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Fuzzy QFD to Risks Prioritization in the Reverse Logistics of Lead-Acid Batteries

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Abstract. This work prioritized the operational risks present in the reverse logistics of lead-acid batteries in Colombia using the FQFD (Fuzzy Quality Function Deployment). The need arises due to the high exposure of people and the environment caused by the batteries' lead residues. Since their high lead composition makes them a source of pollution, as this element is categorized by WHO (World Health Organization) as one of the ten most dangerous chemical elements in the world, and one of the most harmful to the Colombian population. We identified operational risks in the reverse logistics of lead batteries and a probability-impact matrix to define which of these risks should be prioritized with FQFD. In this way, we established the priority of the risks considered. These prioritized risks will help organizations related to this activity to develop action plans to mitigate or eliminate these risks.

Keywords: Lead-acid batteries, operational risk, fuzzy-QFD methodology, reverse logistics.

1. Introduction

According to (Li et al. 2016), with the increasing demand for Lead-acid batteries (LABs), the amount of lead-acid waste batteries (WLABs) has unavoidably increased. Accordingly, the contamination caused by lead and lead-containing compounds from these WLABs has risen to a new level. Otherwise, Lead-acid batteries were widely used as a power supply in vehicles, uninterruptible power supply (UPS), telecommunication systems, and various traction duties. According to statistics, approximately 3 million tons of waste batteries are generated every year. Lead-acid batteries' production will continue to rise even more sharply with the economy's sustained and rapid development. Lead-acid batteries are composed of electrolyte, lead and lead alloy grid, lead paste, organics, and plastics, including lots of toxic, hazardous, flammable, explosive substances that can easily create potential risk sources (Zhang et al. 2016).

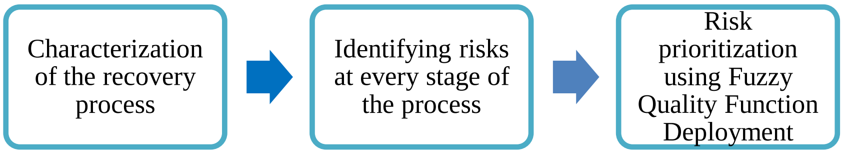

Fig. 1. Methodological design.

On the one hand, according to (Govindan et al. 2017), reverse logistics networks (RLN) are often designed to collect used, refurbished, or defective products from customers and then carrying out some recovery activities. The reverse logistics issue is to take back the used products, either under warranty or at the end of use or the end of the lease, so that the products or parts are appropriately disposed, recycled, reused, or remanufactured (Kannan et al. 2010). But in this case, one of the most important aspects are related to the complex issues depending on social, technical, and legislative factors are: how to prevent the environmental deterioration caused by the generation of hazardous wastes, how to minimize the generation of hazardous wastes, and finally how to recover the valuable material contained by the wastes (Jayant 2015).

On the other hand, operational risk has gained increasing attention in academic research and practice because operational risk directly affects the company's economic results. Due to the influence of risk on logistics performance, implementing risk management has become a critical aspect, and the reverse logistics process is not exempt from operational risks. These situations can affect companies by generating significant economic losses due to sanctions, fines, and compensation, as well as being passed on to the environment: soils, air, and water bringing fatal consequences on the health of people and ecosystems. That is why identifying and prioritizing these risks can be a fundamental activity in establishing actions that are oriented to preserve the health of the people involved in these processes and avoid harmful effects on the environment derived from lead.

2. Methodology

The methodological design for the development of the project is presented below in Figure 1. The methodology will have three phases:

2.1 Characterization of the Recovery Process

It is essential to characterize the reverse supply chain for the recovery of lead-acid batteries, additionally, to identify the processes necessary for this recovery. In this way, with the chain characterized and the processes identified, it will be possible to determine their operational risks.

Table 1. Linguistic scale for the risk identification and fuzzy equivalence for FQFD (Pastrana-Jaramillo and Osorio-Gómez 2018; Osorio-Gómez et al. 2019).

