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Prioritization of Operational Risks in a Reverse Logistics Network for the Recovery of Waste Cooking Oil (WCO)

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Reverse logistics networks for Waste Cooking Oil (WCO) have recently taken on great importance, due to legal requirements, cost-benefit considerations as well as social and environmental responsibility. Companies that manage WCO collection, transport and storage processes in these networks are prone to face various operational risks (such as oil spills, thefts, accidents, fires, among others). Recent studies have also shown that an inadequate management of these risks may generate not only a network disruption, but also lead to a loss of materials, time and money. Taking this issue into consideration, this work carries out the characterization of the focused network and subsequently an identification of operational risks in each process. Finally, the risks are prioritized by applying the Fuzzy-QFD tool, considering their impact on the strategic objectives of the processes, obtaining a priority ranking that provides WCO recovery companies with an essential basis for directing their risk mitigation actions.

Keywords: Fuzzy-QFD, Operational risk, Reverse logistics network, Risk prioritization, Waste cooking oil (WCO)

Introduction

Every year about 162 million liters of cooking oil are generated in Colombia, of which 65% is consumed, leaving 35% to become waste.[1] Taking into account that "pouring each liter of used oil can contaminate up to 1,000 liters of clean water", its disposal must be considered in the light of a series of special conditions. For this reason, recent legal developments have emerged regarding the final management of this waste.[2] Regulations such as Resolution No. 0316 of 2018 by the MMA (Ministerio de Medio Ambiente), establish provisions related to the correct disposal of the WCO in the country, and also determine that oil-producing companies must ensure a collection process, either their own or an outsourced one.

In this way, the first ones that are involved in carrying out this WCO recovery are the oil producing organizations.[3] However, it is also found that the main companies that manage this process nowadays are intermediaries[4], such as secondary material merchants that contain recycling facilities, material recovery companies or consolidation points.[1] All these companies in charge of carrying out the collection, transport and storage processes of this waste are exposed to events such as oil spills, thefts, fires, among others, both in the facilities and during the loading, unloading or mobilization of the product, which can result in serious consequences for being a flammable and a highly polluting waste of water resources.[5] In this way, and according to Jiménez Carabalí[6], they face risks that can negatively affect the performance of the entire chain.

These risks are considered as operational, since they refer to the possibility of unexpected events occurring during the daily operation of the chain, including failures related to people, internal processes, technology or consequences of external processes.[7] According to Hatzisymeon *et al.*[8], the companies that manage the WCO recovery processes require stronger management and security tools and standards for the management of this waste, carrying adequate risk management in their operations. If such management is not carried out, these events may generate an interruption in the main processes of the companies, which would have negative impacts in an extended way towards the rest of the activities throughout the chain.[7] This finally leads to losses in terms of time, materials, money, as well as environmental and legal problems due to non-compliance with regulations.

Henceforward, the present study addresses the specific business sector of companies that actively

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participate in WCO recovery logistics network in the country. As this is an emerging sector, it is observed that there is still a lot of informality and there are no public national information sources which show data of all the companies involved in the WCO recovery processes. However, for this study, only the companies listed in regional databases as legally constituted to accomplish these processes were taken into account. A total of 29 companies in different regions of Colombia were identified and contacted. Finally, 12 companies contributed information to the present study, which represented 41.4% of the identified population.

The purpose of this research is to offer an initial overview of the main operational risks associated with a reverse logistics network for the recovery of WCO, in its collection, storage and transport processes. This will help the companies involved in this network to carry out better mitigation planning and risk management in their operations. Additionally, this work seeks to positively impact the environment, since risk management in this activity could help to directly reduce the environmental effects related to the improper disposal of this type of waste.[9]

The present study also aims to fill a gap in the study of the logistics network for the recovery of WCO regarding the management of its operations.[8] The results of this work are considered to be valid mainly at the national level given the particular socioeconomic conditions that were taken into account for the analysis of the risks in the processes. However, many of the identified risks can also perfectly coincide in WCO's recovery logistics chains at the international level.

The present work is conducted through a process of the network characterization, subsequent risks identification and finally a prioritization of them by applying the Fuzzy-QFD tool. These processes are described below in the methodology section. Then, the results are presented and an analysis of the prioritized risks is also carried out.

