Journal of Systemics, Cybernetics and Informatics (2024) 22(4), 52-59
https://doi.org/10.54808/JSCI.22.04.52

Interdisciplinarity in smart systems applied to rural school transport in Brazil

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ABSTRACT

Interdisciplinarity applied to rural transport in Brazil through expert systems is the focus of this paper. Rural school transport is a challenge, considering the size of Brazil, the great diversity of biomes and insufficient infrastructure. Collaboration between areas by interdisciplinarity articulates individual knowledge through the object and by transdisciplinarity requires developing new knowledge, based on an individual area, going beyond and extrapolating with different criteria. The “Transcolar Rural” intelligent transport system has been developed at the UFMG School of Engineering to plan and manage rural school transport by optimizing routes and costs. The system is used in 13 states in Brazil, 500 municipalities and manages the daily transport of more than 400 thousand students in rural areas. Reducing transportation costs allows resources to be reallocated to other educational activities. The project highlights Brazil's limited resources, recognized by the government, to meet the population's health, education and transport priorities. Transparent information helps managers make decisions and supervise citizens, allowing both parties to determine priorities for resource allocation. The Project demonstrates how interdisciplinarity is effective for complex problems. The project comprehensively addresses the challenges of transporting children in Brazil by integrating technology, exact sciences and applied social sciences.

Keywords: Interdisciplinarity, Building Information Modeling – BIM, Smart Cities, Intelligent Transportation System - ITS.

1. INTRODUCTION

This article discusses the interdisciplinary approach applied to rural transportation in Brazil through expert systems development. The motivation of this paper is the importance of collaboration between experts to solve real problems, bringing benefits to society. Rural school transport represents a significant challenge, considering the vast expanse of Brazil, with long distances and a wide diversity of biomes. Beyond territorial obstacles, the insufficient infrastructure further exacerbates the challenge of providing comprehensive educational and school transport services for all children.

The paper initiates by elucidating the foundational concepts of interdisciplinarity, tracing its historical origins and delineating its scope. The roots of interdisciplinarity/transdisciplinarity are explored, with a historical reference to urban planning and the "Public Health Act" of 1830-1850, which engaged various specialties to combat cholera. The collaborative ethos fostered by interdisciplinarity involves the integration of individual expertise towards a common goal. On the other hand, transdisciplinarity requires generating novel knowledge that surpasses the confines of any singular discipline, transcending boundaries with distinct criteria. The paradigm shift introduced by the "Manhattan Project" is cited as an exemplar, demonstrating that collaborative efforts among mathematicians, physicists, and chemists led to advancements that permeated and enriched each disciplinary domain.

This paper exemplifies a collaborative project carried out by several disciplines at the Federal University of Minas Gerais/UFMG, together with municipal and state authorities. The intelligent transport management system “Transcolar Rural”, developed at the UFMG School of Engineering, integrates expertise from Engineering, Architecture, Computer Science, Education, Arts, Economic Sciences and Geosciences.

The innovation lies in leveraging the collective experience of diverse experts within a smart system, mitigating the shortage of qualified professionals in municipalities. Deployed across 13 states and 500 municipalities in Brazil, the system efficiently manages daily transport for over 400 thousand rural students. Its design incorporates route optimization and transparent cost methodologies, leading to reduced transport expenses. The resultant savings can be reallocated to other educational endeavors, positively influencing the entire system's enhancement. In the context of Brazil's limited resources, particularly in health, education, and transportation, the project's significance is underscored. The heightened transparency facilitated by the system aids decision-making for managers and allows citizen oversight, aligning resource allocation with the community's priorities. The state's commitment to collaboration and citizen welfare is evident in fostering cooperation where it is most needed.

According to the special study commission The National Council for Scientific and Technological Development (CNPq), Federal Agency for Support and Evaluation of Graduate Education (CAPES), FINEP, there is a table of knowledge areas [1]. The main area of Engineering and Computing has a subarea of civil engineering, including transport infrastructure, transport engineering, transport planning, vehicles and equipment, transport and logistics operations and specialties in the operation of transport systems. The main area of Architecture and Urbanism includes technology, landscape and environmental design.

