Exploratory Analysis and Visualization of Brazilian Forest Data from the Forest Document System of the Brazilian Institute of the Environment

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Abstract. This paper presents a study that makes use of several Exploratory Data Analysis and Information Visualization techniques to analyze forest data. Our goal was to carry out a data-driven investigation based on information from the so-called Forest Origin Document (DOF) system, which has been used by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) to control and supervise wood harvesting. The data utilized in this study have been obtained from the IBAMA's website. A comprehensive literature review covering the topics data analysis and visualization was conducted, allowing us to perform graphically oriented inspections and data-driven discussions when handling DOF-type data. Moreover, proposals have been presented in an effort to detect possible signs of fraud and illegality. Finally, by using data analysis tools, it was possible to originate different graphic models and data-based visualizations, thus obtaining summaries and preliminary results about the data of the Forestry Document system.

Keywords: Exploratory Data Analysis · Information Visualization · Forest Origin Document · Amazon Rainforest

1 Introduction

Exploratory Data Analysis (EDA) and Information Visualization (IV) are useful data-based tools successfully used to explore large amounts of records. They contribute to the understanding of several complex environmental and social challenges such as those related to wood harvesting and forest preservation. Thus, making data available as open repositories for research purposes has the potential to improve environmental governance, as well as to assist public policies for combatting illegal practices, hence supporting sustainable logging and agricultural production. These actions can corroborate the mitigation of gas emissions and the adaptation to climate changes [1].

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In Statistics, EDA helps data analysts to better understand the key characteristics of the data, mainly through methods based on visual inspection, which can lead to the formulation of new hypotheses and the design of novel validation experiments. Therefore, EDA is one of the main tasks in Data Science applications in the sense that the more data is pre-processed and visualized, the more information you can get and the better machine learning models you can train [2]. Concerning IV, it gathers a multiplicity of techniques and graphically oriented models for visual analysis and simulations. In fact, conventional visualization methods aim at simplifying data and highlighting relevant information based on domain experience [3].

Illegal logging makes it difficult to locate and quantify the wood being harvested from Brazilian forests, because harvesting often does not form large clearings that can be visualized from satellite images. The problem intensifies when one tries to track regions that do not leave clues which can be captured by satellites. These include logging in areas with difficult access, wherein the wood is transported by rivers. The falsification of documents is another critical issue [4]. Moreover, due to the high rate of illegal logging in protected areas and the lack of transparency in public data, the Amazon Forest turned out to arouse the interest of several Non-Governmental Organizations (NGOs). Since there is a large amount of data publicly available as part of the Forest Origin Document (DOF) system, such a collection is an interesting alternative to carry out data-based evaluations and visual inspection.

By conducting studies with open forest data, to ensure public transparency and a better overview of the logging in the Amazon Forest, in this paper we employ EDA and IV tools for exploring the DOF-IBAMA database. We focus on identifying discrepancies among millions of data records, including the detection of possible signs of fraud and illegality. By performing this exploratory analysis of DOF database, we seek:

- Improve social control over the logging, especially for Amazon Rainforest, to create robust instruments for transparency and systematic surveillance.
- Increase public knowledge about open data in the timber and forestry industry.
- Inspect the distances and transportation costs in the wood flow.
- Collect evidence of occurrence and volumes of different wood species.
- Tracking different types of forestry-derived products in the DOF database.
- Analyze the number of company indicators in different regions.
- Analyze the frontiers in the sense of "how data vary over the borders and migration to new frontiers and transportation routes".

We also intend to offer the visualization of the results concerning the following issues: (i) wood production and abundance, (ii) composition of wood species, (iii) technologies and generated products, (iv) wood prices and income, (v) number of companies in different regions.

