Selecting Transport Routes of Grains in Brazil using Fuzzy Logic

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Abstract. The Brazilian grain production for 2014/15 was estimated at 200.682 million tons, which corresponds to 15.08% of world production. The largest Brazilian producer is the state of Mato Grosso, which produces about 29.3% of soybeans in Brazil. The objective of this study was to develop and analyze a computerized decision model to determine the best cargo transportation route. For this reason, a model was created using Fuzzy Logic on MATLAB®R2015b software. The input values were: US$3.25 / ton / 100km for cost, 27.7 hours for time and 94.2% for reliability, and pointed preferably the port of Itaqui with priority 5.94, to Miritituba priority 5.41, the third choice would be Santos Priority 4.82 and finally the Paranaguá destination with priority 4.02. It could be concluded that it is possible to make the decision to which harbor to export through the use of technical criteria, after testing the model.

Keywords: Transport of grains, Logistics, Fuzzy Logic

1 Introduction

World grain production, harvesting in 2014/15, was estimated at 1,330.6 million tons [1]. The projections showed that Brazil will be responsible for 200,682 million tons, which correspond to 15,08% of the world production [6]. Among the main grains are corn with 78,595 million tons and soybeans with 95,070 million tons [6]. The Midwest region of the country, composed by the states of Mato Grosso, Mato Grosso do Sul and Goiás are responsible for 43,3% of the corn production and 45,9% of soybeans production [6]. This concentration, for its turn, creates a production bottleneck at harvest time, once the production regions use the same export corridors.

The two main Brazilian ports for the flow of grains are Paranaguá city, Paraná state, and Santos, São Paulo state. These Ports are located at a distance between 1.000 and 2.500 Km of production centers in the Midwest. For example, in 2014, Santos and Paranaguá were responsible for the flow of 52% soybeans production [9]. This concentration of routes causes delays due to the traffic jam on the roads and Ports. However, these ports are reliable and have better road infrastructure.

The major producer of corn and soybeans, individually, is the Mato Grosso state, which produces about 22,6% of corn and 29,3% of soybeans produced in Brazil. These grains are destinated, principally, to the international Market [6]. Currently, four main routes are used by the state producers: Port of Itaqui in São Luiz in Maranhão state, Port of Santarém in Pará state, that uses the waterway in Miritituba, besides the already mentioned Port of Santos and Paranaguá [9] and [7].

The Ports where the loads arise are determined by the Trades that operate in Mato Grosso. These Traders take into account the availability of internal transport, docking port of the vessel, flow time and the transport reliability. The Santarém and São Luiz ports are advantageous for transport to the United States and Europe and the ports of Santos and Paranaguá are more advantageous to Asia. Although, such analysis can be made, the inland transport only responds to pre-established international routes increasing, significantly, the Brazilian internal transport costs, which have a lack of infrastructure and availability of high-capacity modal. When the American and the Brazilian transport are compared, the inland transport in Brazil can cost 146% more expensive [9], [8].

Therefore, this paper asks if it is possible to make the decision about which port to export, a technical decision? Taking into consideration that the factors that influence the decision of the Traders are the time

to load the ship, the reliability of the transport system and the cost, would it be viable to develop a decision model that could establish the best transportation route for each load?
Considering these questions, the purpose of this study was to develop and analyze a computerized decision model to determine the best load transportation route for Trades operating in Mato Grosso. Thus, a model using the Fuzzy Logic in MATLAB®R2015b software was proposed.
The model based on the available transport time to attend the ship, the reliability of the required load and the cost per ton/100km suggests routes in order of preference based on a set of rules developed with the opinion of experts in grain transportation.

1.1 Fuzzy Logic

Fuzzy Logic has been used in the industry since the 80's, and has been proven effective in making decisions based on expert knowledge. Created in the 60's by Professor Lotfi A. Zadeh (1921-) at the University of Berkeley, it is a type of technology that converts qualitative content in quantitative, providing ways of transforming human experience into something understandable by computers. [12], [10].
The perception that human beings have of the world around them are often vague and imprecise; this perception is expressed through the language. The fuzzy system deals with linguistic variables accurately, being the only in this mode [13].
The success of fuzzy logic can be realized when [13], asserts that there are thousands of patents in Japan and in the United States related to technologies that use fuzzy logic. In addition, according to [3], this type of system is very successful in different fields of knowledge and recently many organizations such as NASA, General Motors, General Electric, among others, have demonstrated that this technology will generate billions of opportunities in dollars only in North America. So, the fuzzy logic is a good choice to reflect the opinion of experts.