The study involves knowledge in the areas of engineering, architecture, computer science and information for the technical development of the proposal [2]. The intersection of the three disciplines points to the model developed by the Transcolar Rural project, figure 1. The discipline of engineering/architecture holds the technical knowledge of transport and urban planning solutions, being the domain of identifying the problem and applying the solution. The discipline of computer science contributes concepts and techniques for programming and implementing smart systems. The discipline of information science contributes to techniques for organizing and retrieving information.

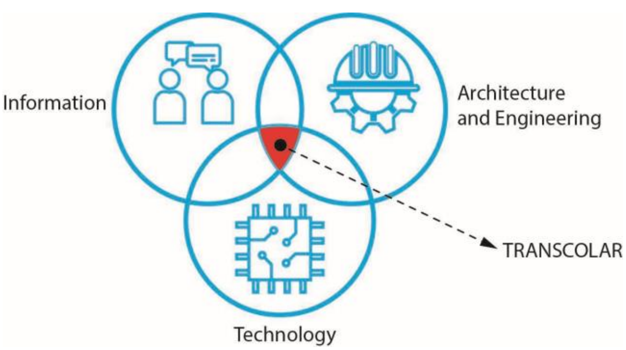


Figure 1 – Interdisciplinarity. Source: the authors

2. INTERDISCIPLINARITY

There is a wide variety of definitions and concepts of interdisciplinarity and transdisciplinarity, as Julie Klein [3] has retrieved. As a practice, interdisciplinarity labor depends on the specific array of the associated disciplines and researchers required to deal with the object, empirical or theoretical, summoned in any empirical or theoretical case. Immanent development and actual consistency of formal and natural sciences provide a strong basis for dialogic interrelation as Marlow & Callaos [4] propose. However, different sciences respond differently to intra and inter-sciences paradigmatic dialog: mathematics, transmitted without distortion, may stop developing, but it does not lose the grounds already conquered. Algorithms nonetheless, although mathematically consistent and applied, will carry the characteristics of the social science paradigm eventually pertinent to their conception. Strong paradigms conquered by mature natural sciences since the eighteenth century offer good support for dialogic interrelations. Still, as Relativity surpassed the highly successful Newtonian theory, we have been confronted with the interference of human representations of time and space into the basic assumptions that could not have been previously taken into consideration. Nonetheless, paradigm development tends to be consistent for a long time and, when standing empirical tests on prevailing laboratory conditions, achieves strong consensus among specialists.

Social sciences and humanities will respond differently to theoretical and empirical objects that usually conform to value and philosophical systems as undecidable bases for the discussion. Non-recognizable common sense intrusions cannot be discarded, and we regularly encounter parallel erudite traditions, as acknowledged by Kuhn [5] whose study focused on natural sciences. Based on different philosophical conceptions and uneven methodological developments, these traditions tend to produce lasting practices frequently dismissed, although not disproven, by hegemonic institutions or scientists in favor of their options. The case of psychology, behaviorism, psychoanalysis, cognitivism and neuroscience are testimonies to increasing, not decreasing discord. The status of their cooperation under interdisciplinarity teams is not a trivial matter but may be addressed by different synthetic metatheories [3].

In social sciences, Klein [3] recognizes the synthetic theories' plight to provide integrative methodology or general conception, be they General systems theory, Marxism, or Structuralism also developing into neo formations when major crises impose themselves. These regular historical options attest to the strong decision of experts of conjectural sciences to stick to their values and perspectives and not to merge into a common paradigm as is the regular case in formal or natural sciences [6]. Nonetheless, there is still another problem to assure rigor in interdisciplinarity associated with social sciences and humanities: it is the dialog between researchers and professionals participating in the same mission but associated to some distinct incompatible philosophical traditions. This problem tends to occur in public research corporations choosing participants through public contests. The interdisciplinarity model of military ideological and staff control present in the paradigmatic Manhattan Project is, in principle, out of reach of public institutions in a democracy. Although nonetheless affecting future practices at universities, this military research that employed from one hundred to four hundred scientific staff members at different times, required: ideological and private life screening of graduate students and senior advisors; that the results be subject to (de)classifications through governmental procedures; universities` special attention for individual effective contribution to teamwork to guaranty it met scholarly standards for attribution of PhD titles; but also rights of intellectual property. Such procedures confronted long-standing university practices and eventually opened up opportunities for the acceptance of industry-financed research objectives and constraints that tend also to limit open access and definition of objectives [7].