The data used in this study consist of subsets (cutouts) taken from the original database of DOF system, because of the large volume of data in the full database. Thus, we select two particular subsets, which comprise the whole data of the Brazilian states of Acre and Rondônia from 2016 to 2018. By taking the DOF database of the IBAMA, we discuss the following points as motivation:

– Determine the sequence of wood flows and individual production chains. A difficult task to be evaluated in the datasets is the following: “how to map the log extraction path within the forest?”.
– Determine the “mass balance” for the wood sector, towards answering the following question: “what is the total wood production in different parts of the chain, considering more raw materials from construction to final wood products?”.
– Gathering evidence of illegal logging: “what is the variation, as measured from the database, to provide clues and basis for illegal logging?”.

Therefore, the goal of this work is to analyze the DOF database of the IBAMA, seeking to identifying patterns and characterizing production chains and the behavior of timber companies. The exploration of species and volumes traded through visualization techniques and exploratory data analysis is another object of study, as well as the identification of possible signs of fraud and illegality concerning wood exploration and transportation.

This paper is organized as follows: Sect. 1 presents the introduction of the work and delineates the research scope, its motivation, and the intended objectives. Section 2 brings the theoretical foundation and literature review. Section 3 describes our study proposals and the methodological steps as conducted in this study. Section 4 gives the experimental results and their discussion, while Sect. 5 summarizes our findings and the conclusions of the work.

2 Basic Concepts and Related Work

As previously mentioned, EDA is a class of techniques that can be used to visually represent the knowledge deeply embedded in a given dataset [5]. In fact, EDA can be understood as the process by which a dataset is analyzed to interpolate useful information. This process usually describes the data in a visual way, allowing decision-making for business entities [6].

2.1 Data Visualization

Data visualization consists of a dynamic manner to quickly react to new developments using virtual environments, network technology, or new computer graphics algorithms. The user – the decision-maker – initially has a total idea about a scenario before focusing on the details, but observations from a graphical model can provide part of the relevant information [7].

2.2 Forest Origin Document System of the Brazilian Institute for the Environment and Renewable Natural Resources

DOF electronic records cover the transportation and the sale of forest-derived products and by-products of native origin, from the forest exploitation area to consumer companies. A single DOF record can contain different wood-derived products and their species, which are listed in the document from the entry of the record lines. However, the precarious filling of the document and the existence of incomplete data fields in DOF records make it difficult to be used for tracking purposes, as well as for social control of the wood chain, including more robust transparency mechanisms [1].

2.3 Brazilian Forests

Forest is any large area of land covered by trees or other woody vegetation areas where the crowns touch, forming a green "roof" [8]. The Brazilian Amazon Rainforest remained completely intact until the beginning of the modern era of deforestation, i.e., before the Transamazonica highway inauguration, in 1970. Deforestation rates in the Amazon have been increasing since 1991 with the deforestation process at a variable but accelerated pace. Although the Amazon Rainforest is deforested for a variety of reasons, livestock is still the predominant cause. In fact, medium and large livestock properties were responsible for around 70% of deforestation activities [9].

2.4 Transportation of Wood Products

The cost of transportation is an important issue when commercializing wood. As it is a bulky and dense product, transporting wood generally entails significant costs for the producer. The cost of domestic wood transportation represents, on average, 3.5% of revenue [10]. The portion of the cost referring to the transportation of native wood is around 12% of the definitive price of the product. According to [11], the cost of transportation represents 44.54% of the expenses related to logging in Brazil.

The vast majority of logs are conveyed from the forest to the processing zones through the 85% road network and, to a lesser extent, the 15% waterway. Road transport has also some peculiarities related to the quality of roads for wood transportation. On average, only 19% of transportation between the logging area and the processing industry is conducted by paved ways (good quality), 36% by poor roads (regular quality) and 30% by non-precarious roads (low quality) [12, 13]. There is a complexity in the transportation of wood due to the large number of variables involved in the process, such as climate variables, distances between the forest and the wood processing unit, maintenance costs, fuel, lubricants, tires, tariffs, among others, so that a decision must be made in order to minimize expenses and distances covered.