Methodology

Characterization of the Reverse Logistics Network for the Recovery of WCO

A supply chain consists of all parties directly or indirectly involved in satisfying a customer's request, as mentioned by Chopra & Meindl.[10] The characterization of the chain is then a tool that allows us to know how it works, describing the links and processes that compose it, its objectives, the input and output elements, the actors that interrelate in it as suppliers and customers of each link, as well as the activities carried out and the resources required in each process. The characterization of the reverse logistics network for the recovery of WCO in this work was accomplished under the approach of "productive chains" followed by Orjuela & Chavarrio[11], in which each link is detailed, identifying how each of these participates in the whole chain.

Operational Risk Identification in the WCO Collection, Transportation and Storage Processes

For the purpose of identifying the operational risks in the WCO's collection, transportation and storage processes, a literature review was initially carried out.

Subsequently, the risks in real WCO management chains were validated, through questionnaires applied to those involved in the respective recovery processes of this waste. In these questionnaires, the level of probability and impact of each risk on its respective process were inquired about.

With the qualification obtained and in order to have a better visualization of the final state of the risks[12], they were placed in a probability-impact matrix (Fig. 1).[12] This is a qualitative analysis tool that allows visualizing which risks have a major priority according to the studied variables, probability and impact.[13]

Establishing the Risks that Most Affect the Strategic Objectives of the Processes by Applying the Fuzzy-QFD Tool

In order to establish which risks are the ones that most threaten the achievement of the strategic objectives of the WCO's collection, transportation and storage processes, it was first necessary to select the risks to take into account in order to prioritize them.

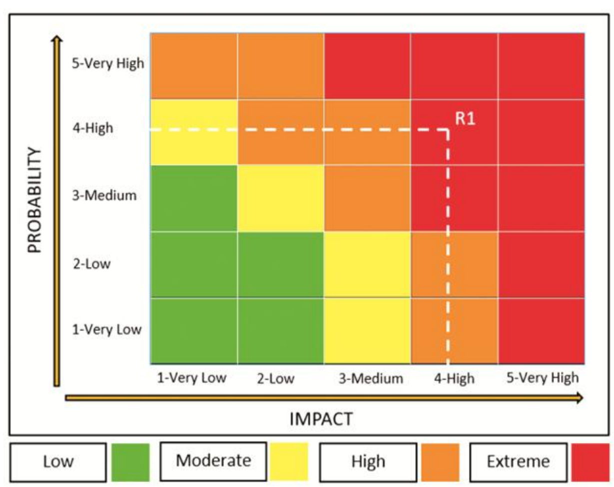

Fig. 1 — Probability-Impact Matrix[12]

Knowing the location of the risks in the matrix, those that are in the high and extreme risk areas (orange and red respectively) were selected, since, according to their rating, they have a significant impact on processes in general and therefore require further attention. This was followed by the definition of an evaluation team and the application of the Fuzzy QFD tool to prioritize the risks.

Definition of the Evaluation Team for the Questionnaire

For the definition of the evaluating team, which is the support to generate the inputs for the application of the prioritization tool, and according to Osorio-Gómez *et al*.[14] and Bevilacqua *et al*.[15], who use a set of criteria for this selection, in the present work the following benchmarks were taken into account: role in the organization, involvement in the processes, global knowledge of the processes and the objectives of each one. Below is an explanation of each benchmark.

The "role in the organization" seeks that the people in the evaluation team hold different positions within the studied chain, in order to have different points of view for the evaluation (e.g., process coordinators, logistics leaders, company directors). "Involvement in the processes" refers to an active participation in the processes studied. It was taken into account that the evaluators had an experience and a minimum time within the logistics network of approximately 2 years. And finally, the benchmark "knowledge of the processes and their objectives" was taken into account to ensure that the people in the evaluation team were aware of all the activities carried out in the processes and how any interruption would affect the achievement of their objectives.

After defining the above, the people who met these criteria were selected. The previous criteria help to guarantee the knowledge of the evaluators in face of the occurrence of different events within the processes and how these can affect the operation of the entire chain and thus the fulfillment of the organizational objectives.