2 Methodology

This paper develops a model that allows carriers or traders, operating in Mato Grosso, to establish better load alternatives according to desirable and pre-established parameters. The steps of this research were:
First: To identify the transport alternatives to the state of Mato Grosso, such as: (i) road transport to the Port of Paranaguá/PR; (ii) transport to Santos/SP using a road-rail transport system; (iii) the use of road transport to Miritituba/PA and then waterway to Santarém/PA through the Amazon River; (iv) and the flow through the port of Itaqui/MA using road transport. These products flow alternatives take into account the existing transport infrastructure in Mato Grosso. Figure 1 shows the respective routes:

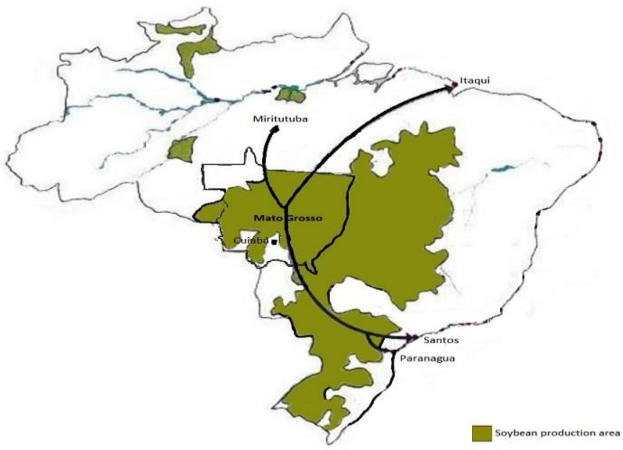

Figure 1: Main Grain Export Routes. Source: adapted from [4], [5].

Second: To establish a decision model we use fuzzy logic control, which was chosen according to the logistic experts criteria, to determine the best flow route of the soybeans produced in Mato Grosso. The system is based on the pertinence relationship between the input variables, cost, time and reliability, according the Table 1.

Table 1: Input Variables (Membership Values)

Cost (ton per 100 km)	Time	Reliability
low (US$0 – US$4,0)	short (0h - 15h)	deficient (0% - 85%)
average (US$2,6 – US$6,6)	average (10h - 30h)	acceptable (80% - 95%)
high (US$5,0 – US$10,0)	long (25h - 40h)	ideal (90% - 100%)

Source: The authors

Third: Shippiment values, time and reliability were established through data collected between Mato Grosso carriers and consulted experts. Later ranges were established to enable the application of Fuzzy Logic.
Fourth: The next step was to set the pertinence functions for available routes. The output variables for Santos, Paranaguá, Miritituba and Itaqui, can be visualized in the Table 2.

Table 2: Output Variables (Membership Values)

Santos	Paranagua	Miritituba	Itaqui
low (0 - 2.5)			
normal (2.5 - 5)			
high (5 - 7.5)			
extreme (7.5 - 10)			

* range from 0 to 10 points (priority). Source: The authors

Fifth: Once the output variables and its scales were defined, 27 rules with all possible combinations of the pertinence functions of the input variables; each rule has as a result of the priorities for each port, identified by the output variables, Table 3. Cost and time were the variables that impacted the most on the decision of the experts to define the destination ports; the reliability variable impacted the weights attribution rules, because in general they are characterized by different forms of modeling uncertainties and disturbances, causing variations in the cost behavior and travel time [11].

Table 3: Basic Rules

Input			Output				Weight
Cost	Time	Reliability	Santos	Paranagua	Miritituba	Itaqui	
Low	Short	ideal	Extreme	High	Low	Normal	1
Low	Short	Acceptable	Extreme	High	Low	Normal	0.66
Low	Short	deficient	Extreme	High	Low	Normal	0.33
Low	Average	ideal	High	Extreme	Low	Normal	1
Low	Average	Acceptable	High	Extreme	Low	Normal	0.66
Low	Average	deficient	High	Extreme	Low	Normal	0.33
Low	Long	ideal	High	Extreme	Normal	Low	1
Low	Long	Acceptable	High	Extreme	Normal	Low	0.66
Low	Long	deficient	High	Extreme	Normal	Low	0.33
Average	Short	ideal	High	Extreme	Low	Normal	1
Average	Short	Acceptable	High	Extreme	Low	Normal	0.66
Average	Short	deficient	High	Extreme	Low	Normal	0.33
Average	Average	ideal	Normal	Low	High	Extreme	1
Average	Average	Acceptable	Normal	Low	High	Extreme	0.66

