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Design of a Lithium-Ion Battery Pack for a Small Urban Electric Vehicle: Challenges and Lessons Learned by a Transdisciplinary Team

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Abstract. Electric vehicles (EVs) are emerging as a feasible solution to combat emissions, reduce reliance on fossil fuels, and gradually replace internal combustion engine (ICE) vehicles. The primary purpose of the traction battery in EVs is to provide energy to power the electric motor. However, the design of these batteries is complex, which presents one of the significant challenges in reducing the cost of vehicle electrification. This article discusses the obstacles a transdisciplinary team faces in developing a lithium-ion battery with a battery management system (BMS) for a small urban vehicle under the "Rota 2030 Program". The case study focuses on the collaboration between researchers from Brazilian technology institutions and two subsidiaries of multinational automotive companies based in Brazil. The team encountered difficulties locating information regarding commercial electric vehicle systems, such as battery sizing details, cell configurations, the chemical composition used, and developing BMS hardware and software, which are constantly evolving. The initial results reveal the complexity and challenges involved in designing a battery that meets the requirements of an EV.

Keywords. Transdisciplinary Engineering, New Product Development, Electric Vehicles, Lithium-ion Batteries.

Introduction

The use of electric vehicles has become increasingly common in urban areas, driven by the growing interest in sustainable technologies. The federal government established the Rota 2030 Program in Brazil to support and promote technological development, competitiveness, and innovation in the electric vehicle sector. In this context, Renault do Brasil S.A., in partnership with other institutions, presented a project for the development of a national technological solution for the development of a lithium-ion battery pack with a capacity of 25 kWh with a battery management system (BMS), whose main challenges and lessons learned referring to the first year of the project were presented and discussed previously [1].

This article seeks to describe and discuss what were the challenges and solutions that a transdisciplinary engineering team faced in the second and last year of this project, which was mainly impacted by the end of the COVID-19 pandemic and the beginning

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of the conflict between Russia and Ukraine, with consequences for global supply chains. First, we will briefly describe the literature associated with transdisciplinarity within the engineering context (Section 1). Secondly, the methodological aspects of the work will be presented (Section 2). Next, the research results are presented and discussed (Section 3). Finally, conclusions are presented, with suggestions for future work (Section 4).

1. Background theory

The Transdisciplinary Engineering (TE) approach seeks to integrate several areas of knowledge and can help solve complex problems, such as designing a lithium-ion battery with BMS (Battery Management System), as seen in Figure 1. This project involves the interaction of various disciplines, including electrochemistry, multiphysics simulations, mechanical engineering, manufacturing intelligence using multi-objective optimization, and electronics to design the BMS, among others.

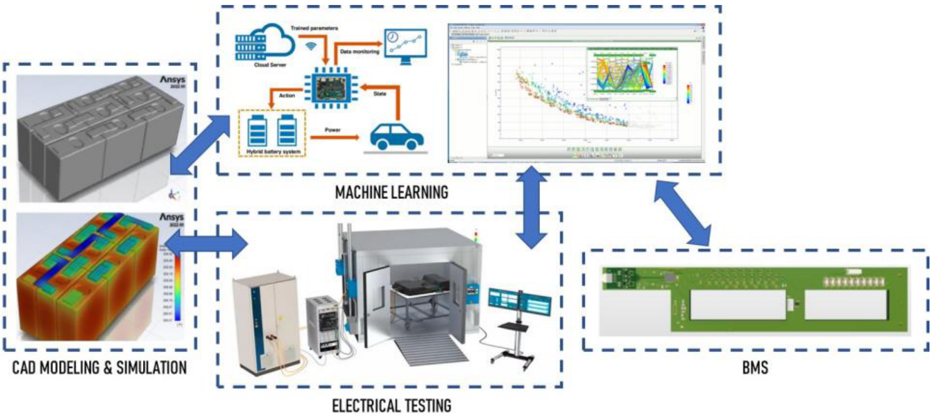

Figure 1. Interaction between principal work packages.