The case study and proposal of rural bus school routes in Brazil update many of these challenges. The country is environmentally diverse, infrastructure is highly unequal in quality, availability and maintenance, the data mapping base is insufficient or irregular, the distribution of rural population is socially and demographically diverse, and local expertise to diagnose, propose and implement the best and least costly solution cannot be counted on. The interplay of a vast array of formal, natural and social sciences will be subsequently presented.

3. RURAL SCHOOL TRANSPORT IN BRAZIL

Rural school transport for children in Brazil is a fundamental activity to guarantee access to education for children who live in rural areas, often far from urban centers. Given the country's vast territorial extension and the presence of dispersed communities, school transport plays a crucial role in ensuring that children have the opportunity to attend school regularly.

Generally, rural school transport involves the movement of children, mainly on school buses, from their communities or farms to schools located in urban regions or more central locations. These vehicles are adapted to ensure student safety, complying with specific standards, such as adequate seats, seat belts and regular maintenance.

The challenge faced in Brazil lies in the country's geographic vastness, with rural areas that are often located at great distances from educational institutions. Furthermore, the diversity of biomes and climatic conditions can impact road accessibility, making school transport planning even more complex.

Regions of Brazilian territory have a low population density that extends over large areas of land. This population dispersion combined with precarious infrastructure means that students in these regions have to travel long distances to get to the nearest school every day. Brazil has a rural population that corresponds to 15.64% of the total and has been gradually decreasing both in percentage and absolute terms since 1970.[8]

Data from the basic education school census over the last ten years show a decrease in the number of schools and enrollment in rural areas and growth in urban areas.

The 2003 school census recorded 103,328 rural schools and 7.9 million enrollments; in 2013, there were 70,816 rural schools and 5.9 million enrollments, a reduction of 32,512 schools and 2 million enrollments. [9]

As a consequence, the number of rural schools has been decreasing and being placed in more centralized locations. This shows that the distances traveled by students to go to schools have increased substantially, especially for those who live in more distant locations.
This number of schools in rural areas fell from 92.172 in 2006 [10] to 63.049 in 2016 [11], a drop of 31.6% in just ten years.

According to the Brazilian constitution, the State must provide free basic education and guarantee means of transport for students [12]. To fulfill its duty, the State must contract private transport providers or acquire vehicles to be operated publicly. In both cases, it must meet the requirements of law no. 8,666/96, which regulates the public bidding process, aimed at ensuring the best use of public resources [13].

To optimize rural school transport and overcome these challenges, some innovative projects have been implemented. For example, the "Transcolar Rural" project developed by the Federal University of Minas Gerais (UFMG) seeks to employ intelligent systems for efficient transport management, incorporating the collaboration of experts from different areas, such as Engineering, Architecture, Computer Science, Education, Arts, Economic Sciences and Geosciences. Transcolar serves more than 500 schools divided between Brazilian states, serving children who live in rural areas.

These efforts aim not only to ensure the safety and efficiency of children's travel but also to optimize routes, reduce costs and provide more transparent and effective management of the rural school transport system. These initiatives are vital to address the specific challenges faced in the Brazilian context and ensure that access to education is a reality for all children, regardless of their geographic location.

The Brazilian Constitution, in Article 205, guarantees that it is the duty of the State and the family to provide children with access to education [12]. According to data from the 2021 School Census, more than 5 million basic education students live in rural areas and are enrolled in more than 50 thousand schools [13]. In these rural areas, there is population dispersion across large territorial extensions. The difficulty in getting these students to educational units is one of the main causes of school dropout. This phenomenon can cause serious social consequences, including the basic training of these students and their future qualification and insertion into the job market, restricting their opportunities and quality of life. Therefore, it is necessary to guarantee access to schools for these students from rural areas. To this end, the Transcolar Rural “(TER)” system was developed by the Federal University of Minas Gerais (UFMG).

The problem identification stems from an understanding of reality, driven by the pursuit of enhancing rural transportation for children. Studies in the Brazilian context underscore the imperative to ameliorate rural transportation. Addressing the complexity and scope of this issue necessitates the involvement of various disciplines. This aligns with the priorities within the field of transportation engineering, which strives to enhance transportation systems comprehensively.

