SUSTAINABILITY LEVELS ANALYSIS: A STUDY CASE OF GRAIN TRANSPORTATION USING ROADRAILERS

ANÁLISE DOS NÍVEIS DE SUSTENTABILIDADE: UM ESTUDO DE CASO DO TRANSPORTE DE GRÃOS UTILIZANDO RODOTRILHOS

ANÁLISIS DE NIVELES DE SOSTENABILIDAD: UM ESTUDIO DE CASO DE TRANSPORTE DE GRANOS UTILIZANDO CARRETERA-CARRIL

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ABSTRACT
Like any other industrial or service activity, transport sector requires sustainable solutions development. Meeting such demands becomes even more urgent in economies that use road transportation for most of their activities. Aiming to propose possible alternatives to road transportation, so that it doesn’t compromise operational performance, this research evaluates potential impacts by adopting RoadRailer intermodal system for low-added value cargo transportation. The study use fuzzy logic, taking as analysis object the sustainability level of individual activities by road and rail for agricultural product movement from countryside to Paraná State’s coast, as well as the way how this indicator can be affected by combination of these modes. The results point to more sustainable options through intermodality, also depending on the adopted transport modes sequencing for routing.

KEYWORDS
Sustainability; grain transportation; RoadRailer; Fuzzy System

RESUMO
Assim como qualquer atividade industrial e de serviços, o setor de transporte requer o desenvolvimento de soluções sustentáveis. O atendimento a tais demandas se torna ainda mais urgente em economias que utilizam o transporte rodoviário para a maioria de suas atividades. Visando propor possíveis alternativas ao transporte rodoviário, de modo que não comprometa o desempenho operacional, esta pesquisa avalia os possíveis impactos da adoção de um sistema intermodal de rodotrilhos para o transporte de cargas de baixo valor agregado. O estudo utiliza a lógica difusa, tendo como objeto de análise o nível de sustentabilidade das atividades individuais por rodovias e ferrovias para o transporte de produtos agrícolas do interior ao litoral do estado do Paraná, bem como a maneira como este indicador pode ser afetado pela combinação dessas modalidades. Os resultados apontam para opções mais sustentáveis através da intermodalidade, a depender também do sequenciamento dos modos de transporte adotados na roteirização.

PALAVRAS-CHAVE
Sustentabilidade; transporte de grãos; Rodotrilho; Sistema Nebuloso
RESUMEN
Como toda actividad industrial y de servicios, el sector del transporte requiere del desarrollo de soluciones sostenibles. Satisfacer tales demandas se vuelve aún más urgente en economías que utilizan el transporte por carretera para la mayoría de sus actividades. Buscando proponer posibles alternativas a este transporte, de modo que no comprometa el desempeño operativo, esta investigación evalúa los posibles impactos de la adopción de un sistema intermodal vial-ferroviario para el transporte de carga de bajo valor agregado. El estudio utiliza la lógica difusa, teniendo como objeto de análisis el nivel de sostenibilidad de las actividades individuales por carretera y ferrocarril para el transporte de productos agrícolas desde el interior hasta la costa del estado de Paraná, así como la forma en que este indicador puede verse afectado por la combinación de estas modalidades. Los resultados apuntan a opciones más sostenibles a través de la intermodalidad, también en función de la secuencia de modos de transporte adoptados en el enrutamiento.

PALABRAS CLAVE
Sostenibilidad; transporte de granos; Carretera-carril; Sistema Nebuloso

1. INTRODUCTION
The more movable, more developed is a country, be it due to the moving of goods for its several regions supply and global trade, or to passenger locomotion, nationally or internationally.

Goods transportation distribution in Brazil concentrates more than half of its activities on roadway transport, which creates a freight dependency on this mode, besides being more expensive and harmful to environment, leading to a need for service relocation by other modalities, like railway and waterway.

The Search for sustainable practices is theme that has been gaining more space within productive sectors. Evidently, this criterion brings constant challenges and concerning in transportation activities, given that, in Brazilian case, roadway mode is used the most, and simultaneously, the biggest greenhouse gas (GHG) generator (HEINOLD; MEISEL, 2018).