Average	Average	deficient	Normal	Low	High	Extreme	0.33
Average	Long	ideal	Normal	Low	Extreme	High	1
Average	Long	Acceptable	Normal	Low	Extreme	High	0.66
Average	Long	deficient	Normal	Low	Extreme	High	0.33
High	Short	ideal	High	Extreme	Normal	Low	1
High	Short	Acceptable	High	Extreme	Normal	Low	0.66
High	Short	deficient	High	Extreme	Normal	Low	0.33
High	Average	ideal	Low	Normal	High	Extreme	1
High	Average	Acceptable	Low	Normal	High	Extreme	0.66
High	Average	deficient	Low	Normal	High	Extreme	0.33
High	Long	ideal	Low	Normal	Extreme	High	1
High	Long	Acceptable	Low	Normal	Extreme	High	0.66
High	Long	deficient	Low	Normal	Extreme	High	0.33

Source: The authors

Sixth: The pertinence functions and the rule basis were inserted into the MATLAB®R2015b software with a fuzzy logic tool box extension which allowed building fuzzy inference engine. No option was made for the use of the Mandini method for inference and the centroid method for defuzzification, because they are more simple and much more used. Figure 2 shows the inference engine with the input and output variables.

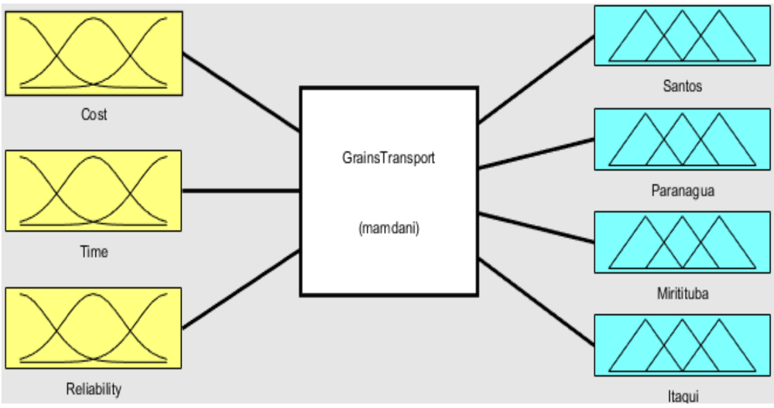

Figure 2: Inference Engine MATLAB®R2015b

Seventh: Finally, they were also plotted in three-dimensional graphics through the Surface Viewer MATLAB®2015b assistant for each port of destination listed in this study. These graphs present the relation between at least two input variables and the priority level (output). The variables Cost and Time were chosen once they are the most significant and impacting on the experts choices.

3 Results and Discussion

Figures 3 to 6 present the destinations Santos, Paranaguá, Miritituba and Itaqui with their respective cost and time relations (areas) expressing higher or lower priority destination. The areas marked in yellow, green, dark blue and light blue indicate higher or lower priority as the basic rules established by the experts.

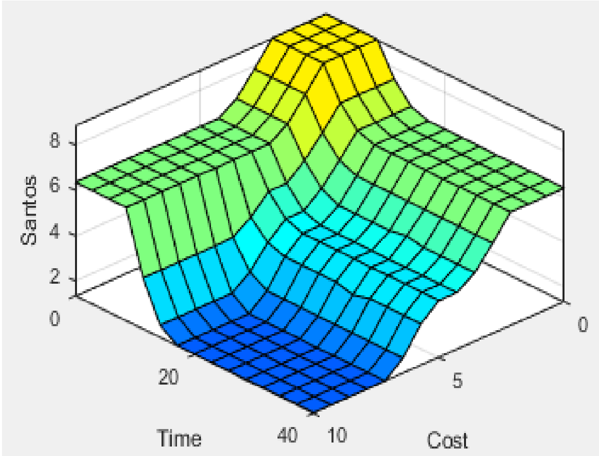

Figure 3: Destination Santos MATLAB®R2015b

For the Santos destination, extreme priority is shown by the yellow area, which indicates that it is more feasible to send shipments, when the cost is low and the time is short, this is justified by the concentration of a significant portion of the soybeans production in the Southern of Mato Grosso and the intensive use of the road-rail intermodal transport in the flow of production [7]. The green area indicates high priority in two situations: (i) with time varying from medium to long as long as the cost remains low; and (ii) short to medium time and high cost. Regions in light and dark blue are cooler, thus with normal and low priority for this destination.

