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International Logistics and Environmental Impact

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Abstract

Regarding the contemporary logistics scenario, it is important to analyze the efficiency and sustainability of the modes of transport used to export fruit in Brazil, and in this study, especially avocados. In general, the predominance of land transport, which is responsible for exporting approximately 75% of national production, stands out in relation to other modes, such as rail, water, and air. The main objective of this study is to identify the most economical option and assess the environmental impacts associated with fruit transportation, as well as the methodology used that includes collecting and analyzing data on exports and logistics costs, using FlexSim software. The results show that road transport is more financially viable than other modes, however, it should be emphasized that the choice of modal should not be based solely on cost, but also on environmental impacts, in view of this, sustainable solutions must be found to mitigate environmental impacts, such as the adoption of electric trucks, to reduce and minimize the carbon's emission and the environmental damage. These initiatives are in line with Sustainable Development Goals (SDGs) 12 and 13, which address responsible consumption and production and action against climate change. In this way, the efficiency of road transport in the export of avocados is made explicit by the validated data collected from FlexSim's results, but it highlights the need to balance between economic efficiency and environmental responsibility in the transport sector for agricultural products in Brazil.

Keywords
Logistics, Simulation, Environment, Sustainability and Transport.

1. Introduction

Regarding the contemporary logistics scenario, it is advisable to choose the main modes of transport, such as road, rail, waterway and air. However, moving to the federal level in Brazil, the road transport system is evident, since around 75% of national production is carried out using this mode. The other 25% is divided between sea and air routes, which are also very well known. According to BALLOU (1993), the routing principle is as important as an essential management activity, and it must help the company to balance its load, bringing benefits through time. In terms of international routes, Brazil currently supplies around US$ 485 million worth of fruit to various countries around the world, including its Mercosur partners, mainly, Argentina, Paraguay, Uruguay, and Bolivia, totaling around 2% of its total net export revenue. Furthermore, one of the most consumed fruits among countries close to Brazil is the avocado, the object of study chosen for the project, representing around US$ 1.3 million of the FOB export value in 2024, and with Uruguay as the main consumer, according to the National Land Transport Agency (ANTT).

1.1 Objectives

The main objective of this project is to identify the most viable and cost-effective mode of transport, promoting cost reduction in international cargo transport. However, to achieve this objective in a practical way, it is necessary to break it down into specific goals that can guide decision-making in a more targeted and efficient manner. First, the aim is to provide visibility in international logistics routes, promoting greater transparency, traceability and understanding of the flows involved in transport between countries. Visibility allows not only real-time monitoring of logistics operations, but also the identification of bottlenecks, delays, and opportunities for improvement throughout the supply chain. This is essential for choosing a more efficient mode, since routes that are not very visible can hide hidden costs or operational risks that compromise financial efficiency. Next, it will be essential to apply simulation studies, which will allow different logistics scenarios to be modeled based on real and hypothetical variables. Simulation offers a prospective view of operations, anticipating behaviors of the logistics system before the actual implementation of changes. This makes it possible to test strategies, assess risks and obtain quantitative data to support the choice of the most economical mode of transport that is best suited to the specific needs of the project.

Another point is to study the effective optimization of the mode of transport, considering criteria such as cost, delivery time, reliability, sustainability, and available infrastructure. The choice of mode of transport (road, rail, sea, air, or intermodal) should be based not only on its direct cost, but also on its ability to meet the operational and environmental demands of the organization in a strategic and sustainable manner. In addition, the project foresees the evaluation of different logistics scenarios as a way of predicting the operational and financial impacts of each alternative considered. Scenario analysis allows for a holistic view of the system, integrating external factors such as exchange rate variations, customs policies, climate change and resource availability. With this, decision-makers will be better prepared to implement resilient, flexible, and results-oriented logistics strategies.

Finally, all these efforts are aligned with the need to achieve the Sustainable Development Goals (SDGs), especially SDG 12 – Responsible Consumption and Production and SDG 13 – Climate Action. The conscious choice of more efficient and less polluting modes directly contributes to reducing the environmental impact of logistics operations, promoting greener and more sustainable logistics, in addition to responsible business practices with the use of resources.

