive than exporting it from Chile or Brazil respectively (Asociación Forestal Argentina, 2015).

As mentioned before, the most important Argentinian forest production is concentrated in the North-East of the country. However, the main export ports are located in the central region, i.e., provinces of Santa Fé and Buenos Aires. The infrastructure that links these two regions is poor and is composed mainly by terrestrial roads (Schwarz, 2014). If we consider that, usually, the wood production in Argentina has to travel on average 1,200 km to the consumption or export centers, and that the majority of the transport in Argentina is done by trucks, which has a relative high cost per shipped unit compare to ships or trains. For example, in an informal survey among companies in the sector, the managers stated that transporting a load of wood from the Misiones province, in the north of the NEA region, to Buenos Aires port costs USD 3,000 while the transport cost from the Buenos Aires port to its main export destinations varies between USD 1,000 and 1,500. It is easy to realize that the competitiveness of the Argentinian forest sector is highly restricted. Therefore, it is urgent to consider the development of other means of transport that reduces the logistic costs.

In order to improve the connectivity between producers and the ports, one of the most promising alternatives is to expand the use of the river transport (Moiraghi, 2011). The North-East of Argentina is crossed by the river basin "Cuenca del Plata", that is the third biggest in the world and extends through the territories of Argentina, Bolivia, Brazil, Paraguay, and Uruguay, reaching a longitude of 3,442km. The Argentinian use of this aquatic network, despite a promising impulse in the 1990s with the creation of numerous ports along the rivers encouraged by special government policies (Schweitzer, 2013), has been affected in the last years by regulation disagreements between the countries that share this river basin and the lack of investment to provide the suitable sailing conditions. From the two main rivers that cross the region, i.e., the Paraná and the Uruguay rivers, only the first one is considered suitable for the commerce since the Uruguay river has an inadequate draft for large vessels and some unavoidable obstructions, like the Salto Grande dam (Schwarz, 2014). In 2002 the only port in the region that had the proper infrastructure to allow vessels trade was the port of the city of Corrientes (Moiraghi, 2002). Unfortunately, this situation has not changed much in the last decades. Only the renewal of the port of the city of Posadas (Schwarz, 2014) and the project for building a port in the city of Itá Ibaté generate some positive expectations for the near future.

Similarly to the river transport, the train, that used to be an important mean of transport in the past through the railway "General Urquiza" that links the North-East of the country with the main ports of the central region, is not reliable for transporting the products due to the lack of proper investments (Carro Donna, 2016; Schwarz, 2014). The project for revitalizing this railway is still in its initial phase.

Consequently, one of the most common mean of transport in Argentina is the truck. Cañete (2011) states that eight out of ten products of any economic activity use the lorry at least two times throughout their value chain. The route network of the North-East of Argentina is composed mainly by two national roads and a few regional ones. However, this network is inadequate for dealing with the increasing trade of wood products (Schwarz, 2014). Additionally, the freight cost of lorries is three or five times higher in comparison with the one of the train or ship respectively (Martinez et al., 2014). For instance, the transport cost of shipping a container of 20ft. and 10t to Buenos Aires from Singapur or Shangai, more than 15,000 km, is cheaper (U$1,800) than transporting it from the Argentinian northwestern city of Salta (U$2,200), around 1.700 km (Cañete, 2011).

Considering this information is not surprising that Argentina holds the 104th position, out of a total of 144 countries, in the competitiveness global ranking 2014-2015 (Schwab, 2014). Schwab (2014) specifies that this low-ranking position can be explained by the poor transport infrastructure. Schwab (2014) recognizes the influence of efficient logistic infrastructure in the arrival of new investments and the general economic development of a country. In relation to this Canitrot and García (2012), indicate that in Argentina the productive logistic cost is dependent on the economic sector and the enterprise size. For example, in primary economic activities, such as agriculture, livestock or forestry, the logistic cost represents about 12% of the added value; whereas in other sectors, such as building, the transport expenses are in the order of 20% of the added value. The incurred logistic cost, expressed in percentage of the turnover, is inverse to the enterprise size: the higher the scale of turnover, the lower the impact of freight cost in the company's revenues. In Fig. 6, the values are expressed in thousands of American dollars per year, it can be seen that in enterprises that have turnovers of more than 5 million dollars, the logistic cost represents only 18% of the incomes, whereas for small enterprises, that earn less than 50,000 dollars, nearly half of the turnover is destined to cover logistic costs.