All costs involved in wood transportation are called total costs, and they are divided into fixed and variable costs. As variable costs, all expenses that vary as production changes are considered, i.e., fuel, lubricants, tires, and maintenance [14].

2.5 Wood Extraction

Legal logging is responsible for promoting sustainability through forest management plans. The forest-based sector extracted approximately 13 million m^3 of logs from Brazilian forests, feeding the wood processing sector to generate approximately R$8 billion in annual revenues [15]. For sustainable exploitation, the authors in [16] considered the following aspects: 1st Costs of pre-exploratory activities in forest management (pre-exploratory activities, IBAMA fees, vine cutting and monitoring fees); 2nd Exploratory costs in the implementation of forest management (exploratory management costs, divided into the maintenance of main and secondary roads, opening of roads, trails, and displacements, in addition to hauling and felling trees.

2.6 Related Work

Several works have already been carried out concerning Exploratory Data Analysis and Visualization applied to forest data. Below, we present some of these reports, focused on environmental protection and wood sustainable management.

In [17], the authors evaluated the economic viability of the forestry activity in a sustainable forest management plan, in an area belonging to Fazenda São Pedro, in the municipality of Nova Monte Verde, Mato Grosso state. To determine the economic feasibility, the Revenue/Cost Ratio method was used. The exploration activity was economically viable, as it presented a Revenue/Cost Ratio of R$ 1,70. Thus, considering administrative and exploratory expenses, the total net income was R$560,405.51 (41.33%), generating, on average, R$71,60 of net income per m^3. The authors reported in [18] that the production capacity of native forests varied according to environment and forest plannings so that it is possible to support the sustainability of the forestry. They also considered characterizing the potential of production and exploratory planning in a reserved area, located in Flona do Jamari - Rondônia (RO), to visualize the dynamics of timber production. They evaluated the aspects of the availability of forest resources and the practice of low-impact exploratory planning.

In [19], the authors analyzed the differences in the explored forest areas over the years 2007 to 2010, on a particular property in the Pará state using Lidar data. Their research estimated the area of canopy gaps per hectare, extracted from a canopy height model. Impacts on the forest understory were also assessed, by using a metric that calculates the proportion of returns below 0.5 m versus total returns. The obtained results indicated large significant differences in the number of canopy gaps between undisturbed and logged forests, but not between harvest years. Considering the work conducted in [12], the authors stratified a forest portion in the Amazon region, in structurally similar areas, by applying multivariate analysis-based techniques in order to improve the planning of forest production. They used methods that rely on clustering and discriminant analysis. A forest census was carried out, in which the following variables were analyzed: Number of trees, Average commercial height, Average diameter at breast height (DBH), Basal area and Commercial volume.

A data-driven study was carried out in [20], by performing exploratory research on the activity sector from secondary databases, as available at the Brazilian Institute of Geography and Statistics (IBGE) website. The computational models applied in the

study proved to be effective in the task of highlighting the effects of increase/reduction of Gross Domestic Product (GDP), hence improving the rural development and green economy. In a similar work, the authors in [21] evaluated the fifteen main forest genera and species legally exploited in the Brazilian Amazon of Acre state. The number of authorizations issued for the exploitation of managed forests, the volume of wood, and the management area licensed by the Acre Environment Institute from January 2005 to August 2012 were also analyzed. Their findings showed that the area and volume of licensed timber had growth during the period, reaching the peak in 2010 and 2011.

Despite the vast number of studies, the majority of works focused on applications such as forest management, sustainable logging, vegetation index, among others. In recent years, only a few works have employed EDA and IV to explore forest data in Brazil from DOF system. Detecting possible signs of fraud and illegality from DOF-type data is another little-explored branch in literature.

3 Material and Methods

Our methodology consisted of taking the bibliographical survey of the literature, the construction of computing frameworks for exploratory analysis and visualization, the DOF system of the IBAMA, and Brazilian Forestry data. More specifically, to perform such analysis and data visualization, two subsets of the DOF system have been considered: the data sets of the states of Acre and Rondônia, under the interval ranging from 2016 and 2018.