In the case of lithium-ion battery pack design with BMS, electrochemistry experts can work with mechanical engineers to design the geometry of the battery cells and enclosure to maximize energy efficiency and heat dissipation [2].

Multiphysics simulations can model and predict battery performance under different environmental conditions, such as temperature and load. The electronics can be designed to monitor and control the charging and discharging of the battery, protecting it against overload, short circuits, and other problems [3]. Manufacturing intelligence can be used to optimize the battery manufacturing process, reducing costs and increasing efficiency. For example, machine learning techniques for multi-objective optimization can be used to find the best battery cell configuration to strike a balance between energy density, lifetime, and cost.

By working together in a transdisciplinary team, these experts can collaborate to identify key challenges and opportunities and develop innovative solutions that meet all project needs. The TE approach can help ensure that all disciplines are involved in the decision-making process, allowing the team to consider all relevant perspectives and make informed choices to achieve the best possible outcomes.

1.1. Transdisciplinarity and transdisciplinary engineering

There is still no clear and consensual definition of the concept of transdisciplinarity in the academic engineering literature. The term "transdisciplinary" is receiving increasing attention in the academic engineering and research funding communities, but it is still poorly defined. No discipline can possess all the knowledge needed to solve the complex problems of our age. Transdisciplinarity characterizes modern research areas in which the natural sciences are integrated with the social sciences, motivating mixed methodologies to carry out the work [4]. The authors explain that there is still no single definition for transdisciplinary engineering (TE); instead, there is a transdisciplinary landscape [5], [6].

However, they propose a definition that encompasses aspects such as integration, collaboration and orientation to complex problems. According to the authors, transdisciplinarity in engineering refers to the "collaborative and integrated approach of multiple disciplines, knowledge and perspectives, with the objective of facing complex and challenging problems of society and the environment" [7], [8], [9] .

Thus, TE is an emerging field that extends and evolves the initial basic concepts known as Concurrent Engineering (CE). TE is an emerging research area capable of evolving traditional engineering approaches and transcending technical disciplines. It can be successfully applied in different fields, combining natural sciences, applied sciences, social sciences and humanities to achieve a higher level of understanding and awareness of the context in which industrial products, processes, systems and services will be implemented and experienced by users [10], [11].

2. Methodological considerations

Design research often requires the researcher to actively participate in the design process by externally observing it. This approach is known as the participant-observer perspective and is widely used [12]. In this work, we use a participant-observer research approach to describe the challenges faced by a transdisciplinary team in designing a lithium-ion battery with BMS for a small urban vehicle in the context of the "Rota 2030 Program". Participant-observer research involves the researcher taking an active role in observation and participation in the research environment. This approach seeks to understand the social interactions, behaviors and dynamics of a specific group. By getting involved in the environment, the researcher has the opportunity to capture nuances and details that may go unnoticed in other research methods. This is achieved through strategies such as informal interviews and recording data through diaries or field notes. the confidentiality of the information collected. Furthermore, the researcher must be aware of his own subjective role in the research and how his own experiences and perspectives can influence the interpretation of the data.

The challenges and lessons learned in the first year of the project were presented in [1], as well as information on the number of researchers, their profiles and participating institutions. Now we intend to report the results and discussions referring to the last 12 months of the project.he information for this study was collected mainly through the project's quarterly monitoring reports (report 4 – 09/02/2021 to 28/02/2022; report 5 – 01/03/2022 to 31/05/2022; report 6 – 01/06/2022 à 31/08/2022; report 7 – 01/09/2022 to 30/11/2022 and report 8 – 01/12/2022 to 28/02/2023) as a link for researchers, associate coordinators, and overall project coordination.