2. Literature Review

International logistics plays a fundamental role in global trade, being responsible for the efficient movement of goods between countries. Several studies highlight that the choice of transport method directly influences operational costs, delivery times and the competitiveness of companies in the international market (Ballou, 2006; Christopher, 2011). The main modes of transport — sea, air, rail, and road — have distinct characteristics in terms of cost, time, capacity and environmental impact, and their choice should be made based on a strategic analysis of the type of cargo, destination, and urgency of delivery. The literature shows that sea transport is widely used because it is more economical for large volumes, although it has a longer transit time. Air transport, on the other hand, is the fastest, but has a significantly higher cost, and is suitable for high value-added or urgent cargo (Bowersox et al., 2014).

Recent studies have also emphasized the growing importance of sustainable logistics practices, which reinforces

the need to consider not only direct costs but also environmental and social aspects when choosing a mode of transport (Rodrigue et al., 2020). Thus, the appropriate selection of the means of transport can represent a significant competitive advantage in the global scenario. In addition, the advancement of information and communication technologies has positively impacted logistics management, allowing greater visibility of the supply chain and facilitating comparisons between different modes in terms of time, cost, and risk (Langley et al., 2017). Tools such as TMS (Transportation Management System) systems and integrated digital platforms contribute to more accurate decisions aligned with the organization's strategic objectives, especially in complex environments such as international trade.

Another relevant point addressed by authors such as Chopra and Meindl (2019) is the influence of trade policies and local infrastructures on the choice of transport. Customs barriers, bilateral agreements and the quality of transport routes are factors that can significantly alter the economic viability of a means of transport on certain routes. Therefore, a complete analysis must consider both internal factors of the company and the external environment, ensuring operational efficiency and reducing logistics costs in international trade.

3. Methods

In order to calculate the choice of transport mode and obtain the quantity required to export avocados to neighboring countries such as Argentina, Bolivia, Paraguay and Uruguay, cost compensations were made between three types of transport: air, road, and water. To validate and confirm the calculations, we used the simulation software, FlexSim, which made it possible to accurately ensure the choice of the most efficient transport mode, since the calculations were performed, indicating a more beneficial cost through road transport. With the simulation, it was possible to identify the correct number of drivers and vehicles required. FlexSim is a 3D simulation software used to model and optimize systems such as factories, distribution centers, hospitals, and services. It works with discrete event-based simulation, allowing the user to visualize the functioning of processes in real time, in addition to generating reports and statistical graphs that assist in analysis and decision-making.

It is a powerful tool for identifying bottlenecks, testing improvements, and simulating scenarios without affecting real operations. For this reason, it is widely used in the areas of production engineering, logistics, healthcare, and services.

4. Data Collection

Data collection began with a study, which was conducted on the country's export levels and the main consumers, considering the quantity exported and its costs, according to the National Land Transport Agency (ANTT). Thus, through transportation data (Figure 1), it was possible to obtain the following information:

Figure 1. International Demand Data.

TOTAL ANNUAL DEMAND	837.363,59	100%
URUGUAY DEMAND	806.062,31	96%
ARGENTINA DEMAND	13.232,87	2%
BOLIVIA DEMAND	10.181,27	1%
PARAGUAY DEMAND	7.887,14	1%

Source: National Land Transport Agency (ANTT).

Thus, due to the data accuracy and precision, it is possible to begin the simulation analyses along the whole study, in a way that provides the answer of the best mode transportation needed in this situation.

