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Lithium-ion Battery Procurement Strategies: Evidence from the Automotive Field

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Abstract: Electric and hybrid vehicle diffusion is nowadays promising but still limited, also due to the high costs of key components such as lithium-ion batteries (LIBs). A significant contribution to these relevant economic values is given by not optimized supply chain structures. Therefore, car manufacturers approaching electrification are considering different strategies to either purchase complete LIBs or producing them in-house. However, literature lacks quantitative studies assessing the logistics implications of LIB procurement policies in the automotive sector. The present work proposes a decision-making approach leveraging the main logistics and environmental issues involved in both internally producing and buying complete LIB packs. Such a framework is intended to increase the awareness about the complexity of the supply chain of batteries for electric and hybrid vehicles in order to further stimulate its investigation. Future research will extend the approach to include additional aspects as well as procurement configurations.

Keywords: automobile industry; electric vehicles; LIB supply chain; procurement; decision-making; logistics

1. INTRODUCTION

Car manufacturers have recently included electric and hybrid vehicles in their product portfolios as a way to react to the increased relevance of pollution and climate changes (Franco et al., 2016). However, the current market share of these vehicles is limited because they are based on some crucial components, such as electric engines and the associated lithium-ion battery (LIB) packs, whose costs are still high and their environmental impact not negligible (Chen, Wen, Fan, Bando, & Golberg, 2018; Gao et al., 2019). Among them, battery packs play a significant role in order to decrease the total costs of vehicles and, as a consequence, foster their diffusion (Kalaitzi, Matopoulos, & Clegg, 2019). Thus, with the aim of achieving this goal, the battery pack supply chain (SC) needs to be properly designed and managed. In particular, battery pack procurement models adopted by carmakers can become primary decision levers to increase SC efficiency in both operational and economics terms (Rafele, Mangano, Cagliano, & Carlin, 2020).

The existing literature shows that there is a limited number of contributions addressing the LIB SC, usually focusing on specific aspects such as raw material procurement, manufacturing, storage, and transportation conditions, (Arenas Guerrero, Ju, Li, Xiao, & Biller, 2015; Li, Dababneh, & Zhao, 2018; Pelletier, Jabali, Laporte, & Veneroni, 2017). Few papers address battery procurement by car manufacturers and in this field there is a substantial lack of quantitative approaches helping carmakers in the strategic decision about whether internally produce or buy batteries (C. Huth, Kieckhäfer, & Spengler, 2015; Özel, Ernst, Davies, & Eckstein, 2013). In order to contribute to bridge such a research gap, the present work studies a carmaker that is currently starting to deal with the procurement of LIBs to be included in its new low impact cars equipped with electric or hybrid propulsion systems (Scorrano, Danielis, & Giansoldati, 2020). In particular, this contribution presents a preliminary approach supporting the analysis of make or buy strategies for battery pack supply. The authors adopt a logistics perspective and focus on the battery SC portion from suppliers to vehicle manufacturing plants. The proposed analysis framework helps understanding the key variables companies should focus on when approaching a similar strategic decision.

The paper is structured as follows. Section 2 provides a review of the relevant literature on low impact vehicle SC as well as the SC of the associated batteries. Section 3 details the structure of the approach, while Sections 4 and 5 discuss the outcomes of its application to the case car manufacturer. Then, discussion, implications and conclusions are presented in Section 6.

2. LITERATURE BACKGROUND

The authors are interested in exploring the portion of the battery SC regarding the purchasing and the delivery to vehicle manufacturers, which is also an early phase of the SC of their electric and hybrid vehicles. These two topics will be discussed in the remainder of the present section.

The battery pack structure includes three components, namely cells, modules, and packs. The starting point of the battery SC is raw materials (e.g. lithium, cobalt, and

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and cells. The total transportation costs are computed by summing up all the cost items to carry either complete batteries or single cells from the origin to the destination site, including material handling and transport logistics costs. The procedure for identifying the most suitable battery manufacturing facility location is presented in Figure 1.

Fig. 1. Defining battery production facility location

The best location for the battery production plant out of the application of the Network Design Theory is adopted in the subsequent scenario analysis. Detailed geographical information about this location cannot be provided again for company confidentiality reasons.