Among many alternatives to individual road transportation there’s an intermodal systems implementation, which consists on integration and better use of positive characteristics that each mode has to provide (LOWE, 2005). The RoadRail system is an intermodal transport feature that presents a combination of roadway flexibility in initial and final stretches with the bigger capacity by railway haulage (JOHNSTON; MARSHALL, 1993).

This research has the goal to develop a sustainability levels analysis model among different grain transportation alternatives from production area and storage to the more than half of its activities on roadway transport, which creates a freight dependency on this mode, besides being more expensive and harmful to environment, leading to a need for service relocation by other modalities, like railway and waterway.

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This research has the goal to develop a sustainability levels analysis model among different grain transportation alternatives from production area and storage to the shore. For that, it settles a comparison between road or rail individual transportation and RoadRailer system, considering as assessment parameters the time required performance related and GHG emission.

2. LITERATURE REVIEW
Goods transportation in Brazil is made around 60% by trucks (CNT, 2019). However, there is gap this modality cannot individually fulfill in terms of sustainability. It is the low added value products case for long distances, not being this the more suitable transport mode for such service. Besides, this mode responds for over 90% of transport sector pollutant emissions (SOLIANI, 2021).

Railroads, on the other hand, have as main characteristic an inferior operational performance to highways. In addition to lower speed, a lot of time is spent on terminals loading operations (ANTT, 2022). Such condition is directly related to divestments followed by privatizations during the 90s (SILVEIRA, 2002).

2.1. Transport sustainability
According to (BRUNDTLAND, 1987), sustainable development is defined as:

devlopment that meets the needs of the present without compromising the ability to future generations to meet their own needs.

In addition, sustainable development must achieve a three-win solution, being socially inclusionary, environmentally sustainable and economically viable (SACHS, 2010).

However, despite sustainability and sustainable development are considered important frames to structure policies and debates, it still lacks a clear consensus of what is a sustainable development, its desirability, or how to achieve it. Such issue requires integrating activities over simple pursuing independent list of goals (MANCEBO; SACHS, 2013). Furthermore, the authors quote subsidiary goals which must be achieved, like gender equality, insurance of healthy lives, insurance of food security and good nutrition, quality education and lifelong learning offer, universe access to water and sanitation, secure and sustainable energy, among others

In transportation sector, two main dimensions are highlighted. The first one refers to trip number decreasing, through spatial distribution planning and land use. The second one refers to higher energy efficiency and preference for vehicle supply with renewable power sources (BANISTER, 2018). The highway-railway integrated system in Europe is one positive outcome example of intermodal transportation options (MINÁRIK, 2021).

Rail transportation advantages over roadways, from an environmental point of view, are already broadly grounded. Such indicator can be verified by energy consumption or emitted pollutants amount per transported unit by each mode (BIGAZZI, 2019; PINCHASIK et al., 2020; WINEBRAKE et al., 2008). In face of this fact, the looking for solutions backed to intermodality can lead to benefits, not environmentally only, but economics as well (HAVENGA et al., 2011).

Rajak, Parthiban and Dhanalakshmi (2016) propose an evaluation concerning urban public transportation, in which environment, social, economic and service effective aspects are considered. Under this perspective, cargo transportation might be analyzed as well. Zhao et
al. (2020) address an increasing of scientific researches about sustainability in transport services for the last two decades, including "sustainability", "model" and "carbon emission" as three top keywords.

Finally, given that transportation activities affect directly quality of life, people participation plays an important role on making decisions, setting policies and strategies, considering transport multiple indicators (STEG; GIFFORD, 2005).

2.2. RoadRailer system

The RoadRailer constitutes an interchangeable system of rail traction of semi-trailers. Its main feature is the ability to handle freight compartments both by highways and railways, providing agility to goods transference with no need for transshipment between modes, which can reduce cargo operation and handling time required at yards and terminals (LOWE, 2005).