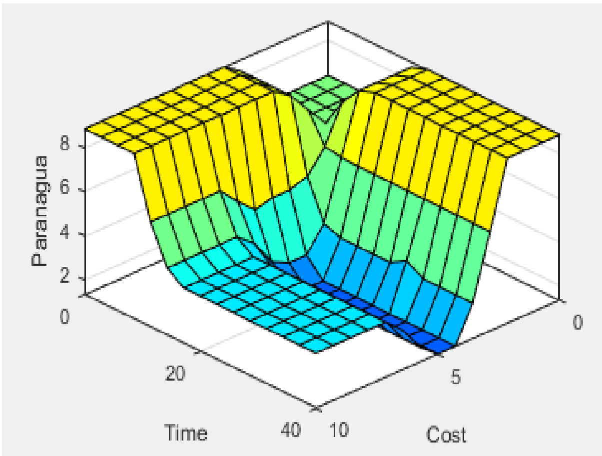

Figure 4: Destination Paranaguá MATLAB®R2015b

For the destination Paranaguá the priority will be considered in two situations: (i) when the cost is low and the time is between medium to long; and (ii) when the cost is between medium to high, and the time is short. In both situations the scenario is elucidated by the export price that soybeans receive, due to the source and destination of the exported product [2], [4], even considering the large waiting time at the port above its pairs. When the time is short and the cost is low, the priority for this destination will be higher. Regions in light blue and dark blue are cooler regions, so with priority from normal to low for this destination.

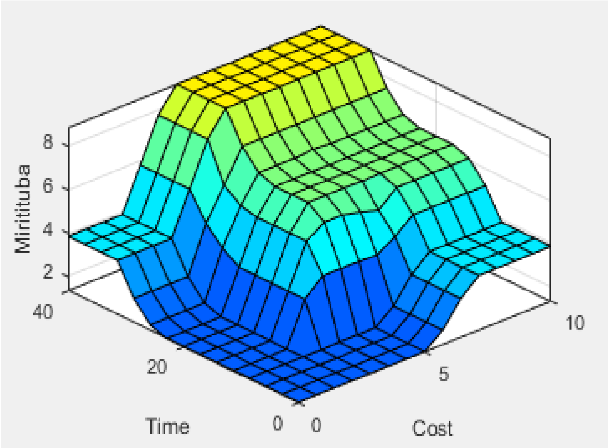

Figure 5: Destination Miritituba MATLAB®R2015b

The Miritituba destination must present priority when the cost is between medium to high, and the time is long. The high priority for Miritituba occurs when the cost is between medium to high and the time is medium. The normal priority should occur in two situations: (i) when the cost is low and the time is high. The other situations present low priority. This scenario is justified when bearing in mind that the transportation occurs only through roads, and BR163 (Cuiabá- Santarém) that connects the producing areas of Mato Grosso and Miritituba terminal show precarious trafficability conditions, and needs more time and consequently a higher cost in transport due to the quality function of the highway and the travel time to bring the soybeans from its origin to TUP of Miritituba [5].

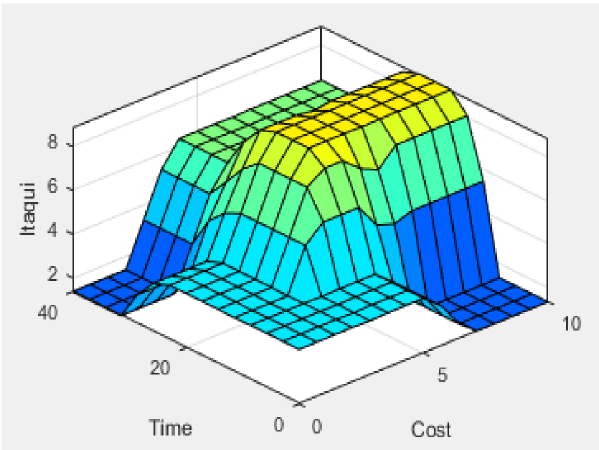

Figure 6: Destination Itaqui MATLAB®R2015b

Itaqui has priority when the time is medium and the cost is between medium to high. Highest priority will be when the cost is between medium to high and the time is long. For the normal and low priority this destination presents precisely the opposite of Miritituba destination. In areas where Miritituba has low priority, Itaqui has normal priority and where Miritituba has normal priority, Itaqui has low.

According to [7] although the Itaqui Port is the closest to markets such as Europe and Asia, logistical access structure ends up decreasing its competitiveness, it is necessary to make investments in flow paths in the northern state allowing that the soybeans only made the transfer North-South reducing the total route.

Another important factor to be observed in these images is that because it is a system that uses functions, there is a subtle transition between the priorities, which can be seen with mixed colors areas.

In addition to the Surface Viewer assistant, used to generate three-dimensional graphics, MATLAB®2015b also has the Rule Viewer assistant that allowed simulating and plot results for fictitious data in the system input variables. Figure 7 shows a simulation carried out, considering as input values: US$3.25 for cost, 27.7 hours for the time and 94.2% for reliability.