Linguistic Scale	Very low (VL)	Low (L)	Medium (M)	High (H)	Very high (VH)
Numerical equivalence	1	2	3	4	5
Triangular fuzzy number	(0,1,2)	(2,3,4)	(4,5,6)	(6,7,8)	(8,9,10)

2.2 Identifying Risks at Every Stage of the Process

According to (Aqlan and Lam 2015), risk identification is the most important activity in the supply chain risk management system. We use the methodology presented in (Pastrana-Jaramillo and Osorio-Gómez 2018; Osorio-Gómez et al. 2019), a literature review, and application of questionnaires to experts; we identified the main risks associated with the battery recovery process shown in figure 3. The questionnaire's application was carried out individually and allowed the experts to rate the risk, both in probability and impact, using the linguistic scale illustrated in Table 1. In the same table is presented the numerical equivalence used in the prioritization stage.

The data obtained apply Equation 1 and Equation 2 to get the percentages of risk application and weighted averages of the occurrence probability and magnitude of impact (Pastrana-Jaramillo and Osorio-Gómez 2018; Osorio-Gómez et al. 2019):

$$\overline{\mathrm{X}}_i = \frac{\sum_{j=1}^{n}(\mathrm{B}_{i,j} \times \mathrm{M}_{i,j})}{\mathrm{n}};\ \forall\, i, \tag{1}$$

$$\overline{\mathrm{Y}}_i = \frac{\sum_{j=1}^{n}(\mathrm{B}_{i,j} \times \mathrm{P}_{i,j})}{\mathrm{n}};\ \forall\, i. \tag{2}$$

X_i = Weighted average of the magnitude of risk i
Y_i = Weighted average probability of risk i
$B_{(i,j)}$ = Expert's criterion j if i applicable as risk $(1,0)$
$M_{(i,j)}$ = Expert's qualification j on the impact of risk
$P_{(i,j)}$ = Expert's qualification j on the probability of risk i

After getting these data, we built the Impact Matrix. We use the following terminology per section: green are negligible risks, while yellow and red are critical. The latter are the ones selected for the next phase.

2.3 Risk Prioritization Using Fuzzy Quality Function Deployment

Risk prioritization is fundamental to success in defining actions to mitigate or eliminate risks. In this sense, it is crucial to determine this priority based on the companies'

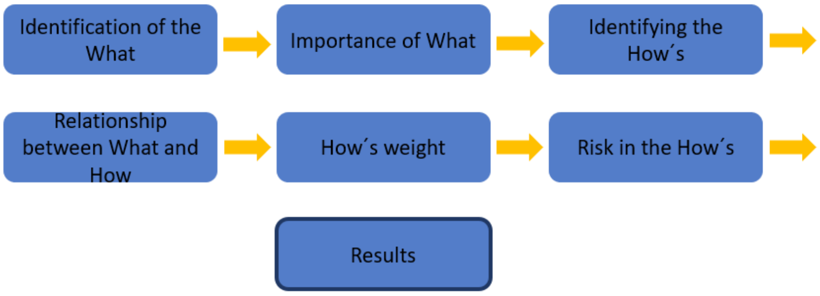

Fig. 2. Fuzzy Quality Function Deployment to risk prioritization (Osorio Gómez et al. 2017).

strategic objectives so that the risks directly impact these objectives so that these are the first to be treated. Some papers use QFD y FQFD in supply chain management and risk management such as (Bevilacqua et al. 2006; Wang et al. 2007), and especially (Gento et al. 2001; Costantino et al. 2012; Lam and Bai 2015) are focused in risk management, but these applications are not with fuzzy logic and are not to risk prioritization. The Fuzzy QFD methodology for risk prioritization is shown in Figure 2. This is according to (Osorio Gómez et al. 2017).

3. Results

Following the methodology presented above, the next results were obtained.

3.1 Characterization of the Recovery Process

Figure 3 present the typical reverse logistics network to lead-acid batteries and figures 4 and 5 show the process of recovering lead-acid batteries. The next phase is to identify the risk in each of the processes.

It is essential to mention that this type of chain typically shows four actors: the producers of the batteries, the distributors of them, the users (who be-come the suppliers of the reverse logistics process once the batteries end their useful life), and those responsible for the collection, transport, and recovery that for this work we call them third parties, as shown in Figure 3.

3.2 Identification of Operational Risks

Table 2 presents the identified risks and the results of the application of the questionnaire. Figure 6 shows the probability impact matrix. In this case, the risks that continued to the next stage are R4, R5, R10, R12, and R13.