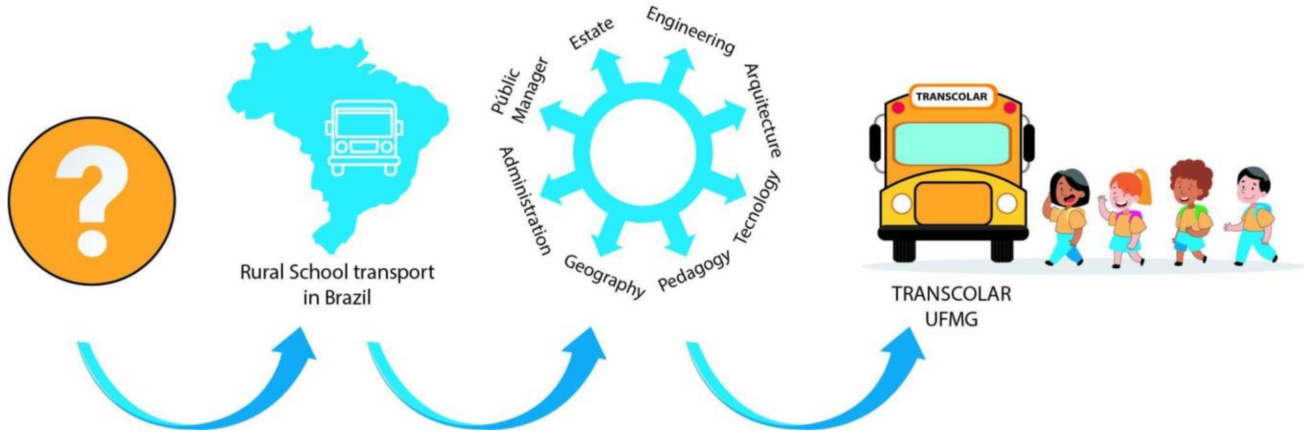


Figure 2 – Framework. Source: the authors

In the current study, the focus lies primarily on improving public and shared transportation. In tandem with transportation engineers, architects and urban planners play a crucial role in conceptualizing transportation solutions that integrate with the landscape and social arrangements within communities and cities. Urban and regional studies encompass urban planning, demography, technical aspects, information systems, design, social, economic, physical-environmental, community-related, legislative, transportation, and urban and regional traffic considerations.

4. "TRANSCOLAR RURAL" PROJECT

Transcolar Rural is a rural school transport planning and management system that encompasses the main information to provide transparency and efficiency. The system has been used in several states in Brazil (Figure 3), Rondônia, Goiás, Mato Grosso and Espirito Santo, where more than 400 thousand students are cared for.

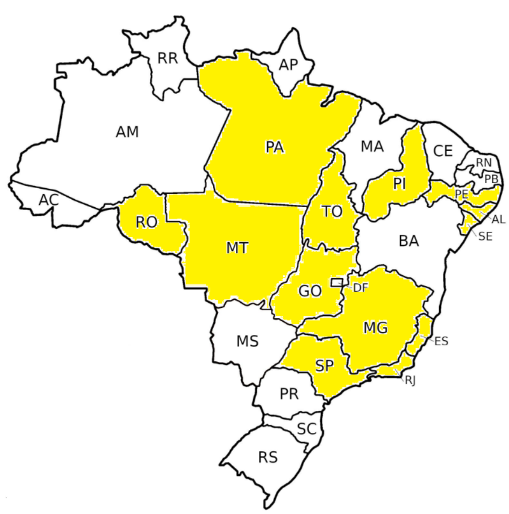


Figure 3 - States that used the Transcolar Rural system. Source: Transcolar Rural.

Table 1 contains the total of students by state who use rural school transportation. In regions with more dense populations, such as the state of Espírito Santo, the number of students is higher compared to the absolute areas of the states. In the city of São Paulo it represents 1/5 of the total of students.

A study in the State of São Paulo in 2021 proves the potential of the system for urban transport. The system presented transport planning for more than 200,000 students from the south zone of the city of São Paulo (capital). The results point to a reduction in the fleet and costs for carrying out transport compared to what was carried out.