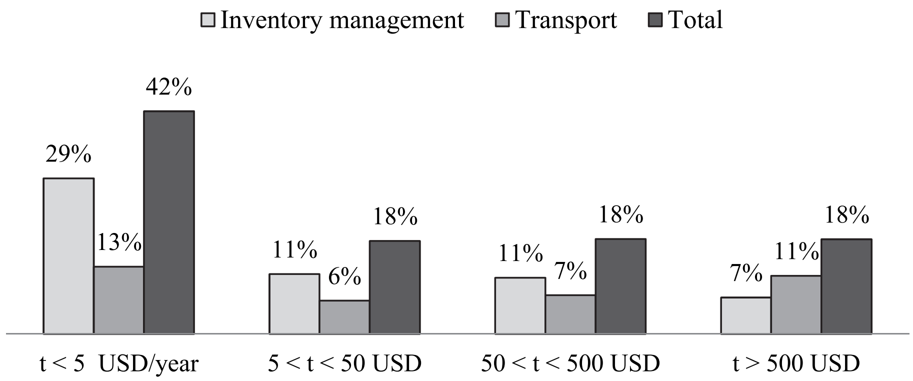

Fig. 6. Average logistic costs, as component of total turnovers, expressed in thousands of American dollars (Canitrot and García, 2012)

3.4. Decision support systems in Argentina

Operations Research is one of the main scientific backgrounds for decision support systems, however, in Argentina, this research line was applied to forestry systems and the implementation of specific software has a slight development in comparison with neighboring countries, such as Chile and Brazil. Despite of the mentioned competitive advantages for wood production, forest production is adversely affected by management practices. A survey of diverse companies in the sector, reveals that, in general, the decision support systems are uniquely based on the experience of the decision makers. There are some exceptions for the few large companies in the sector, which have specific software for handling management aspects. However, SMEs, which as we mentioned are the majority (see Table 5), are characterized but the use of rudimentary tools in production planning, such as spreadsheets with basic operations and relations. And, although leaders' expertise is a priceless asset for a company, sometimes experience by itself it is not enough for performing good business strategy in such a competitive and uncertain environment as the current forest sector. The valuable human resources are obliged to invest much time in monitoring routine operative aspects of the production and distribution processes and, therefore, have less time to focus on more strategic issues that affect the long run.

4. How to enhance Argentinian forest production?

Having revised the current practices in the global forest sector and studied the main characteristics of the Argentinian forest sector, we consider that, in order to overcome the limitations to the sector development, there are some actions and research lines that can be addressed by stakeholders.

Firstly, Argentina suffers from some serious transport infrastructure problems. This negatively affects the base scenario where decision making and supply chain management has to take place, reducing the overall competitiveness of the sector. Solving this, through huge but also crafty investments, should be a must to exploit the natural Argentinian potential and try to approach the leading countries in the sector. The most advisable investment should be focus on providing the infrastructure to take advantage of the river network connection and, in a second stage, the train network. The geographic distribution of these recommended logistic network is illustrated in Fig. 7. We also think that the current state of decision support systems, based almost entirely on the experience of the human resources to generate craft-made plans, is a huge drawback. In the previous sections, several examples of how several problems in the sector can be addressed through Operations Research models. It is true that several of the studies presented in Section 2 were carried out considering the particular conditions of the countries were they were applied. Therefore, this cannot be directly replicated in Argentina. However, it is important to remark that, in general, these were carried out in countries with much unfavorable geographic conditions, such as overly long shifts and difficult transportation conditions. In this sense, it would not be extremely hard to develop a decision-making support tools in a local manner, being possible to adequate the tools for the local supply chain problems and avoiding to use general planning tools which have a general approach and are not directly adaptable to specific problems.