After scenario setting, the authors and the company representatives selected the criteria against which Scenario 1 and Scenario 2 should be compared. Based on the analysis of mainstream logistics literature and expert knowledge, four interconnected aspects are considered. Each of them is represented by an associated quantitative variable:

- The *number of trips* required every year to carry batteries and the different components to produce packs is analysed. This is a key aspect for assessing a logistics network and the associated characteristics (Černá, Zitrický, & Daniš, 2017). In the analysed case, each truck can carry up to 56 complete LIBs.
- *Transportation costs* of the above mentioned trips are an important driver for logistics decisions that needs to be accurately estimated (Guijarro-Rodríguez, Cevallos-Torres, Valencia-Nuñez, Wilches-Medina, & Correa-Barrera, 2018). The case company outsources transportation to a third party logistics (3PL) provider. The 3PL fee takes into account the distances covered, the transportation mode (Less Truck Load – LTL or Full Truck Load – FTL) and the shipped volume in cubic meters, as well as the special humidity and temperature conditions required by goods (Kouchachvili, Yaïci, & Entchev, 2018) Both material handling costs and truck shipment costs are considered.
- The *level of CO_2 emissions* is assessed for each scenario due to the relevance of the environmental issues (Pierre, Francesco, & Theo, 2019). The grams of CO_2 emitted for each kilometre travelled are computed for any individual trip.
- *Reverse logistics costs* are calculated based on the return flows of unit loads in order to account for the entire logistics process. In fact, reusable unit loads are employed in the studied scenarios (Rogers, Lambert, Croxton, & García-Dastugue, 2002).

The purchasing costs of batteries and cells are not included in the analysis because in Scenario 2 the lower cell costs are compensated by the investment costs in the battery production plant. On the contrary, Scenario 1 requires a greater expenditure on complete LIBs but does not require investing in any additional manufacturing facilities.

4. SCENARIO ANALYSIS

This section focuses on the quantitative analysis of the scenarios discussed in Section 3. The numerical values of the input variables part of the framework cannot be disclosed because they are confidential. For the same reason, all the results are expressed as percentages of the values related to Scenario 2, namely manufacturing LIBs in-house. In both the scenarios, the suppliers and the associated logistics network have been already defined by the focus company. Scenario 1 includes two European battery pack suppliers, and four car production facilities. Batteries are collected from the suppliers and directly delivered to the customer plants. The average distance weighted by volume equals 1,400 km. In Scenario 2, the best location for the battery production plant provided by the Network Design Theory is part of a logistics network constituted by different suppliers, regional hubs, and car production facilities. The minimum distance between two network nodes equals 100 km and the maximum distance is equal to 1,920 km. The average distance weighted by volume equals 1,200 km. Finally, the base case for the investigated scenarios relies on a battery demand level equal to 300,000 units per year, according to the best demand forecast for low-impact vehicles available to the company. Then, in order to validate the obtained results, a sensitivity analysis is performed. In particular, the scenarios are furtherly assessed under two different potential battery demand levels agreed with the company, namely 200,000 units per year and 400,000 units per year.

Figure 2 shows the total number of yearly trips from suppliers (of batteries, cells or other required components) to manufacturing plants in the two scenarios for all the three demand levels. They have been calculated by simulating the logistics flows that buying complete LIBs and single cells would imply with the assumed logistics networks.

Fig. 2. Number of trips

In the base case Scenario 1 requires the largest number of trips due to the lowest saturation of containers as a consequence of the safety and stability issues to be addressed while moving battery packs. On the contrary, in Scenario 2 purchasing cells enables a better saturation of unit loads and a reduced number of trips. However, the need for also transporting the components other than cells necessary to produce finished batteries increases the total number of trips. All these reasons make the difference between the two analysed scenarios equal to 37%. Therefore, this criterion suggests the role of the physical structures of the products to be purchased and transported when setting an appropriate procurement strategy. When the yearly battery demand level increases or decreases, the associated number of trips changes in a similar way. The lower the demand level the less the opportunity to exploit economies of scale in transportation. In fact, when the number of necessary batteries equals 200,000 units, the number of trips decreases by 11.7% compared with the base case. On the contrary, when the demand is equal to 400,000 units, the trip increase is of just 10.2%

Transportation costs (Figure 3) have been calculated as the product between the travelled distances, according to the number of trips previously discussed, and the related transportation fees for both FTL and LTL.

Fig. 3. Transportation costs

In the base case, Scenario 1 yields the highest costs since purchasing assembled battery packs requires a larger number of trips and the payment of an additional fee to the 3PL for carrying dangerous goods and guaranteeing appropriate humidity and temperature conditions during shipping. The same fee applies to the shipment of cells, which also requires particular refrigeration conditions to keep their electrochemical properties. The 3PL charges a separate fee for the refrigeration service. However, the resulting total cost in Scenario 2 is lower than in Scenario 1 because of the already mentioned better unit load saturation and the geographical proximity of suppliers and customers. In fact, in Scenario 1 complete batteries are delivered from their suppliers to car manufacturing plants, while in Scenario 2 the battery pack manufacturing facility is located near the vehicle production plants. Thus, only the required components are moved from their suppliers to the battery production facilities.