3. Results and discussion

As previously described, the project is part of the context of sustainable electric mobility, seeking to develop a national technological solution that is intelligent, connected, and inexpensive. One of the biggest challenges for vehicle electrification is the battery pack and its management, with strict monitoring and control of several parameters. Renault do Brasil S.A., Clarios Energy Solutions Brasil Ltda., UTFPR-PG, UTFPR-CT, and SENAI-PR submitted and had a proposal approved by FUNDEP's Rota 2030 program to develop a battery pack with a capacity of 25 kWh with a BMS to meet the energy demand of small vehicles, with a voltage between 250V and 300V and DC 25 kW and AC 11 kW recharge.

The resolution of complex problems, as in the case of the design of a lithium-ion battery pack with BMS (Battery Management System), involves a transdisciplinary approach, which can bring several difficulties, whose main problems are described below. Communication can be challenging in a transdisciplinary team, as experts from different fields may have different vocabularies and terminologies. It is essential to ensure everyone understands what is being discussed and avoid using technical jargon. Experts from other domains may have differing opinions on how to solve a problem. Ensuring that all perspectives are heard, and solutions that meet all needs are found is crucial. Furthermore, there may be specialists of different levels of expertise in a transdisciplinary team, leading to inequalities in participation and collaboration. Ensuring all team members are involved and allowed to contribute is vital.

Complex projects can be time-consuming and require significant resources, which can be challenging for a transdisciplinary team. Establishing clear priorities and ensuring that tasks are evenly divided among team members is essential. The design of a lithium-ion battery pack with BMS can involve many disciplines and be challenging to understand. Taking a systemic approach and finding solutions that consider all parties involved is necessary.

The main difficulty encountered during the project was related to purchasing battery cells. At first, the cells would be bought by a supplier of the original Renault cell, but communication with this company was complicated. Both the chief engineer of the project at Renault and the general coordinator of the project repeatedly demanded a return from the supplier, and they took a long time to respond. Finally, the delays in negotiations with this supplier of the original cell ended up delaying and impacting the stage in which the documentation was required to transport dangerous cargo. Thus, the search for a second option for supplying the cells began. However, there were also delays concerning the documentation required for transporting the cells, and the fact that the cells are designated as dangerous goods makes the documentation process more rigorous. When the purchase was already settled, and thus the process could proceed. However, in the project management system of the Research Support Foundation - FUNTEF, there was no longer a period for updating this import because there were less than 90 days for closing the project according to the original signed agreement.

Thus, it was necessary to amend the agreement, signed on February 8, 2023, to extend the project for another six months to continue importing cells. However, the new company supplier informed us that it would only be able to deliver the cells within 90 days, making it impracticable due to the short period we have to complete the entire execution. Thus, another cell manufacturer was sought with characteristics very close to the one we were negotiating and which could be delivered within 45 days. But to update all the documentation necessary for import, FUNTEF needs to return the process, and the response to the project's demands has always been relatively slow.

Lessons learned include building trust between team members is critical to the success of the transdisciplinary approach. It is vital to establish mutual respect and that everyone's perspectives are heard and considered. The team should have clear, shared goals for the project so that everyone is working in the same direction and can collaborate effectively. Leadership is critical to coordinating the team and ensuring all members are aligned and working toward project goals.

The transdisciplinary approach can provide continuous learning opportunities, allowing team members to learn from experts in other fields and improve their skills. The team must adapt to changes and challenges throughout the project. It is crucial that the group is open to change and can adapt quickly to ensure the project's success.

The COVID-19 pandemic, which started in 2020, has brought many hardships to the electronics industry, including the shortage of electronic products from China. Supply chain disruption: The pandemic has caused disruptions to the global supply chain, including the production and distribution of electronic components. China's shortage of electronics was a reflection of this disruption. With many people working from home during the pandemic, demand for electronics has increased significantly. However, due to the shortage of electronic components, the supply could not keep up with the order. The shortage of electronic products has led to an increase in the prices of electronic components, which has affected electronics manufacturers and consumers alike. Disruptions to global supply chains and electronic component shortages can lead to product development delays.