This system is similar to container operations, with the difference that the transference equipment is less complex. It is required only the semi-trailers, mechanical adaptors, so that the semi-trailers can operate as wagons too, transference pneumatic devices and rail bogies support (MINDUR, 2016). Figure 01 indicates the components to operate a RoadRailer system.

2.3. Fuzzy sets

Be X a set of points. A fuzzy set A in X is characterized by the membership function $f_A(x)$, which associates to each element $x \in X$ a membership degree within [0, 1] interval (ZADEH, 1965). The author takes as example the $f_A(x)$ function that represents the “numbers much bigger than 1” set, so that number 5 has a membership degree closer to 0.0 than number 100, in this set. Insofar as $x$ holds off from 1, closer the membership function will be to 1.0 within the settled interval.

Unlike classical logic sets, a fuzzy system is constituted by linguistic variables that may belong to more than one set simultaneously. Temperature is a variable example that might assume “low”, “medium” and “high” classifications, depending on beholder (GOMIDE; GUDWIN, 1994). By Figure 02, one can see that insofar as temperature approximates 50 °C, its membership degree to “Medium” function increases and decreases for “Low” function.

When approaching final destiny by rail, it is also possible to transfer the compartments, using as changing points in Ponta Grossa, São José dos Pinhais and Morretes cities, from which cargo can be transported by road to the final destiny. By this arrangement, 14 different routes were identified, varying among transition possibilities road-to-rail and rail-to-road. It wasn’t adopted railway paths shorter than 200 kilometers. Figure 04 describes possible routes to transport the agricultural products.

3. METHODOLOGICAL PROCEDURE

Brazilian railway system presents low operational speeds in most of its network. However, another factor that increases grain transportation spent time are waiting and delays at terminals for cargo shipping from warehouses to wagons.

Aiming to evaluate possible improvements sustainability-related, it was simulated transport performance by RoadRailer intermodality on moving agricultural products from Brazil’s southern region countryside to the coast for foreign trade, in order to establish a comparison with transport operations and railway vehicles loaded through transshipment process. RoadRailers operational data were obtained indirectly from registered data by Ferreira and Sigut (1999).

Taking the premise that there’s a better operational performance by trucks, and minor environmental impacts by trains given their lower greenhouse gas emissions (GHG), it was taken as reference Seara LLD grain terminal movement along initial stretches as well, allowing mode transshipment since the origin in Londrina, and roadway transshipment process. RoadRailers operational data were obtained indirectly from registered data by Ferreira and Sigut (1999).

The study case steps to determine the routes sustainability levels across the bounded region are divided in: data collection, fuzzy system modeling and output parameterization to classify the alternatives.

4. STUDY CASE

As options to move the grains from countryside to the coast, there are railway and roadway transportation with transshipment in Londrina, and roadway movement along initial stretches as well, allowing mode exchange to rail through RoadRailer intermodality at intermediate rail yards, in cities such as Apucarana and Mauá da Serra.

When approaching final destiny by rail, it is also possible to transfer the compartments, using as changing points in Ponta Grossa, São José dos Pinhais and Morretes cities, from which cargo can be transported by road to the final destiny. By this arrangement, 14 different routes were identified, varying among transition possibilities road-to-rail and rail-to-road. It wasn’t adopted railway paths shorter than 200 kilometers. Figure 04 describes possible routes to transport the agricultural products.

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Table 01: Obtained data.
Source: Authors.

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Simulation softwares</th>
<th>Simulated data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ARENA Simulation®</td>
<td></td>
</tr>
<tr>
<td>Performance (hours)</td>
<td>Input Analyzer</td>
<td>19.87</td>
</tr>
<tr>
<td>GHG emission (tons/TU)</td>
<td>Output Analyzer</td>
<td>50.86</td>
</tr>
</tbody>
</table>

Table 02: Defuzzification parameters.
Source: Authors.