Application of the Fuzzy QFD Tool to Prioritize Risks

For the prioritization of risks, the quality function deployment tool (QFD) was selected since its usefulness is based on satisfying the client's needs from the translation of these into technical engineering requirements that allow generating actions and process plans.[7]

In addition to the application of this tool, the fuzzy theory was used, which according to Bevilacqua *et al*.[15] and Ding[16] allows to take multiple qualitative assessments, which can generate imprecision in the information, and convert these into fuzzy numbers, which are defined numerical sets, in this case triangular numbers, which can be analyzed in a more logical and effective way.

Then, the 'fuzzy QFD' implementation methodology proposed by Osorio-Gómez *et al*.[14], was followed, which consisted of the following stages:

a. Identification of "WHATs"
b. Determining the relative importance of the "WHATs"
c. Identification of "HOWs"
d. Determining the correlation between "WHATs" and "HOWs"
e. Determining the weight of the "HOWs"
f. Determining the impact of risks on the strategic objectives "HOWs"
g. Obtaining the risk priority index
h. Consolidation of the risk priority ranking

a. Identification of "WHATs"

The expectations of each process were defined, which are the priorities of each of the processes involved. This was done by interviewing the members of the evaluation team.

b. Determining the relative importance of the "WHATs" (Iw)

From the fuzzy linguistic scale suggested by Bevilacqua *et al*.[15] the level of importance of each "WHAT" was determined for each member of the evaluation team. This was done through a questionnaire. Taking the ratings of each evaluator, they were converted to the fuzzy number (see Table 1).[15]

c. Identification of "HOWs"

The "HOWs" refer to the strategic objectives of the process. An analysis of the activities of each process was made and interviews were also conducted with the members of the evaluation team to complement the information.

d. Determining the correlation between "WHATs" and "HOWs" (Rwh)

The relationship between the expectations of the process and its strategic objectives was established,

Table 1 — Fuzzy Linguistic scale[15]

Linguistic scale		Fuzzy number
Very Low	VL	(0,1,2)
Low	L	(2,3,4)
Medium	M	(4,5,6)
High	H	(6,7,8)
Very High	VH	(8,9,10)

for which the members of the evaluation team scored using the linguistic scale.

e. Determining the weight of the "HOWs" (WEh)

To calculate the weight of each "HOW", the evaluators' scores were first averaged to obtain a single correlation data (Rwh). Then the information on the relative importance of the "WHATs" (Iw) and the correlation between WHATs-HOWs (Rwh) was taken and Eq. (1) was applied.

$$WE_h = \frac{\sum_{w=1}^{W}(R_{wh} \times I_w)}{w} \quad \dots (1)$$

where,
$WE_h = Weightof\ "HOW"\ h$
$R_{wh} = Correlation$ "WHATs&HOWs"
$I_w = Relative\ importance\ of\ the\ "WHATs"$
$w = "WHATs"$
$h = "HOWs"$

f. Determining the impact of risks on the strategic objectives "HOWs" (RIrh)

Each member of the evaluation team determined, for each of the processes and according to the same scale used, the impact of each risk on each strategic objective "HOW".

g. Obtaining the risk priority index (RPIr)

To obtain the priority level of the selected risks, Eq. (2) was applied, taking the information of the weight of the "HOWs" and the average of the impact of the risks on the strategic objectives. The result is the risk priority index (RPIr).

$$RPI_r = \frac{\sum_{h=1}^{H}(RI_{rh} \times WE_h)}{h} \quad \dots (2)$$

where,
$RPI_r = RiskPriorityIndex$
$RI_{rh} = Riskimpactronthestrategicobjective\ h$
$WE_h = Weight\ of\ the\ "HOW"\ h$
$r = risks$
$h = "HOWs"$

From this equation, the triangular number of priority index was obtained. However, in order to objectively compare the RPI values of each risk and finally define the priority ranking, it was necessary for them to have unique and not triangular values. Therefore, in Bevilacqua *et al*.[15] the use of Eq. (3) proposed by Facchinetti *et al*.[17] is recommended to convert a fuzzy number to a single value number, this value is known as Non-fuzzy RPIr.

$$\text{Non-fuzzy}RPI_r = \frac{a_1 + 2 \times a_2 + a_3}{4} \quad \dots (3)$$

where,
$Non\ fuzzy\ RPI_r$
$= Unique\ value\ of\ the\ RPI\ of\ the\ risk\ r$
$a_1 = First\ value\ of\ the\ triangular\ number$
$a_2 = Second\ value\ of\ the\ triangular\ number$
$a_3 = Third\ value\ of\ the\ triangular\ number$

h. Consolidation of the risk priority ranking

To consolidate the priority ranking of the risks of each process, it was first necessary to establish the limits to identify the priority zones on which the risks will be located. These are "very high", "high", "medium", "low", "very low", and thus be able to identify the urgency of attention to each risk.