The data were obtained from secondary and official resources, but they can also be downloaded from IBAMA website, as a set of spreadsheets grouped by states. Notice that IBAMA is the main agency responsible for the DOF database, which includes all the states of the federation, except Pará and Mato Grosso states, which use the Forest Products Commercialization and Transport System (Sisflora), and Minas Gerais, which takes the Integrated Environmental Information System (SIAM).

The data were analyzed using open-source software and tools, such as Python and Python-related libraries.

4 Results and Discussion

Since its implementation in 2006, the DOF system has been modernized and technically improved. Moreover, the total number of documents issued by the states of Acre (AC) and Rondônia (RO), to accompany the transportation of legalized wood and native products, grew substantially from 2011 to 2014. Concerning 2016 and 2017, Fig. 1 shows the year-on-year evolution of DOF emissions for the Brazilian states of Acre and Rondônia, where RO had a much higher number of DOFs issued.

Figure 2 shows the comparison of DOF emissions w.r.t the destination states of wood products in the Brazilian market, grouped by years. One can observe that the DOF emission destinations have been increasing year on year during the period.

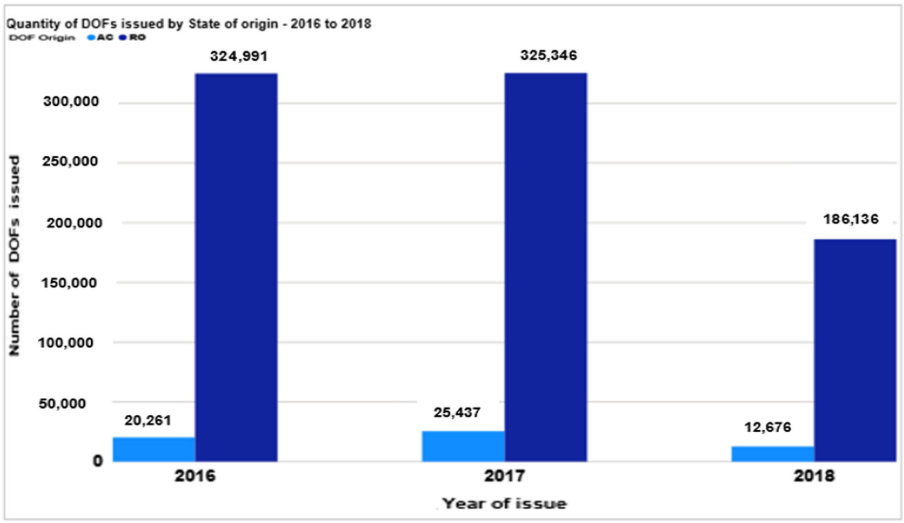

Fig. 1. Total number of Document of Forest Origin (DOF) issued between the years 2016 to 2018 by the Brazilian states of Acre (AC) and Rondônia (RO).