A transdisciplinary engineering team could adopt several strategies to overcome the difficulties related to importing essential components for designing a lithium-ion battery pack with BMS. Some possible solutions include diversifying the supply chain by considering working with suppliers in different regions to reduce the risk of interruptions in component supply. The team may seek to establish partnerships with suppliers of BMS cells and electronics to ensure the supply of essential components for the project. It could assess the possibility of using other battery or BMS technologies that do not depend on the parts having difficulty importing. For example, the team can evaluate the option of using batteries from another chemistry and developing alternative components for the BMS if importing the necessary parts is impossible. For example, the team could create a battery management system based on domestically manufactured electronics or develop custom battery management software.

The Covid-19 pandemic and the conflict between Ukraine and Russia showed the importance of being prepared to deal with unpredictable situations and how crucial it is to have contingency plans to minimize impacts on the project. Furthermore, it highlighted the need for closer collaboration with suppliers to assess the supply status of materials and components in advance and take proactive steps to avoid delivery delays. As a result, the project team learned and adapted, strengthening its resilience and crisis management capacity for future projects in an increasingly complex and volatile global environment. We summarize the main challenges and lessons learned in Table 1.

Table 1. Main challenges and lessons learned in the project.

Challenges	Lessons Learned
Development of a lithium-ion battery with BMS applied to a small urban vehicle in a transdisciplinary project with several institutions involved.	The importance of clear and effective communication between the different teams involved in the project.
Need to ensure the safety and efficiency of the battery and its management, with strict monitoring and control of various parameters.	The value of adapting to unexpected changes along the way and being flexible around deadlines.
Dealing with input shortages and delays stemming from the COVID-19 pandemic and a war in global supply chains.	The importance of careful planning, which considers possible risks and unforeseen events along the way.
Challenges in working on a project with multiple disciplines, including engineering, applied sciences, social sciences, and humanities.	The need to find innovative and creative solutions to complex problems and the importance of transdisciplinary teams in achieving these solutions.

The pandemic and the conflict between Ukraine and Russia have shown the importance of managing risks and preparing for supply chain disruptions. Companies may consider creating contingency plans to minimize the impact of future outages. Effective communication with suppliers, customers, and other interested parties is highlighted. Maintaining an open and transparent dialogue is essential to ensure everyone is aware of changes and challenges. The importance of adaptation and flexibility to deal with unexpected changes was identified. Companies may consider adopting a more agile approach to product development.

Faced with these challenges, project management interventions can be implemented to bring about improvements and mitigate the effects of exogenous shocks. Here are some interventions that could be considered.

Supply chain diversification: The cross-disciplinary team could work to identify alternative and geographically dispersed suppliers, thereby reducing reliance on a single source of components and materials. This would help mitigate the risks associated with disruptions within a single geographic region.

Risk and Contingency Assessment: The team could conduct a detailed risk analysis in the supply chain and develop contingency plans to deal with potential disruptions. This could involve identifying back-up suppliers, strategic safety stocks, or even internalizing certain steps in the supply chain.

Ongoing monitoring and reporting: It is essential to establish an effective supply chain monitoring system to detect early signs of disruption. The team must maintain a regular dialogue with suppliers to be aware of potential problems and collaborate in finding solutions.

Strategic partnerships: The transdisciplinary team could consider establishing strategic partnerships with key suppliers or even with other companies in the automotive sector. These partnerships can provide privileged access to resources, expertise and supply assurance.

New Technology Investigation: In the face of geopolitical uncertainties and supply chain challenges, the team may explore developing alternative battery or BMS technologies. This could include evaluating new materials, energy storage technologies or innovative battery management approaches.

When considering these interventions, the transdisciplinary team must consider several trade-offs. For example, diversifying the supply chain can increase transportation and logistics costs, but also reduce vulnerability to disruptions. Likewise, establishing strategic partnerships may require upfront investments and sharing intellectual property, but it can also strengthen the team's position in the marketplace.