5. Results and Discussions

5.1 Numerical Results

After collecting the data, a study was conducted to begin by choosing the best method, considering the country's export levels and its main consumers. Thus, through transportation calculations (Figure 2) and basic cost compensations, it was possible to obtain the following results, according to the demands of each location:

CAMPINAS-ARGENTINA		
CALCULATION	**ROAD**	**AIRLINE**
TRANSPORTATION COST	R$ 156.178,80	R$ 183.142,97
TRANSIT STOCK	R$ 227,07	R$ 34,13
FACTORY STOCK	R$ 35.775,10	R$ 56.487,00
	R$ 192.180,97	R$ 239.664,10

CAMPINAS-BOLIVIA		
CALCULATION	**ROAD**	**AIRLINE**
TRANSPORTATION COST	R$ 31.040,75	R$ 39.808,75
TRANSIT STOCK	R$ 226,42	R$ 16,37
FACTORY STOCK	R$ 23.065,53	R$ 36.419,25
	R$ 54.332,70	R$ 76.244,37

CAMPINAS-PARAGUAY		
CALCULATION	**ROAD**	**AIRLINE**
TRANSPORTATION COST	R$ 13.159,00	R$ 18.140,42
TRANSIT STOCK	R$ 20,11	R$ 4,34
FACTORY STOCK	R$ 8.473,05	R$ 13.378,50
	R$ 21.652,16	R$ 31.523,26

CAMPINAS-URUGUAY		
CALCULATION	**ROAD**	**AIRLINE**
TRANSPORTATION COST	R$ 4.584.642,30	R$ 4.723.525,15
TRANSIT STOCK	R$ 5.613,80	R$ 933,53
FACTORY STOCK	R$ 15.063,20	R$ 23.784,00
	R$ 4.605.319,30	R$ 4.748.242,68

Figure 2. Transport Calculation.
Source: Prepared by the authors.

Thus, it can be concluded that the most economical form of transportation to the chosen countries is by road, reflecting very well the country's real scenario, totaling a cost of R$ 4,873,485.12 according to the data collected. Beyond the calculations, the data collected was also put into a simulation, on FlexSim, and the obtained result is that eight trucks are needed to accomplish all the delivery courses and demand.

5.2 Graphical Results

To make the flow of deliveries and receipts of the chosen transport object a smooth one, it was essential to create a flowchart (Figure 3), responding to the necessary inputs, similar to the simulation, so that it reached the points according to the percentage distributed.

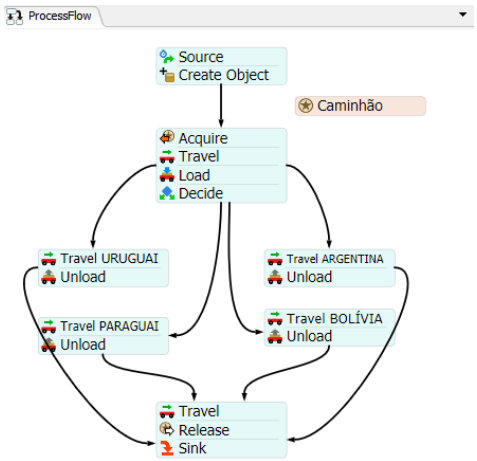

Figure 3. Distribution Flowchart, Source: FlexSim Software.

Along with the numerical results presented, it was possible to visualize the results obtained graphically through the flowchart. In addition, the FlexSim software itself provides a selection of graphs to determine the user's evaluation, and in it the results of a proportional output per hour and distribution center, confirming the simulation accuracy with de collected data (Figure 4) and a stable working in progress, assuring the eight trucks are enough and efficient to transport all the demand needed (Figure 5).

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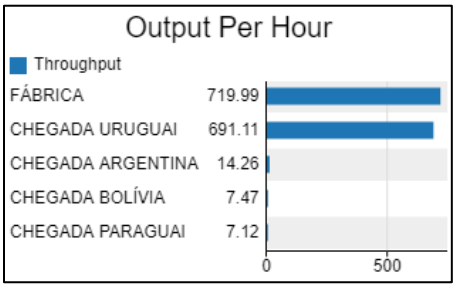

Figure 4. Output Per Hour and Distribution Center Analysis Source: FlexSim Software.