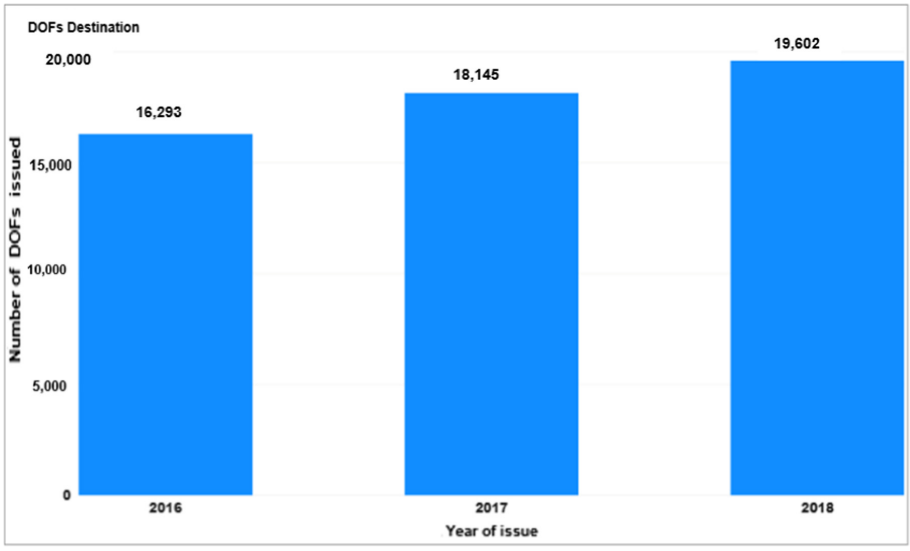

Fig. 2. Total of Forest Origin Documents, issued between the years 2016 to 2018, for DOFs' destination.

Table 1 shows the number of companies that send the timber sector in different regions between the years 2016 and 2018. Notice that the state of RO covers the highest number of companies in the North region of Brazil. In 2016 and 2018, 1,477 wood product shipping companies were registered in the North Region of the country.

Table 1. Total of wood product shipping companies in the North between 2016 to 2018.

Region/State	Companies
Brazil	**1,477**
North	**1,477**
Acre	149
Rondônia	1,328

Table 2. Total of companies receiving wood products in the different regions between the years 2016 to 2018.

Region/State	Companies
Brazil	**32,712**
North	**23,252**
AC – Acre	8,947
PA – Pará	7
AM – Amazons	70
RO – Rondônia	14,201
RR – Roraima	4
TO – Tocantins	23
Northeast	**929**
CE – Ceará	185
RN - Rio Grande do Norte	70
PB – Paraiba	82
AL – Alagoas	85
SE – Sergipe	75
BA – Bahia	299
PE – Pernambuco	68
PI – Piaui	35
MA – Maranhão	30
Southeast	**5,557**

(*continued*)

Table 2. (*continued*)

Region/State	Companies
SP - São Paulo	2,412
MG - Minas Gerais	2,038
RJ - Rio de Janeiro	690
ES - Espírito Santo	417
Midwest	**935**
DF - Federal District	100
GO – Goias	565
MT - Mato Grosso	125
MS - Mato Grosso do Sul	145
South	**2,039**
RS - Rio Grande do Sul	651
SC - Santa Catarina	526
PR – Paraná	862

Table 2 shows the number of companies directed to the timber sector in different regions between the years 2016 to 2018. The state of Rondônia has the largest number of companies represented in the activity of the national timber sector. Also, note that the North region holds most recipient companies - possibly as "intermediate" companies that receive products from several smaller companies in the region and ship them to large production centers such as São Paulo, Distrito Federal, and Rio de Janeiro.

Table 3. Summary of products presented by the DOF system.

Products	By-products	
Finished wood products	Soft	Floors and floors
	Portal or Jamb	Decks
	Lining (Lambril)	Tacos
	Solid Flat Door	Baseboard
	2-sided planed wood (S2S)	4-sided planed wood (S4S)
Round wood	Record	Roller
	Soft Platforms (TS)	Toretes
	Tortes (ts)	Chubby stands
Lumber	Wood (beam)	Wood (board)

(*continued*)

Table 3. (*continued*)

Products	By-products	
	Wood (plate)	Wood (beam)
	Batten	Block, square or fillet
	Wood (unfolded plank)	Wood (beam)
	Short beam	4-sided planed plate (S4S)
	Short kidney	Short board
	Wood (stem)	Little goats
	Short beam Slats	Short clapboard Short slat
Wood waste	Waste from the wood industry for industrial purposes	Wood industry waste for energy Purposes ‘
	Waste for energy purposes	Blade residue
Laminate	Unrolled Blade Knife blade	
Barbs	Chips (ts) Barbs	
Firewood	Firewood Firewood	
Chips	Chips	
Mourao	Posts	
Stacks	Stacks	
Bark	Cartridges	

Table 3 lists all products, and by-products registered in the DOF system. Notice that since there are many products derived from wood. As a result, these were categorized according to the summary of products presented in the DOF system. Lumber is the group that gathers the largest number of by-products, followed by Finished Wood Products and Wood Waste.