Selection of the winning interventions to save the project will depend on a careful analysis of risks, available resources, project goals and specific constraints. The transdisciplinary team should carry out a comprehensive assessment of the pros and cons of each intervention, as well as its technical and economic feasibility.

In Table 2, some discoveries were categorized according to relevant factors for the development of the project. In the area of technology development, suggestions involve exploring alternative materials for lithium-ion batteries, improving the battery management system and looking for innovative recycling approaches. The team diversity category highlights the importance of promoting equal participation of different groups and fostering multidisciplinary perspectives. In the work environment, it is suggested to establish an inclusive culture, foster open communication and encourage experimentation. Finally, suggestions related to partnerships and collaborations highlight the importance of establishing strategic partnerships, seeking international collaborations and involving relevant stakeholders. These categories were defined to encompass the different aspects necessary for the success of the project, providing a comprehensive and targeted approach to addressing the identified challenges.

Table 2. Relevant factors for the development of the project.

Categories	Discoveries and Suggestions
Technology Development	- Explore alternative materials for lithium-ion batteries, aiming to improve efficiency, safety and cost; - Research and develop advanced Battery Management System (BMS) technologies to maximize performance and extend battery life; - Investigate innovative approaches to recycling and reusing lithium-ion batteries, aiming to minimize the environmental impact.
Team Diversity	- Promote diversity in the development team, encouraging the equal participation of different groups; - Valuing multidisciplinary perspectives and celebrated experiences to promote innovation and creativity; - Foster collaboration between multidisciplinary teams, seeking insights from different specialties to address challenges comprehensively.
Work Environment	- Establish an inclusive and collaborative work culture, where all team members feel valued and respected; - Encourage open and transparent communication, promoting the exchange of knowledge and ideas; - Foster an environment that encourages experimentation and continuous learning, allowing the team to explore innovative solutions.
Partnerships and Collaborations	- Establish strategic partnerships with universities, research institutes and other companies to share knowledge and resources; - Seek international collaborations to access best practices and global expertise in the area of batteries and electric vehicles; - Engage in dialogues with relevant stakeholders such as governments, industry associations and non-governmental organizations to align goals, exchange information and seek support.

4. Conclusion and future work

The transdisciplinary approach presents a promising alternative to solve problems involving multiple domains in a scenario where the challenges are increasingly complex. The project described in this article reinforces the need to encourage collaboration between different areas of knowledge and to establish effective partnerships between universities, industries, and professional training institutions to develop innovative and sustainable solutions.

In this article, several challenges faced by the team in the design of a lithium-ion battery with BMS applied to a small urban vehicle were presented. However, the complexity of the procurement process for cells and electronic components stands out in a project that took place during the end of the Covid-19 pandemic and the beginning of the conflict between Ukraine and Russia, which brought consequences to global supply chains and significantly impacted the supply of inputs for the project. With the interruption of commercial activities and closed borders worldwide, many suppliers could not meet agreed delivery deadlines, resulting in project delays. The scarcity of raw materials and essential components also increased production costs and led to the need to seek supply alternatives. The report on lessons learned highlights the importance of effective communication between all parties involved and of a contingency plan with stricter and more comfortable deadlines for execution. We stress the importance of a risk management plan to deal with unforeseen circumstances. The team learned that it is essential to have plans B and C and maintain clear and constant communication with everyone involved to solve problems quickly.

The participant-observer methodological perspective proved valuable for understanding the challenges faced by a transdisciplinary team during the execution of the project. As a proposal for future work, we suggest the development of new methodologies and strategies to improve coordination and communication between transdisciplinary teams. This may include online project management and collaboration tools to enhance communication and traceability of each team's activities. In this way, transdisciplinary engineering can be used to design and build safer, more efficient, and sustainable batteries capable of meeting the ever-increasing demands of electric mobility.

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