State	Students
Goiás (GO)	95530
Rondônia (RO)	67673
Mato Grosso (MT)	117150
Espírito Santo (ES)	124592
São Paulo (SP)	*214724*
Total	**619669**

Table 1 – Students per state. Source: Transcolar Rural.

The system is being implemented in the states of Pernambuco, Minas Gerais, Rio de Janeiro and Sergipe, with a total of students above 1 million in a short space of time.

The Transcolar Rural project [14, 15] is the result of continuous scientific research which incorporates the best transport practices in each state.

This knowledge constructed in an interdisciplinary way is implemented in the smart transport system. The system makes up for the lack of specialists in route planning and transport costs that occur in most municipalities. The system presents concrete and applicable solutions for non-expert users. The system is free online. [16] The implementation of the system can be summarized in four phases.

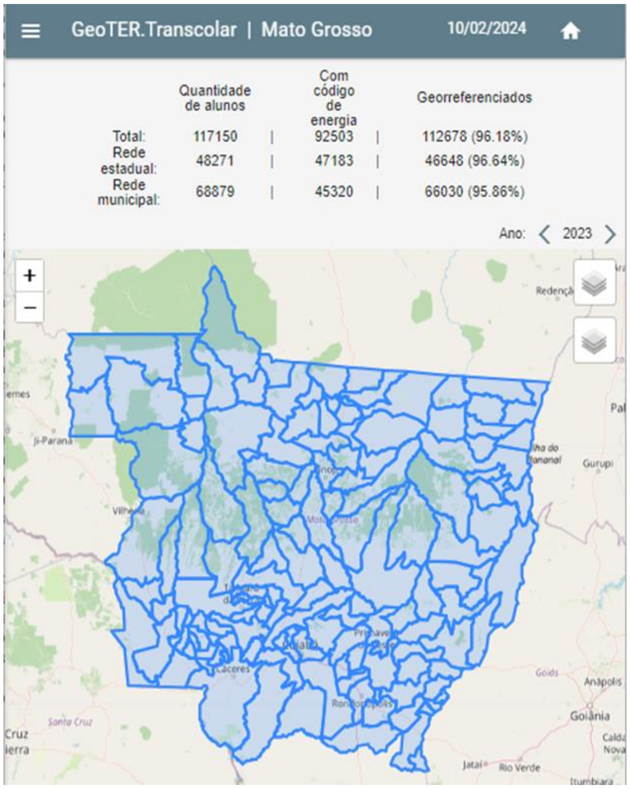


Figure 4 – Transcolar Rural por Estado-Mato Grosso. Source: authors.

Phase I - Current transportation and cost methodology

Phase I is the data collection phase on rural school transport from each municipality in the State that joins the system. The State and municipalities input the system for all transportation of students from rural areas.

The trips are managed by the State or municipalities, some transport students exclusively and others share. At the same time, the price and cost parameters to be applied globally and those specific to each municipality or region are registered.

The estimated cost of each trip registered in the system is calculated. The set of trips for each vehicle is used to calculate the fixed cost and variable cost and apply it to the distance traveled on the day. This includes the daily cost and the cost for all school days in the year [17]. This cost calculation methodology is open and transparent and approved by State Accounting Courts that oversee contracts and the execution of rural school transport in several states.

Phase II- Students and transport

Phase II can be divided into two activities that occur simultaneously. The first activity is to input data from students who use rural school transport. State school students are transferred through system interoperability and updated directly from the state enrollment system.

Students from municipal schools can be transferred through the interoperability of the system or they can be inserted directly into the system if this interoperability is not established. Some municipalities do not have systems or technical support for the task.

The second activity informs, for each trip registered in the system, the list of students who will embark on that trip. The second activity informs, for each trip registered in the system, the list of students who will embark on that trip. At the same time, the identification of the student's energy bill that contains the geographic position of latitude and longitude is registered.

A map with residence markings or a mobile application can be used to identify each student's residence. The driver can use an app to capture the route of each trip and student pick-up points. This process can georeference each student on the trip, completing the information for those who did not present an energy bill. Mobile apps were developed to work offline as there is no full communication network in rural areas. Data transfer occurs when the user connects to your school's Wi-Fi network.