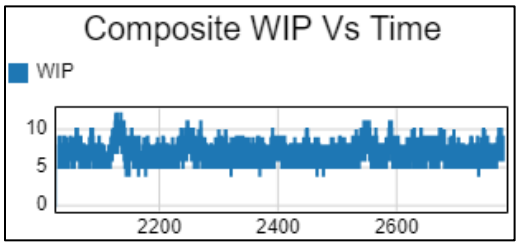

Figure 5. Work In Progress Analysis. Source: FlexSim Software.

5.3 Proposed Improvements

Furthermore, with the need for 8 trucks to meet the pre-determined demands of consumer countries, one of the factors that most harms the environment is made clear, which is carbon emissions, largely resulting from the burning of combustible gases used by means of transport such as the one chosen in this simulation. Therefore, the method of choosing this mode was based on the lowest possible logistics cost, reflecting the reality already known to many.However, the best choice should not always be based solely on financial savings, but also on environmental preservation, especially when it comes to exporting products that come from the land itself, such as fruits. Therefore, the importance of combining means that reach both sides is highlighted, for example, the use of electric trucks, which began their routes in April 2024, and tend to appear more and more on highways, providing better care for the environment, in addition to achieving Sustainable Development Goals number 12 – Responsible Consumption and Production and 13 – Action Against Global Climate Change.

5.4 Validation

The validation of the results obtained in this study was conducted through comparative analysis between the data found and the simulations generated in the FlexSim software, which ensures the methodological consistency of the research. The export logistics data were compared with market information and reliable sources, such as official statistics from the agricultural sector and performance reports of the transport modes. The computer simulation allowed the verification of different transport scenarios, considering variables such as time, cost, distance, and carbon emissions. The agreement between the empirical data and the simulated results reinforces the reliability of the instructions on the forecasts of road transport for the export of avocados. However, the importance of continuously considering environmental aspects in the decision-making process is highlighted, since the validation of the data does not exclude the need for sustainable solutions to the challenges of the Brazilian logistics sector.

6. Conclusion

This makes it clear that a transport mode that is already widely used and known to all is chosen: road transport, which has proven to be very efficient and economical in the international transport of fruits, such as avocados. In a way, due to the volume of international exports from Brazil, other modes of transport are used when shipping to Europe, for example. However, in the case of Mercosur countries, road transport has met expectations.

However, as mentioned, it is not only the costs that should be analyzed, but also the environmental impacts, which have been extensively studied for their reduction, which is extremely necessary. Thus, the land and the environment cannot be forgotten since our entire lives depend on them.

In addition, it is necessary to recognize that sustainability in the logistics sector is no longer a trend and has become a global requirement. In this sense, the use of clean technologies, such as electric vehicles and alternative fuels, has been gaining ground as viable solutions for reducing pollutant gas emissions. Such measures, when applied to road transport, can transform this mode into an even more efficient alternative, aligned with internationally assumed environmental commitments.

Furthermore, the conscious choice of transport mode must consider not only the destination and cost, but also its contribution to sustainable development, meeting goals such as SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action). Thus, economic efficiency must go hand in hand with environmental responsibility, ensuring that logistical progress does not occur to the detriment of quality of life and ecological balance.

Therefore, while the success of road transport in export operations between Mercosur countries is highlighted, the urgency to rethink its practices and adopt sustainable strategies becomes evident. The preservation of natural resources and respect for the environment must be guiding principles for all logistical decisions, since it is from the land that it is extracted everything that gives our living.

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Maria Clara da Silva Nogueira is a Production Engineering student at FACENS University, Sorocaba, São Paulo, Brazil. She graduated in logistics from ETEC Fernando Prestes de Sorocaba (2023). She has two projects published in JOINS (Journal of Innovation and Science: research and application), carried out during her studies at FACENS, the first article is related to Decision Support Systems, where the project aims to implement an inventory control system together with a company, with the aim of avoiding waste and delays in deliveries; the second project is related to Safe Mobility, where possible improvements in daily life were discussed, using a smart pedestrian crossing system. She currently works at Companhia Brasileira de Alumínio, in aluminum plate process engineering.

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