Considering the products reported in Table 4, Sawn wood is the one which holds the highest rates of commercialization and emission of DOF's documents in several regions between the years 2016 to 2018, representing 246,392,99 of the total of transported volume.

Table 5 tabulates the wood species transported between 2016 to 2018. From the listed species, one can observe that Caripé (*Licania longistyle*) was the one that presented the highest representation in the volume transported between the years 2016 to 2018, comprising more than 499 thousand cubic meters. Embirema (*Terminalia amazonica*) appears in the second place in this ranking, with a volume greater than 456 thousand cubic meters, and finally Jabota (*Calycophyllum spruceanum*), in the last position, with more than 151,000 m^3.

Table 4. Products and volumes transported and sold between 2016 to 2018 in Brazil.

Products	Year of marketing and transport			
	2016	2017	2018	Total volume
Finished wood products (cubic meters)	13,288,37	124,380,22	10,486,33	148,154,92
Round wood (cubic meters)	11,384,25	80,412,97	25,403,46	117,200,69
Wood (cubic meters)	180,798,67	48,345,86	17,248,46	246.392,99
Wood waste (cubic meters)	16,806,81	13,100,19	18,813,14	48,720,14
Laminate (cubic meters)	13,380,46	13,143,67	12,579,12	39,103,26
Chips (cubic meters)	9,255,59	15,298,30	13,565,37	38,119,25
Firewood	39,147,26	11869,80	17,750,64	68,767,71
Chip (cubic meters)	14,172,80	17,680,44	13,194,88	45,048,12
Bark	20,244,19	24,259,54	23,065,95	67,569,68
Coal	33,853,45	26,467,66	26,013,92	86,335,03

Table 5. Wood species transported in greater volume between 2016 to 2018.

Scientific name	Popular name	Volume (cubic meters)
Licania longstyle	Caripe	499,383
Terminalia amazonica	Embirema	456,611
Qualea paraensis	Jequitibá	423,034
Pithecellobium spp.	Jaguarana	413,641
Centrolobium paraense	Araribá	356,361
Inga spp.	Garlic	330,033
Qualea dinizii	Libra	312,103
Cedrelinga cateniformis	Cassava plant	269,113
Qualea dinizii	Cedar	254,275
Qualea spp.	Yellowish	241,411
Buchenavia macrophylla	Angelim	236,212
Calycophyllum spruceanum	Jatoba	151,967

Figure 3 shows the annual volume of wood transported, highlighting the years 2016 to 2018 in the state of Rondônia. Notice that there was a decrease in the volume of wood

transportation in during three consecutive years in different states, except for the state of Rondônia.