To establish these limits, the calculation was made for each of the processes, assigning the impact value corresponding to the area against all the strategic objectives or HOWs, and in this way obtaining the RIrh value of each area and subsequently obtaining the RPIr values and their non-fuzzy value.

Finally, to generate the rankings, the risks were ordered from highest to lowest according to their priority index value along with the limit values.

Results and Discussion

Characterization of the Reverse Logistics Network for the Recovery of WCO

Based on studies and the consultation of processes carried out by different companies in the region, it was possible to identify 5 chain links for the WCO recovery. In this characterization process, a lack of standardization throughout the WCO recovery system in Colombia was identified. However, a general panorama of the processes was presented according to the information collected. In Fig. 2 a diagram is shown where the chain links are appreciated, as well as the main processes and the actors related to the interior of the chain.

I Link: Suppliers (WCO Generators)

In this link the main input of this chain is generated, the Waste Cooking Oil (WCO). The identified actors can be specified in two large groups: Households and businesses.

II Chain Link: Recovery

In the recovery link, 3 processes take place: Collection, Transportation and Storage of WCO. The first process begins with the contact between the WCO generator or collection point and the collection company, in which dates and frequency of collection are stipulated and the respective containers or drums are delivered to the generators or collection points

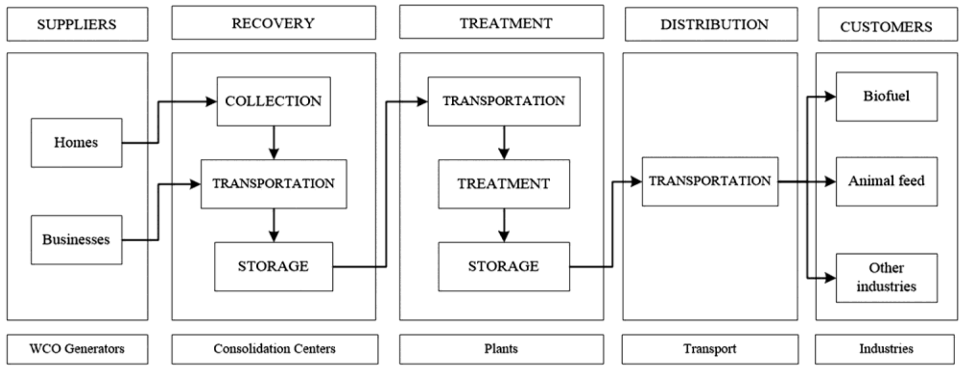

Fig. 2 — WCO Reverse Logistics Network

where they will collect the WCO. In accordance with the stipulations, the company arrives at the generator site to collect the full container and instead leaves an empty one.

After the WCO is collected, the transport process continues. At this point, the containers collected from each collection point (store) or business are taken in a vehicle provided by the company to a consolidation center or storage area. In this last process, the WCO is generally poured into a tank, so that the containers are reintegrated into the collection process. The oil is stored until it passes to the next link, either to be treated or directly until another organization requires it for its use in the generation of new products, as it is in most cases in the sector.

III Chain Link: Treatment

In this chain link, the initial treatment of the WCO is executed, which consists of filtering and refining, where all unwanted substances such as moisture, impurities and solid waste from the WCO are eliminated, among the companies that take place in this link are some of those involved in the previous one.

IV Chain Link: Distribution

In the distribution link, the collecting companies are in charge of distributing the treated WCO to the industries that require it for its use, for this process there are different situations. The first is that the industry requests the WCO and the collection companies themselves are in charge of bringing the oil to them. The second situation is the case in which the different industries are those who have their own vehicles to collect the oil for its use.