Phase III - Transportation Planning

During the execution of phases I and II, a team digitizes, using satellite images, the municipal road network of the municipalities that georeferenced at least 90% of their students. The process begins with the creation of the initial road network imported from the OpenStreetMap vector model that contains the urban road network and federal and state roads. There is no information on the rural municipal vector network available in Brazil.

Then, for each georeferenced student, their path to the edge network is scanned and their connection to their school is verified. Interroad networks are also digitized to allow route systems to have more route options.

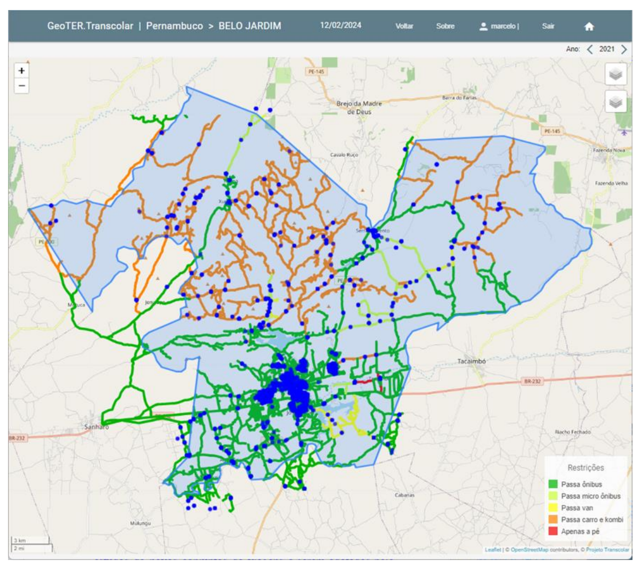


Figure 5 – Municipal road network with students. Source: authors.

The road network needs to be constituted in a correct and complete topological model so that optimization systems can traverse the nodes and edges, with their respective weights. Measuring the break between touching edges is an important step to obtain good results in routing.

A characterization of the road network is necessary to inform the restrictions, if any, on the type of vehicle traveling on the road, restrictions that differ from the design speed and the type of pavement (Figure 5). Most rural roads in Brazil are not paved.

The system allows users to manage comfort parameters when transporting students, such as the time they can remain on board, the distance each student can walk to the boarding point, and students who require special assistance (Figure 6), among others [18].

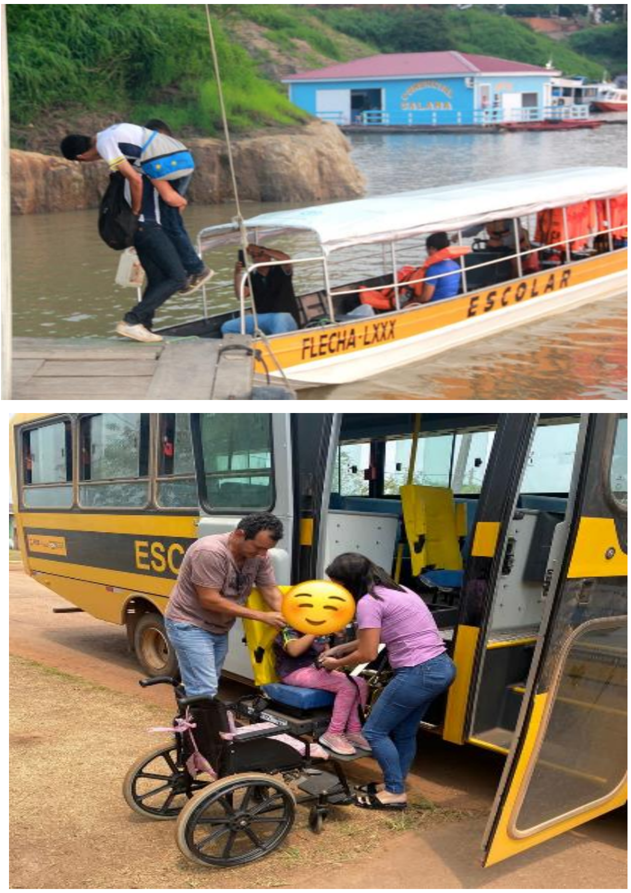


Figure 6 - Boarding disabled students. Source: authors.