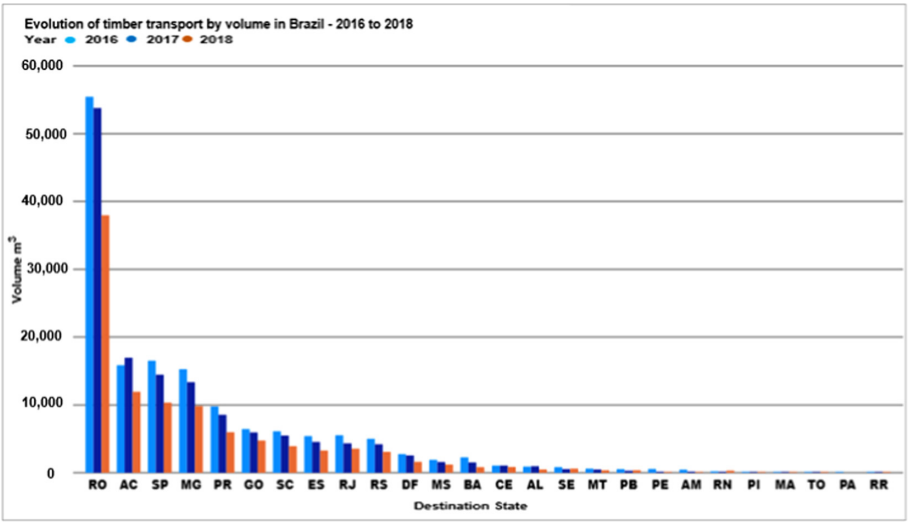

Fig. 3. Evolution of wood transport in Brazil - 2016 to 2018.

Figure 4 displays the transportation of wood products, organized by regions of Brazil between the years 2016 to 2018. From the plotted graphs, one can check that the main destinations of wood products are the North, Southwest, and South regions.

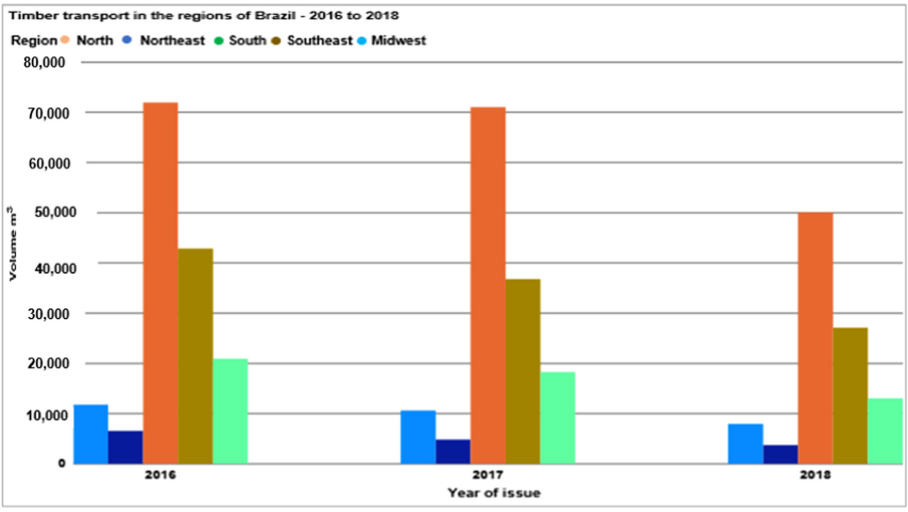

Fig. 4. Evolution of wood transport by regions - 2016 to 2018.

Figure 5 shows that most wood products come from the Amazon region. It was found that most of the cargoes of wood products in the Northern region are transported to the municipalities located in Rondônia and Acre, with Roraima and Tocantins having few records of transporting wood cargoes.

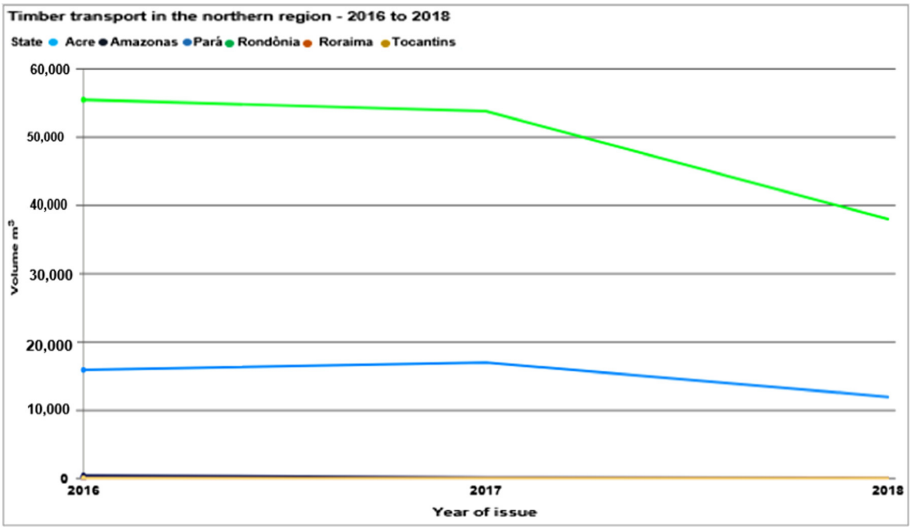

Fig. 5. Wood transport in the North - 2016 to 2018.