V Chain Link: Customers (Industries)

In this last link, the different industries receive WCO treated as raw material to be used for the generation of new products. The greatest example of the exploitation of WCO is the Generation of Biodiesel. However, it is worth mentioning that there are other industries that use WCO as a raw material for the generation of new products such as: chemicals, cosmetics, paints, cleaning materials, animal feed, among others.[18,19]

It was observed that most of the organizations considered in this study that carry out these processes in the country are small and emerging and only operate up to the recovery link, since these companies studied do not have large economic resources and the activities corresponding to this link do not require a great strength in this area, as the following links do, which are treatment, distribution and exploitation.

In addition, as it is an emerging process in the country, some issues were observed. On the one hand, there is still a high informality in the business sector and on the other hand, there is little willingness and interest from some companies in managing these processes and their risks since they are focused on their operation. In this regard, some authors mention that adequate incentives could help to increase the participation from actors and to have more control over the processes within the recovery chain of this waste.[20]

Operational Risks Identification in the WCO Collection, Transportation and Storage Processes

From the perspective of the literature, a total of 50 risks were identified, 14 for the collection process, 25 for the transportation process and a total of 11 risks for storage process. The identified risks were validated in real WCO recovery chains, considering their stakeholders, as developed in Hatzisymeon *et al*.[8] This was carried out through a designed questionnaire, which was directed to various companies nationwide that have experience and knowledge in the respective WCO collection, transport and storage processes. Responses to the questionnaire were received by twelve companies, obtaining the probability and impact of each of the risks in the analyzed processes. The consolidated data can be seen in Table 2.

The risks of each process were placed in probability-impact matrices to have a better visualization of their final state, see Fig. 3.

Once all the risks of each process were reflected in the probability-impact matrix, this allowed selecting the risks in order to continue prioritizing them through the application of the Fuzzy QFD tool.

Establishing the Risks that Most Affect the Strategic Objectives of the Processes by Applying the Fuzzy-QFD tool

Selected Risks

The risks selected to apply the Fuzzy-QFD prioritization tool are those that are in the high and extreme risk areas (orange and red respectively) of the Probability-Impact matrices. These were 31 risks in total, 10 for the collection process, 16 for the transportation process, and 5 for the storage process.

Definition of the Evaluation Team for the Questionnaire

Prior to the prioritization phase and according to the criteria defined in the methodology, the evaluation team was defined as: E1 – Operational director

Table 2 — Risks identified in the WCO collection, transportation and storage processes and their probability and impact

COLLECTION				TRANSPORTATION			
R	Description	P	I	R	Description	P	I
RC1	WCO drips or leaks	1.92	2.08	RT1	WCO drips or leaks	2.50	2.92
RC2	WCO spill	2.25	2.67	RT2	WCO spill	2.50	3.00
RC3	Fire	0.83	1.33	RT3	Fire	1.00	1.42
RC4	WCO contamination	1.67	2.00	RT4	Mechanical failures in the vehicle	2.33	2.67
RC5	Non-compliance with WCO requirements	2.58	2.83	RT5	Driver recklessness	2.14	2.95
RC6	Containers at capacity limit	2.83	2.83	RT6	Vehicle documentation problems	2.92	3.42
RC7	Containers deterioration	2.83	3.25	RT7	Traffic accident	3.00	3.33
RC8	Non-delivery of WCO by the supplier	2.33	2.48	RT8	Criminality	2.00	2.42
RC9	Communication problems with suppliers	2.67	2.67	RT9	Public demonstrations	1.50	1.94
RC10	Difficulty of access to collection area	1.92	2.42	RT10	Delay due to traffic inspection	0.92	1.08
RC11	Theft of containers	3.08	3.25	RT11	Disasters on the road	1.83	2.25
RC12	Insufficient collection capacity (vehicle)	2.42	2.58	RT12	Roads in poor condition	2.25	2.67
RC13	Low recycling rate	3.17	3.33	RT13	Traffic congestion	2.50	2.50
RC14	Competition with informal collectors	4.25	4.42	RT14	Bad weather conditions	1.33	1.40
				RT15	Earthquake (or other natural phenomenon)	1.17	1.50
STORAGE				RT16	Breach of traffic regulations	2.83	3.00
R	Description	P	I	RT17	Non-compliance with WCO transport regulations	3.25	3.50
RS1	WCO drips or leaks	2.58	3.00	RT18	Limited vehicle load capacity	1.92	2.08
RS2	WCO spill	2.75	3.08	RT19	Communication problems with transporter	1.83	2.33
RS3	Fire	1.92	2.17	RT20	Rise in the cost of fuel	2.75	2.67
RS4	WCO contamination	2.00	2.17	RT21	Vehicle fuel depletion	2.33	2.58
RS5	Deterioration of containers or tanks	2.83	3.42	RT22	Difficulties in finding some directions	1.92	2.08
RS6	Improper storage	2.58	3.08	RT23	Non-compliance by outsourced transport company	2.33	2.50
RS7	Theft of containers	1.92	2.17	RT24	Improper handling of the product	2.75	3.00
RS8	Excess of the maximum allowed storage time	1.25	1.67	RT25	Inadequate distribution of containers in the vehicle	2.42	2.67
RS9	Pipes obstruction	1.67	2.25				
RS10	Floods	1.92	2.83				
RS11	Earthquake (or other natural phenomenon)	1.50	2.08				