Phase IV - Daily transport operation

Cost parameters are established, schools and their students are georeferenced and the topological road network is characterized, making it possible to carry out transport studies and change comfort parameters to find the ideal one for each municipality.

The system has different optimization models developed by researchers [19, 20, 21]. For each optimization study, an optimal solution is proposed with a set of trips, determining each type of vehicle that will carry out each trip, the students and boarding points (Figure 7), in addition to the individual costs of each trip (Figure 8). The system generates reports for all managers, from planners to those who carry out contracting and operations, with all costs involved [22].

The system allows the manager to make decisions based on a consolidated report, comparative between all studies, incorporating in this result all the expertise of the smart system that integrates different interdisciplinary knowledge. Studies demonstrate that reductions of up to 30% are possible due to the applied optimization models [23]. The planning of current trips is carried out, almost entirely, empirically and focused on the operator's vision and not on the student's comfort. Having defined in Phase 3 the initial study that will be adopted for the next academic year, the operation phase deals with the adjustment and daily control of transport.

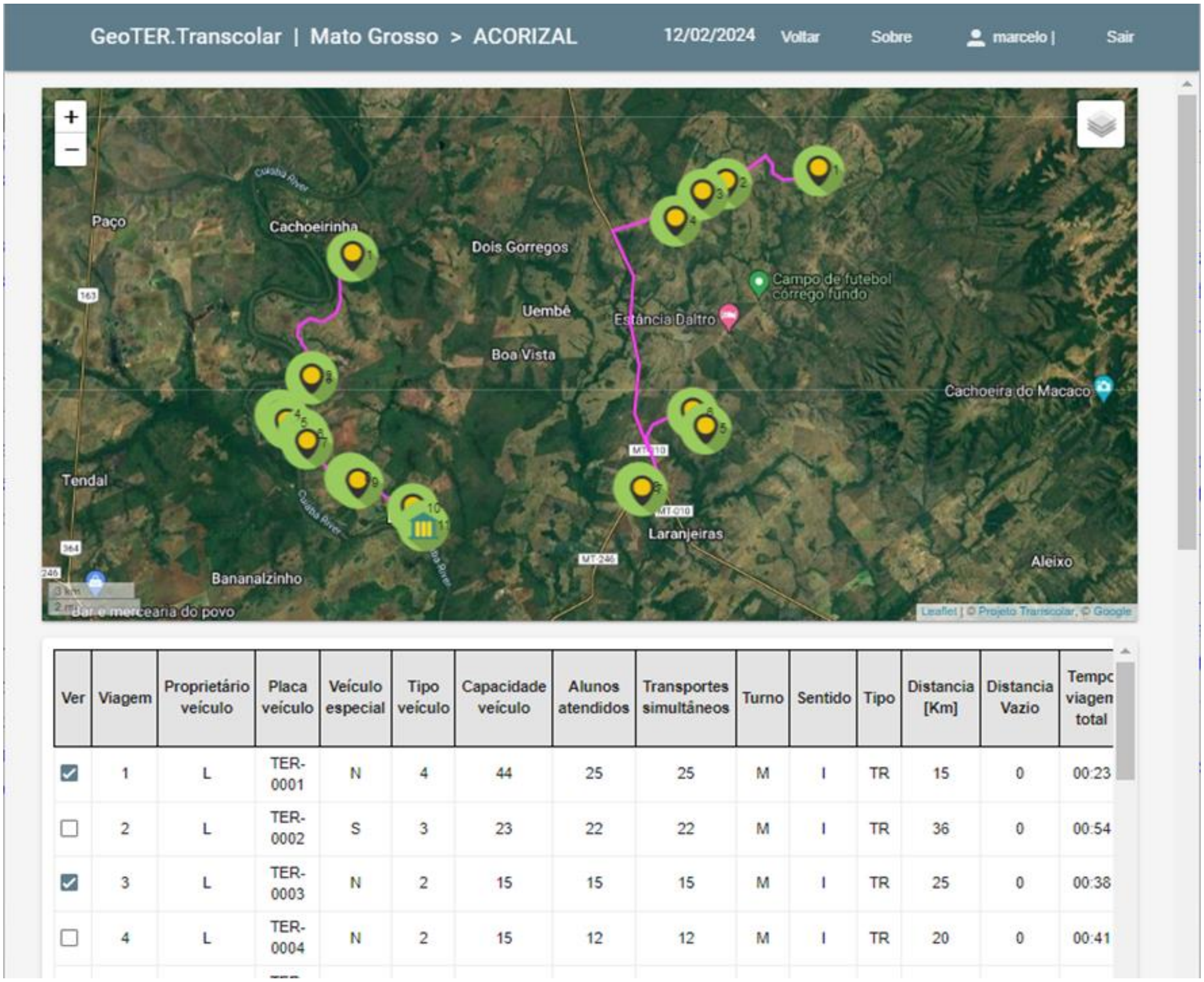
Figure 7 – Boarding students on rural school transport. Source: authors.