<table>
<thead>
<tr>
<th>Fuzzy set</th>
<th>β</th>
<th>τ</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>-12.00</td>
<td>18.00</td>
<td>1.0</td>
</tr>
<tr>
<td>Very low</td>
<td>2.00</td>
<td></td>
<td>2.0</td>
</tr>
<tr>
<td>Low</td>
<td>3.00</td>
<td>4.00</td>
<td>3.0</td>
</tr>
<tr>
<td>Moderate</td>
<td>7</td>
<td>5.00</td>
<td>5.0</td>
</tr>
<tr>
<td>High</td>
<td>6.00</td>
<td>6.00</td>
<td>6.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>-12.00</td>
<td>-78.00</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Figure 05: Membership functions of independent variables.
Source: Authors.

4.2. Fuzzy system modeling

The fuzzy system first step construction consisted in assessment index normalization, by attributing the membership functions according to each linguistic variable classification. The membership functions of independent variables take a triangular shape given by equation (1).

\[ \mu(x) = ax + b \]  

(1)

Equations (2) and (3) define the sustainability levels’ membership functions, which assume sigmoid shapes for the extreme classifications (minimum and maximum) and gaussian shapes for intermediate sets, respectively.

\[ \mu_1(x) = \frac{1}{1 + e^{-\beta(x - \tau)}} \]  

(2)

\[ \mu_2(x) = e^{-(x-\tau)^2} \]  

(3)

Figure 02 provides the adopted parameters from equations (2) and (3), being a direct reflection from their shapes and positions.

The association rules between independent variables

<table>
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<tr>
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<tr>
<td>Maximum</td>
<td>-12.00</td>
<td>-78.00</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Table 03: Association rules of alternatives’ sustainability levels.
Source: Authors.

5. RESULTS AND DISCUSSION

Roadway individual transportation presented the highest operational performance, given its higher speed compared to any other alternative. Yet, its low energy efficiency made it the worst environmental performance. About individual railway transshipment mode, it was observed the opposite phenomenon to roadway. Hence, the centroid areas for individual modes routes alternatives are placed exactly where horizontal axis marks 4.00.

The output data that concerning about travel time performance and emission rates are expressed by Table 04. Based on Ross (2010) proposed fuzzy structure, and Dumane, Sarate and Chavan (2018) guidelines, the current procedure has led to the following sustainability defuzzification parameters. Figure 07 represents \( x^* \) value from Equation (4) related to each route. Appendix A’s Figure 08 illustrates the respective areas for centroid calculation in each available alternative.

Based on the obtained results, it is verified that intermodal routes R2, R6, R8 and R10 presented superior sustainability levels to individual transport mode alternatives. On the other hand, intermodality presented the worst results for routes R3, R7 and R11, which are belong to “Moderate”, “Low”, “Very low”, and “Minimum” set levels, even if in low degree in the last group. It stands out that operational performance and environmental impact had the same importance degree on sustainability analysis structuring.

Table 04: Alternatives sustainability level.
Source: Authors.
6. FINAL CONSIDERATIONS

The present work focused on the possibility to implement a cargo intermodal transport system as an alternative to accomplish higher sustainability indexes in this service sector. Given the necessity of continuous search for less harmful practices to the environment, it is always effectual to understand alternatives that make possible this goal without big losses to operational feasibility. The research identified four alternatives with better sustainability levels for goods transportation in relation to the movement by a unique mode. That reinforces Minárik (2021) and Havenga et al. (2011) statements about intermodal transportation’s potential advantages.

The methodological procedures had similar aspects to Hemdi, Saman and Sharif (2013) case study, in which resorts to fuzzy analysis to settle sustainability levels on electric power generation. The authors use Equation (4) in order to determine the best alternative considering parameters like pollution, technology, cost, safety, among other. It is important to quote that the authors consider environmental, economic and social aspects for sustainability assessment.

Rajak, Parthiban and Dhanalakshmi (2016) also evaluate sustainability indexes by fuzzy system logic. Besides method similarity with the present article, the authors attribute different weights to each parameter, providing good data precision related service users perception.

For future research, it is suggested to assess other independent variables and their implications to transport sustainability levels, such as cost, reliability, frequency, safety, and others. It is also recommended variables assessment under different importance weights, once shippers might not consider the indicators as equally prioritizable.

REFERENCES


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APPENDIX A

Figure 07: Defuzzification outputs.

Source: Authors.

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