Notes. R: Risk, P: Probability, I: Impact

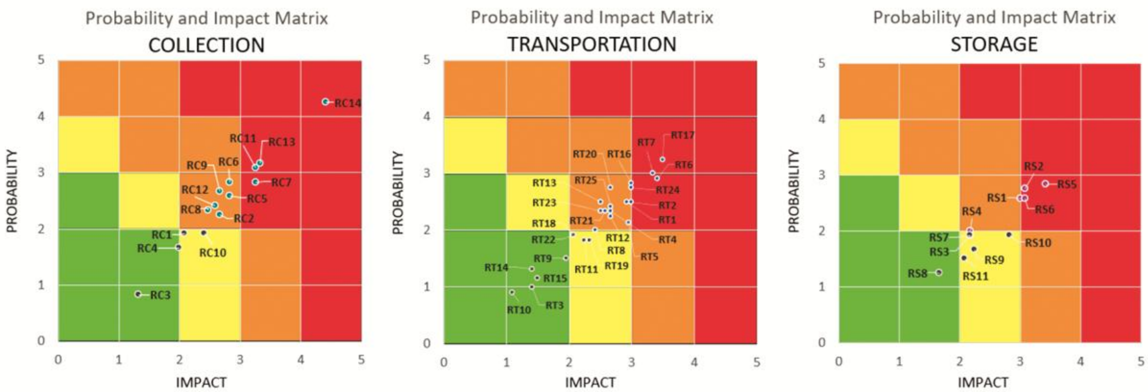

Fig. 3 — Probability-impact matrices of identified risks

company 1, E2 – Logistics co-leader company 2, E3 – Operational director company 3, E4 – Logistics co-leader company 4 and E5 – Director company 4.

Application of the Fuzzy QFD Tool to Prioritize Risks

As presented in the methodology, risk prioritization is carried out from a multi-criteria approach. In the literature there are authors who have used methods such as Fuzzy AHP[21,22], however, in this process the Fuzzy QFD tool is used, which is novel in its implementation for risk prioritization. In addition, this study seeks to take advantage of one of the greatest benefits of this method, which is the alignment of processes with the strategic objectives of the companies.

a. & b. Identification of "WHATs" and their relative importance

The results of the first two phases within the application of the Fuzzy-QFD tool are shown in Table 3. This corresponds to the expectations or "WHATs" defined for each process and their relative importance (Iw) converted into a fuzzy number.

c., d. & e. Identification of "HOWs" and their weight

The Strategic Objectives or " HOWs " identified for each of the processes, as well as their final weights (WEh) are shown in Table 4.

f. g. & h. Risk Impact on Strategic Objectives, Risk Priority Index and Consolidation of the risk priority ranking

The impact of each risk on each strategic objective was calculated and then the Risk Priority Index (RPIr) was found. Finally, ordering the risks from highest to lowest according to their priority index, they were placed in a table with respective limits and colors for a better visualization of their priority. The final consolidated can be seen in Table 5.