When the yearly battery demand, and so the associated required transportation volume, decreases to 200,000 units, the transportation costs increase by 8.5%. In this situation the 3PL has less opportunities to saturate truck loads and optimize transportation, so it charges the company a higher cost. On the other hand, when the yearly battery demand is equal to 400,000 units the decrease in transportation costs is of 15.8% compared with the base case. Figure 4 presents the levels of CO_2 emissions in the two scenarios. They are obtained by multiplying the distances travelled during transportation trips by the CO_2 emissions per kilometre of the truck. The last value represents the average value of the emissions reported in the technical sheets of the considered truck models.

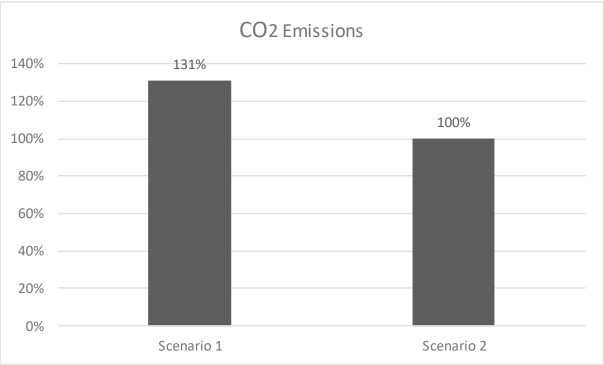

Fig. 4. CO2 emission levels – base case

In the base case, Scenario 1 is associated with the highest emission levels because of the largest number of required trips. On the contrary, Scenario 2 presents lower emissions since the overall number of trips is considerably smaller. These results also depend on the total distances travelled for the considered yearly battery demand. In fact, as pointed out in the previous sections, in Scenario 1 battery packs, with their considerable volumes, are shipped from suppliers to manufacturing plants. In Scenario 2 lower transportation volumes are moved from suppliers to battery production plants, which accounts for the longest distances. Then complete batteries will cover a shorter distance being assembled close to the vehicle production sites.

Figure 5 and 6 illustrate the number of trips to return empty unit loads to their owners and the consequent reverse logistics costs. Unlike in Scenario 2, where foldable plastic boxes are adopted, Scenario 1 relies on traditional metal bins. In fact, they are necessary to carry heavy assembled battery packs. Thus, the return transportation costs of empty unit loads in Scenario 1 are significantly higher than in Scenario 2, where the empty folded boxes make the number of trips and their total costs be limited.

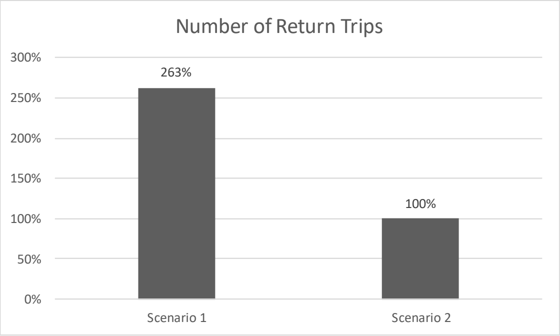

Fig. 5. Number of return trips – base case

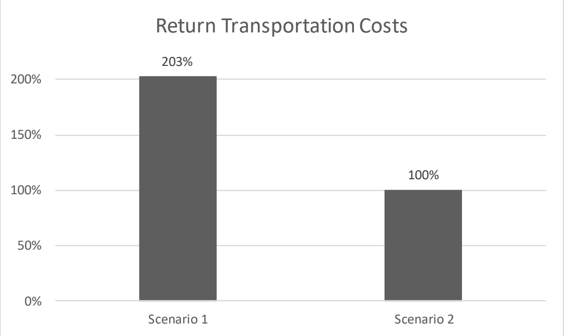

Fig. 6. Return transportation costs – base case

Producing batteries in-house significantly decreases reverse logistics costs due to the transportation of smaller and lightest components that can be accommodated in boxes that are folded when they are empty. This enables a reduction in the return physical volumes to be moved. To better understand the difference in the reverse logistics costs of the two scenarios, it is worth highlighting that the additional fee for carrying dangerous goods is not charged by the 3PL when moving empty unit loads, while in Scenario 2 the refrigeration fee is still paid because the truck insulation system cannot be deactivated.