The first step, the interoperability of municipal registration systems with the Transcolar Rural system, updates enrolled students daily. First, students who changed schools, shifts or left the municipality's school network are excluded from their respective trips. This list includes students who joined the network. A change system seeks to include these students' existing trips, respecting the comfort criteria that were defined in Phase III. The route of each trip is then updated and this information is exported to the drivers' app.

These routes may change daily and, according to current legislation, may only vary by 25% of their initial contracted value. Eventually, the system may exclude trips or propose hiring new models.

If school vehicles have a satellite tracking system, which rarely happens, each trip made by the vehicle can be automatically compared with the planned trip. Therefore, if any boarding point has not been served within the scheduled time, the payment for the service will be recalculated to the value corresponding to the shortest route, disregarding that boarding point.

Automated monthly reports guarantee agility, security, transparency and greater control of this public service. In specific cases, the vehicle application can be used for this purpose.



Ver	Viagem	Proprietário veículo	Placa veículo	Veículo especial	Tipo veículo	Capacidade veículo	Alunos atendidos	Transportes simultâneos	Turno	Sentido	Tipo	Distancia [Km]	Distancia Vazio	Tempo viagem total
☑	1	L	TER-0001	N	4	44	25	25	M	I	TR	15	0	00:23
☐	2	L	TER-0002	S	3	23	22	22	M	I	TR	36	0	00:54
☑	3	L	TER-0003	N	2	15	15	15	M	I	TR	25	0	00:38
☐	4	L	TER-0004	N	2	15	12	12	M	I	TR	20	0	00:41

Figure 8 – Trips created by the system.Source: authors.

5. DISCUSSION

The Rural Transcolar Project, developed by the School of Engineering at UFMG in partnership with the government, is an excellent example of how interdisciplinarity can be applied to solve complex problems. By bringing together different disciplines such as technology, exact sciences, and applied social sciences, the project comprehensively addresses the issue of transporting children to school in rural areas of Brazil.

Interdisciplinarity allows for a holistic approach to dealing with the complexity of the problem, taking into account not only technical aspects but also social, economic, and quality-of-life factors for children during the school journey.

Furthermore, the project demonstrates the importance of social responsibility by proposing solutions aimed at providing comfort, efficiency, and safety in children's transportation, highlighting the sensitivity of the issue and seeking ways to measure the impact and cost-effectiveness of the interventions.

The use of logical reasoning and precise calculation in the development of algorithms to compose a "smart system" demonstrates an innovative and technologically advanced approach to solving practical challenges.

The fact that the project is being expanded on a larger scale and adopted by more states in Brazil indicates that the achieved results are being recognized and that the proposed solutions have the potential to generate a significant impact nationally.

The Rural Transcolar Project is an inspiring example of how collaboration between different disciplines and the application of technology can contribute to improving the quality of life and social development in rural areas of Brazil.

6. ACKNOWLEDGEMENTS

We would like to express our deep gratitude to Professor José Ricardo Queiroz Franco and Professor Mário Lúcio Pereira

Júnior for their comprehensive and detailed reviews of this document, as well as for their suggestions that improved the final version."This work was carried out with the support of Coordination for the Improvement of Higher Education Personnel - Brazil (CAPES) - Financing Code 001". The Transcolar Rural Project of the Engineering School, Federal University of Minas Gerais - Brazil (EEUFMG).

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