The numerical values (RPIr) obtained in the risk priority ranking are associated with the impact that

Table 3 — "WHATs" of the processes and their relative importance

ID	WHAT		Iw	
	COLLECTION PROCESS			
WC1	The WCO has the required conditions	6.4	7.4	8.4
WC2	The WCO is delivered properly stored	5.2	6.2	7.2
WC3	Availability of WCO suppliers to deliver it	5.2	6.2	7.2
WC4	Collecting the largest amount of WCO	4.8	5.8	6.8
	TRANSPORTATION PROCESS			
WT1	Sufficient capacity for transportation	5.6	6.6	7.6
WT2	Avoid spillage and product loss	6.0	7.0	8.0
WT3	Prevent theft of containers	3.6	4.6	5.6
WT4	Prevent product contamination	6.4	7.4	8.4
	STORAGE PROCESS			
WS1	The WCO is preserved in good condition	6.8	7.8	8.8
WS2	The product is not contaminated	6.8	7.8	8.8
WS3	Large amount of stored WCO	5.2	6.2	7.2
WS4	Containers are in good condition	6.0	7.0	8.0

each risk has on the achievement of the strategic objectives of the analyzed processes in the WCO logistics chain. These values are relative and are directly related to the "WHATs" (expectations) and "HOWs" (strategic objectives) established in this particular study. Therefore, they would not be comparable with those obtained in other similar studies given its particular characteristics. However, within the study these values are indeed comparable to each other, indicating that the highest are the most critical.

Additionally, it is important to remember the intervals derived from the fuzzy scale that was defined in the methodology. These intervals are very low-low, low-medium, medium-high, high-very high, and are essential to better visualize and understand the criticality of risks.[15] Within these intervals, the risks that are in the highest interval, in this case medium-high, must be addressed immediately, since the materialization of these risks would have the most serious effects on the fulfillment of the objectives of the processes, in comparison with the other risks.

Table 4 — "HOWs" of the Processes and their weight

ID	HOW - Objective	WEh		
	COLLECTION PROCESS		-	
HC1	Contact more suppliers	23.9	34.8	47.7
HC2	Provide variety in remuneration	22.9	33.6	46.3
HC3	Communicate requirements clearly	29.4	41.1	54.8
HC4	Provide standard containers	24.6	35.6	48.6
HC5	Make various delivery methods available	24.0	34.9	47.8
	TRANSPORTATION PROCESS		-	
HT1	Have the appropriate vehicles	30.5	42.4	56.3
HT2	Have control of spills inside the vehicle	23.8	34.3	46.8
HT3	Ensure appropriate driving practices	24.6	35.3	48.0
HT4	Verify the correct condition and disposition of containers	30.4	42.3	56.2
	STORAGE PROCESS		-	
HS1	Control the maximum storage time	25.5	36.8	50.1
HS2	Store containers properly	40.5	54.2	69.9
HS3	Avoid exposing the product to high temperatures	27.4	39.0	52.6
HS4	Ensure hygiene conditions and pest control	33.1	45.5	59.9
HS5	Have enough storage capacity	31.2	43.6	58.0

For the collection process, the risk of "competition with informal collectors" was the most critical. According to the evaluation team, it represents a great concern since there is a black market, that puts this oil in the initial consumer market violating all health measures and putting people who purchase this oil at risk. For this reason, in addition to the actions that companies subsequently should take to mitigate this risk, it is evident that its management demands external public policy actions that transcend the organizations themselves and are expected to be built within the country.

The next risks in this interval in order of priority of the collection process are "communication problems with suppliers" and "non-compliance with WCO requirements". The first refers to the difficulty in establishing contact with suppliers and coordinating the times and spaces for the collection of the WCO. Second, WCO does not meet minimum quality and storage characteristics. If this happens, it would be difficult to coordinate and carry out the subsequent processes of transport, storage and even subsequent sale and treatment of the WCO.