The CO_2 emission levels, the number of return trips, and the return transportation costs do not show any significant variations as the number of batteries changes in the defined range of values.

5. SUMMARY OF RESULTS

The comparison of the two scenarios against the set criteria allows to develop a comprehensive understanding of their advantages and disadvantages.

Buying complete LIBs is the most expensive solution because it requires high physical volumes and a large number of transportation trips. This aspect, together with the relevant distances between LIB suppliers and vehicle manufacturing plants, makes CO_2 emission levels significant. The high physical volumes also motivate the values of reverse logistics costs. Purchasing single cells to be assembled into modules and then in battery packs proves to be convenient from a pure logistics perspective. However, such a strategy implies relevant investments related to the battery production facilities, as well as additional operational costs and skilled human resources. In the present study investment costs are not considered because the case company can easily convert some of its current facilities for the production of batteries. Moreover, battery manufacturing requires adequate human resource skills as well as a vertical integration capacity by carmakers that cannot be taken for granted. However, the performed analysis reveals that once the starting investments have been re-payed, a more efficient SC can be achieved, especially when the battery manufacturing facilities are located close to the car production lines. Of course, this can be possible only in the long term with a significant decrease in the LIB costs, and an electric and hybrid car market that is well-established and whose production volumes are significantly higher than the current ones. Meanwhile, intermediate options, such as purchasing modules to be assembled in order to obtain battery packs, can be explored as possible viable solutions towards a full integration of LIB production by carmakers.

The focus company will approach the electrification process by adopting Scenario 1, at least in the short-medium run, because it is the most flexible one, although being quite expensive and risky due to the dependence on just two battery suppliers. Flexibility appears to be quite relevant, especially in the current mobility transition from traditional to new propulsion systems. In addition, procurement flexibility, together with the possibility of not carrying relevant fixed costs, are crucial elements during the current transition phase towards electrified mobility. Another aspect supporting the company decision can be related to the specific competences required for undertaking Scenario 2. These skills are still not fully established in the company under study, and more in general among car manufacturers, wherein companies often outsource the production of batteries for their low impact vehicles. However, in the next years, in the case of an increase of the demand for electric and hybrid cars, it is reasonable to deal with a gradual shift to the purchasing of the single battery components.

6. DISCUSSION AND CONCLUSIONS

This work discusses a preliminary approach to analyse the different strategies for procuring LIBs part of vehicle propulsion systems. The purpose is supporting the identification of the relevant aspects to be taken into account, with the final goal of guiding the definition of the most suitable SC configurations. The proposed contribution focuses on the main logistics costs and environmental issues. The presented approach provides a quantitative framework that contributes to enhance the literature about both LIB and electric and hybrid vehicle SCs. This approach is practical and straightforward in nature, thus offering an easy-to-implement methodology that can be adapted to the needs of specific car manufacturers. Moreover, the approach structure can be used as a reference guide to add additional criteria to the analysis. As such, the present work is one of the first attempts to conduct formal yet operational studies on the procurement of LIBs in the automotive sector, which is highly beneficial to design SCs able to contribute to decrease the total battery SC cost. Finally, the proposed research suggests how different vertical integration levels affect logistics and SC management, thus integrating the existing literature on this topic (C. Huth et al., 2015).

Some theoretical and practical implications can be drawn from this contribution. From an academic point of view, it stimulates deepening the study of the SC of batteries for electric and hybrid vehicles, by suggesting how complex this system is. Furthermore, the present paper might encourage the development of battery procurement models by taking into account more quantitative and operational aspects. From a practical point of view, the proposed preliminary approach can assist automotive companies in the selection of LIB supply or production strategies by considering different vertical integration levels together with their effects on SCs. Additionally, the structured LIB procurement management approach suggested by this study is able to support carmakers in effectively designing their SCs.

However, the present work suffers from some limitations. First, logistics operational aspects associated for instance with warehouse activities are not included in the approach. Second, the costs of the auxiliary components (e.g. cables and connectors) that are needed for instance to produce battery packs are not considered. Finally, intermediate scenarios between buying battery packs and producing them in-house are not explored.

Based on these considerations, future research will address additional decision-making criteria, including those related to the internal material handling tasks required by different procurement and assembly policies. Also, the cost of any additional material involved in the battery production process will be considered. Finally, the approach will be extended to analyse multiple options corresponding to different intermediate vertical integration levels.

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