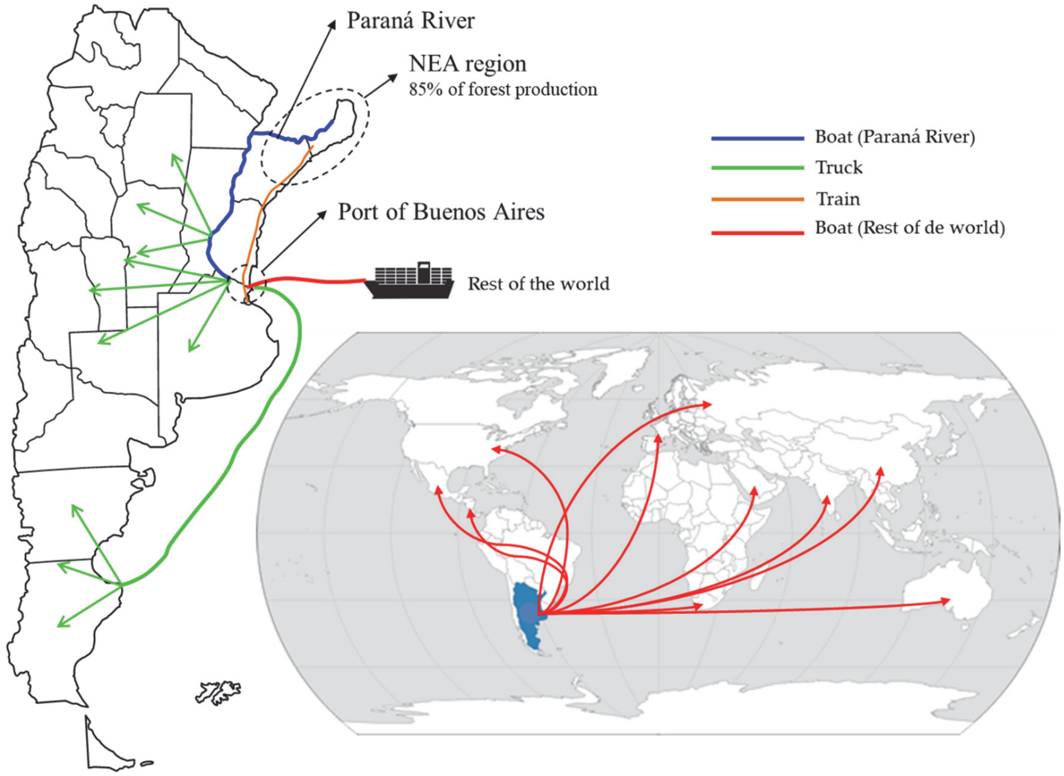

Fig. 7. Logistic network for Argentinean North East (NEA) forest sector.

The conformation and consolidation of research groups on Operations Research in these forestry topics in Argentina is in increasing development. Particularly, in the province of Misiones (one of the province of the Argentinean North East) some new interdisciplinary and inter-institutional research groups are consolidating, what represents a promising future for the issue. Several of the operational models that have been presented in Section 2 can be applied to the Argentinian sector in its current state. To some extent, also the tactical models are feasible to Argentina. However, some adaptations should be performed, such as adapting the planning horizons for Argentinian reality. Moreover, with the inclusion of management techniques, it would be possible to add more resilience to the forestry sector, enhancing its capability to deal with uncertainty, battling against unfavorable situations and capitalizing favorable circumstances.

Finally, we think it is fundamental to performed a throughout analysis of the value chain of the Argentine forest products, something that neither the private stakeholders nor public sector have performed yet. Not only because this will lend a fresh general integral perspective to the sector but also because it will allow to determine more specific characteristics, such as the most convenient mean of transportation to take NEA's production to the main consumption points or the actual situation of the forest industry: its level of integration and its distribution across the territory. Moreover, this analysis will be useful to categorize the severity of the different limitations of the industry, allowing us to separate crucial problems that need urgent attention from more trivial issues that can be addressed in a posterior stage. After the analysis of the value chain, we consider that another line of research that can strengthen the Argentine forestry sector is the development of business models. Once that the basic value chain study has been performed, it will be necessary to develop efficient business models to improve value-added of the forest products and encourage the development of the sector. In this area is where we think that specific DSS developed for Argentine forest sector can make an important contribution by refining the current decision-making process, which has a major impact in industrial forest systems (see Section 4).

Another research line that requires attention from stakeholders is the ecological sustainability of the NEA's forest industry. In this sense, research is required to prevent, for example, the so-called adjacency problems considering the characteristic Argentine topography, problems of soil compaction due to the impact of heavy traffic of forest activities on a surface that is subjected to a severe rainfall regime or problems related to an inadequate balance between CO_2 sequestration and release. These studies would contribute to preserve Argentine forest ecosystems and also to limit the generation of negative externalities towards other human activities.

Last but not least, we consider that all these actions should be accompanied by integral and effective public policies that promote private stakeholders involvement. This can be done through strategic economic planning for the sector that reduces the uncertainty in the long run. Additionally, the state can contribute to the reduction of levels of the high level of labor informality through specific tax benefits but also with stronger monitoring policies. Apart from its obvious positive social effects for the families affected, we consider that this improvement in labor conditions can be enhance the quality of human resources, which is an asset for implementing more complex decision support systems.

5. Conclusion

Currently, local forestry management is passing through a paradigm change, where economic, social, environmental and logistics aspects are being redefined. This scenario demands robust and integrated decision-making support tools. In spite of its rarely favorable geographic and climatic characteristics, such as having one of the largest growing rates in the world, a suitable topography, low fire risk, a high rain regime, industrial forestry culture and low land costs, Argentina faces major challenges in order to take full advantage of its special natural conditions for forest production.

In this paper, we have presented a throughout description of the Argentinian forest sector, identifying its main characteristics and potentialities. Moreover, based on this description we were able to determine some limitations to the development of the sector. Among these drawbacks, the current poor logistic infrastructure is a basic aspect that needs urgent attention because it affects the overall efficiency of the sector. Large infrastructural investments are required especially in river transport. We consider that, the full potential of the Paraná-Paraguay waterway, which should play a key role in the sector, is still untapped. Also, a more adequate integration among the different means of transport would be an asset for the sake of the sector. The railway network also requires an increase in its operational capacity.

Another aspect is the very limited usage of Decision Supports Systems (DSS) in the current decision-making process in the Argentinian forest industry. The adaptation of the DSS tools that are used in other regions that were revised in this paper, such as mathematical optimization, geographic information systems, and big data, would allow the upgrade of the current management capabilities of the sector.

We consider that these measures, and others that can be proposed from the value chain analysis, can help to unleashed the potential of a forest sector that has unique natural characteristics.

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