In the transportation process, the risk of "roads in poor condition" was given the highest priority. These

Table 5 — Risk Priority Ranking

COLLECTION

R	Description	RPIr
H	*High*	261.4
RC14	Competition with informal collectors	224.0
RC9	Communication problems with suppliers	209.0
RC5	Non-compliance with WCO requirements	188.8
M	*Medium*	188.4
RC8	Non-delivery of WCO by the supplier	165.9
RC13	Low recycling rate	165.3
RC12	Insufficient collection capacity (vehicle)	165.1
RC2	WCO spill	153.5
RC7	Containers deterioration	145.8
RC11	Theft of containers	132.8
RC6	Containers at capacity limit	121.3
L	*Low*	115.5

STORAGE

R	Description	RPIr
H	*High*	317.0
RS6	Improper storage	285.3
RS5	Deterioration of containers or tanks	247.6
M	*Medium*	228.3
RS2	WCO spill	210.8
RS1	WCO drips or leaks	205.2
RS4	WCO contamination	193.6
L	*Low*	139.6

TRANSPORTATION

R	Description	RPIr
H	*High*	279.6
RT12	Roads in poor condition	225.5
RT4	Mechanical failures in the vehicle	221.5
RT2	WCO spill	218.7
M	*Medium*	201.5
RT1	WCO drips or leaks	197.4
RT5	Driver recklessness	196.5
RT7	Traffic accident	182.1
RT17	Non-compliance with WCO transport regulations	175.9
RT24	Improper handling of the product	171.3
RT16	Breach of traffic regulations	166.8
RT25	Inadequate distribution of containers in the vehicle	156.4
RT6	Vehicle documentation problems	147.2
RT20	Rise in the cost of fuel	134.9
RT13	Traffic congestion	134.1
L	*Low*	123.3
RT23	Non-compliance by outsourced transport company	118.2
RT21	Vehicle fuel depletion	107.8
RT8	Criminality	87.9
VL	*Very Low*	45.2

can sometimes cause the partial or total loss of the product and organizations must act by taking alternate routes or slowing down, generating delays in the process. The second highest priority risk in the transportation process is “mechanical failures in the vehicle”. This could lead to accidents or the vehicle stranding, and this can consequently lead to the loss of the product due to possible spills or due to its exposure for a considerable period to inadequate storage conditions.

A third and final risk within this priority range of the transportation process is the "WCO spill." In the first instance, this can cause the loss of the product because it cannot be recovered or because it has been contaminated. At the same time, this can create a much higher risk of fire or explosion in the vehicle as it is a highly flammable liquid.

Finally, for the storage process, it is observed that the risks with the highest priority index are “improper storage” and “deterioration of containers or tanks”. The evaluation team stated that improper storage can cause spillage or loss of the product. On the other hand, a poor condition of the containers could also cause contamination and loss of the required characteristics of the WCO. This could lead to difficulties for its subsequent transfer, sale or treatment.

Based on the aforementioned, the need for organizations that carry out WCO recovery activities to consider the mitigation of these risks as improvement objectives is evident. By defining the priority of attention to risks in this descending ranking, a route of treatment of these risks is offered. After addressing the above medium-high interval risks, organizations can proceed to address the next low-medium interval risks.[14] It can also be observed that the categorization by intervals of the risks helps to identify those that are in the lowest interval. Although these risks should be addressed, they would not have a high level of urgency and therefore do not denote immediate actions for the organization.

In accordance with the analysis made, the results in this study will help those involved in the different WCO management processes analyzed, to identify the most critical risks, their causes and to carry out action plans in a systematic and efficient way to control or mitigate them first, taking into account that these are the ones that would most affect the fulfillment of the strategic objectives of the processes. In this way it would be possible to obtain greater stability and security in the operations of these organizations.

Conclusions

Through the characterization process of the WCO chain, it was possible to determine its main links. These are generation, recovery (which is also made up of collection, transport, and storage process), treatment, distribution, and exploitation.

In the literature review performed, 50 operational risks were identified. Then, with the participation of different companies, it was possible to determining the probability and impact of these.

The Fuzzy-QFD tool made it possible to efficiently prioritize the risks. When executing the tool, 8 high priority risks were established, which represents 25.8% of the selected risks for prioritization and require immediate attention since they affect to a greater extent the fulfillment of the objectives of each process.

Some limitations in this research were related to the methodological process, as this implies interaction with those involved in the chain's processes, which requires time and coincidence. This limits the responses received and thus the possibility of extending the level of generality of the results. However, for future developments, there is an opportunity to expand the study to other processes within the WCO logistics chain, such as treatment and conversion of WCO into new products, or to other reverse logistics chains related to the management of waste materials.

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