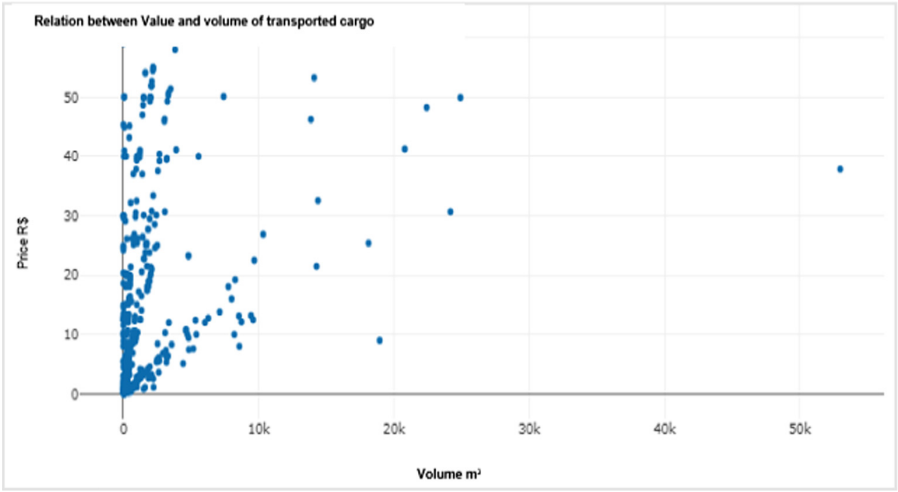

Fig. 6. Relation between the value (R$) and the volume ($m^3$) of the transported cargo

Finally, in Fig. 6, we discuss the relationship of the price against the volume of transported wood. From the plotted data, one can verify that some points holding a large

volume of wood were registered at low prices, as well as small volumes of transported cargo with extremely high prices. This last case may be explained because some species of noble and protected trees have greater values when commercialized in the market. However, aiming at finding potential irregularities, we searched the spots where exceptionally low volumes and extremely high prices were declared in the DOF's documents. By inspecting these documents, we found out that the same shipping company declared all the records, which may be an indication of some kind of irregularity or documents filled out wrongly. Thus, this is a real case of data-driven analysis, wherein a ground check could be properly conducted in order to eliminate any doubts about the issue.

Still regarding Fig. 6, since the transportation cost varies as the distance changes, the location of the yard and consumption centers are strategic decisions and require detailed planning by the transportation companies. The longer the journey, the higher the unit cost per volume of wood transported. Several factors are related to the transportation of wood loads: the vehicle types, the distance of transportation, the unit value of the freight, the conditions in which the road mesh is found, the waiting time for loading and unloading, the load capacity in volume the vehicle carries, local and regional conditions. As a result, it is hard to perform a complete investigation only by taking DOF-type documents, requiring a more comprehensive investigation of different data resources.

5 Conclusion

This work applied Exploratory Data Analysis and Information Visualization tools on data from the Brazilian DOF system. We focused on exploring forest/wood data concerning two Brazilian states, i.e., Rondônia (RO) and Acre (AC), from 2016 to 2018. After carefully analyzing the forest data from DOF database, it was possible to better understand the relationship between different variables from the full database, as the total amount of extracted wood, transportation prices, destinations, etc.

The main wood shippers and recipients were also analyzed in this study, including the states with the highest / lowest number of transported wood loads and the relationship between price and volume of wood traded, as discussed in Fig. 6.

A future work, we intend to develop a new set of visually oriented tools to better explore DOF system data.

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