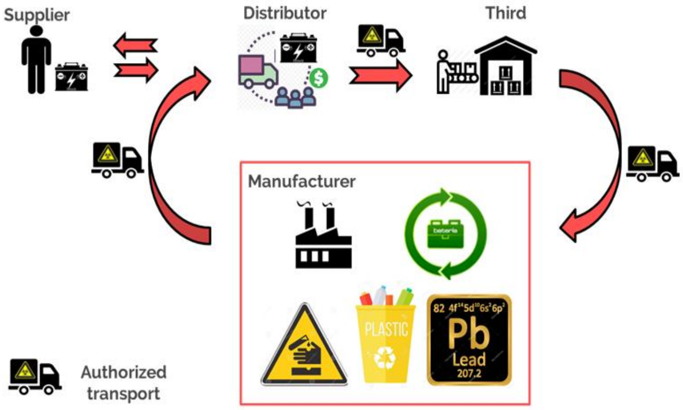

Fig. 3. Reverse logistics network to lead-acid batteries.

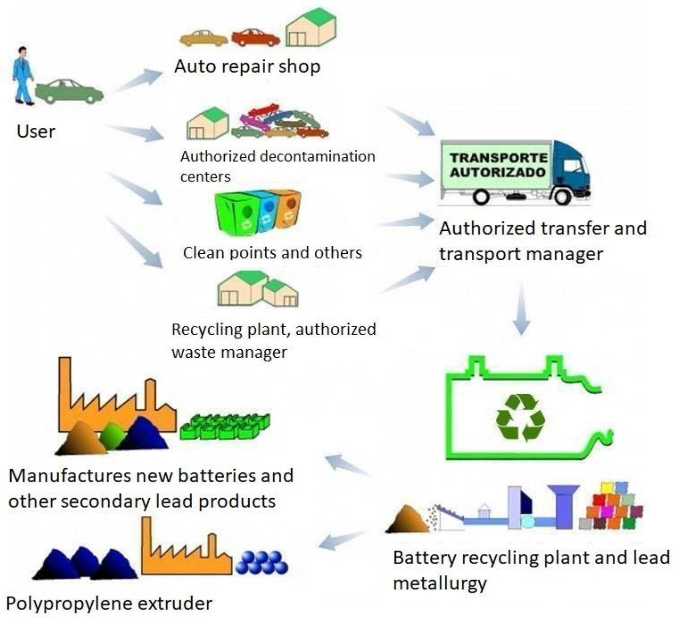

Fig. 4. The battery recovery process in a Colombian company.

1.1 Prioritization of Operational Risks

Following the methodology presented, Table 3 shows the WHAT´S and its importance. We used the triangular fuzzy numbers presented in Table 1.

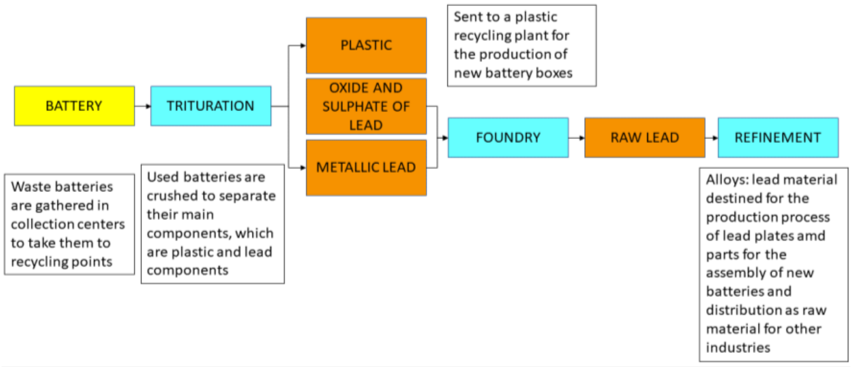

Fig. 5. Battery recovery process.

Table 2. Validation and weighted averages of operational risks.