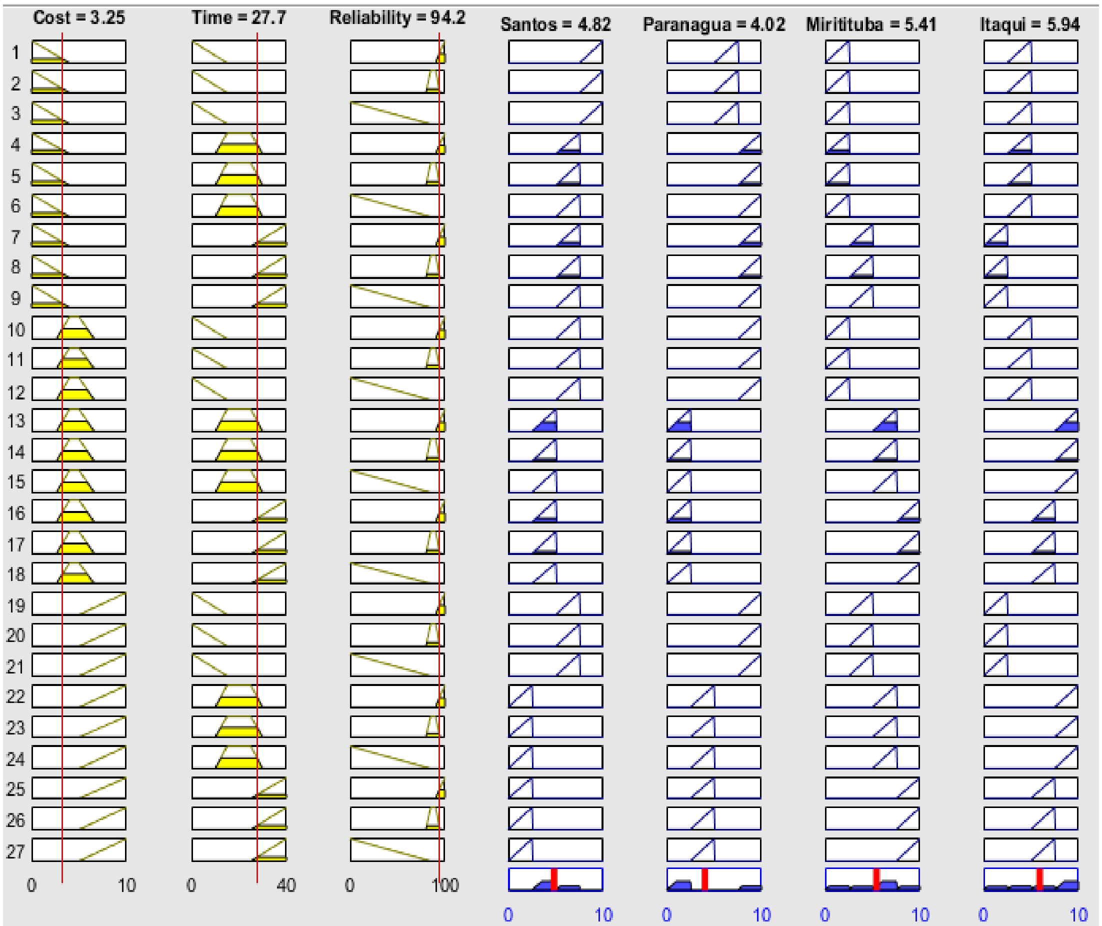

Figure 7: Simulation MATLAB®R2015b. Source: The authors

The results point to the priority values between the destination ports. For this scenario the Itaqui destination should be preferred with 5.94 of priority, the second option pointed to Miritituba with 5.41 of priority, the third choice would be Santos with 4.82 of priority and finally the Paranaguá destination with 4.02 of priority. In front of this scenario, the carrier could choose the first option and send the whole load to Itaqui or proportionally split the load to its destination.

4 Conclusion

The presented model considered many scenarios to describe the best flow routes of Mato Grosso soybeans production. Although the recommended scenarios are guided by technical variables such as: cost, time and reliability, it is necessary to consider the constant transformation that the sector had been through in the last few years, both in structural aspects (roads improvement, ports, multimodal terminals) as well as the production aspect (growth of the production area, volume and productivity, new frontiers) and economy (importance to the Brazilian trade balance, employment and income).
After testing the model it can be concluded that it is possible to make the decision on which port to export as a technical decision. Also infer that it is feasible to develop a decision model to establish the best transportation route for each load, based on the parameters of time, reliability and cost.
The next steps of this search is to verify the applicability of the model in real testing operations.

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