RISK DESCRIPTION	ID	PROBABILITY OF OCCURRENCE	IMPACT
Sulphuric acid spills in collection and transport	R_1	2,13	2,25
Lead leaks that are incorporated into the soil	R_2	1,13	1,75
Electrolyte spillage (sulfuric acid) in rivers or lakes	R_3	1,38	1,88
Manual battery handling	R_4	3,00	3,50
Soil and environmental pollution from surrounding areas	R_5	2,50	2,63
Dust released from shredders and mills	R_6	1,38	1,63
Inhalation of lead settled in the vibration equipment	R_7	1,75	2,25
Water pollution	R_8	1,50	1,50
Lead dust from process water	R_9	1,13	1,13
Release of fragments and lead dust at the recycling plant	R_{10}	2,25	2,50
Inhale lead vapor	R_{11}	1,75	1,88
Contaminated dust in the screening	R_{12}	2,38	3,00
Poor knowledge about lead toxicity and its management	R_{13}	2,75	3,13

Continuing the proposed methodology, the How´s and their relationship with the What´s were established to obtain the Weight of the How´s. Table 4 presented these. And finally, in Table 5, the results of risk prioritization are obtained. In this case, the most critical risk is insufficient knowledge about lead toxicity and its management.

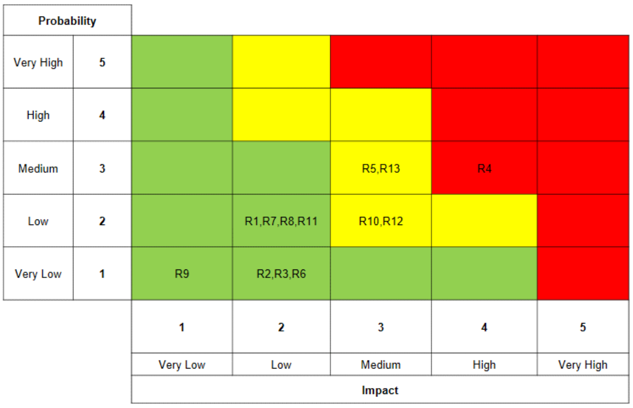

Fig. 6. Risk probability-impact matrix.

Table 3. Internal Variables and their relative importance.

		Weight of WHAT'S		
W1	Preserving the environment	8	9	10
W2	Improvement of people´s health	8	9	10
W3	Satisfy the need of costumers to generate energy	6	7	8
W4	Having a competitive portfolio in the market	7	8	9
W5	Profitability of the company	7	8	9
W6	Alignment with the standards of the parent company	6	7	8
W7	Use of adequate equipment and logistics for handling batteries	4	5	6

However, it is essential to mention that all risks remained in the range between High and Very High, which means that the five risks must have high priority when establishing actions oriented towards mitigation or elimination by those involved.

4. Conclusions

Lead is an element recognized for its toxicity, whose handling carries many risks in its recycling process, including storage, transport, and manufacturing. According to the results, the most critical risks are related to human participation, precisely due to such toxicity. The application of the FQFD allows for prioritizing risks considering the strategic objectives of the processes associated with the reverse supply chain. By considering these objectives and the impacts that risks have on them, better actions can

Table 4. Weight of the How's.

	Strategic objectives or "How's	Weight of How´s		
H1	Continuously improving processes	45	59	76
H2	Safe working methods	43	57	74
H3	Preserving the environment	46	61	77
H4	Ensuring the quality, reliability and technology of machinery and materials	44	58	74
H5	Customer satisfaction	43	57	73
H6	Ensuring battery tightness	43	57	73
H7	Generate added value to the services offered	45	60	76
H8	Support people's personal and professional growth	42	56	72

Table 5. Results of prioritization.

N°	DESCRIPTION OF THE RISK	IPRF
	Very High	**478**
R13	Poor knowledge about lead toxicity and its management	462
R10	Release of fragments and lead dust at the recycling plant	462
R5	Soil and environmental pollution from surrounding areas	458
R4	Manual battery handling	439
R12	Contaminated dust in the screening	436
	High	**375**

be defined or targeted, achieving a more significant effect on the reverse supply chain's overall performance. From the results obtained, the mitigation actions should be geared towards training the staff involved in battery recovery activities to minimize harmful health effects.

Because lead is a highly polluting material, and its extraction and processing negatively affect the environment, recovery from it is significant to minimize such effects. However, if this process's risks are not considered, the benefits that can be obtained in the environment would be counteracted with the negative impact on people's health. This is one reason why prioritization and intervention of these risks is critical Future work could comprise the specific actions towards mitigating or eliminating these risks; other possible works could consider the effects in the environment using, for instance, systems dynamics models to evaluate the environmental impact in the long term.

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