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METHODOLOGY FOR THE MANAGEMENT OF RISK IN THE STORAGE AND TRANSPORT OF HAZARDOUS SUBSTANCES

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Abstract: The decision making has great importance in the formulation of prevention and recovery policies against technological accidents in the chemical process industry and companies that handle hazardous substances. The main objective of management of technological risks in storage and transport activities along the supply chain, is the search of alternatives to reduce or mitigate the major hazards without eliminating the obtaining of benefits. The objective of this research is to develop a general procedure and its methodological instruments for the management of risks of major accidents in activities of storage and distribution of hazardous substances. It includes multicriteria analysis, risk measurement methods and control tools to identify, characterize and hierarchize the storage areas and distribution routes of greater danger. The application of the procedure enables the reorientation of organizational efforts supported by information technologies and ensures a continuous improvement approach. This research takes as case of practical study the logistics network of Fuel Trading Company of Villa Clara and uses the strategy of multiple explanatory cases in different companies that operate with hazardous substances in the province. As a result, a ranking was obtained of the activities where dangerous substances are manipulated, for the execution of evaluation and mitigation actions.
Keywords: risk management; hazardous substances; multicriteria analysis; control tools

INTRODUCTION

Modern industry is characterized by continuous growth of the unitary power on its plants, to obtain better performance[6]. Regardless of the scientific technical development, the increase in the complexity`s degree of technological processes generates risk conditions in society and natural environment that acts as support for it [1, 7]. Given this reality, the paradigm of technological risk management and the conceptual approach (social, economic and environmental) that underlies it, have evolved from the theoretical point-of-view in a remarkable way [10].

The importance of risks management in the handling of hazardous substances is given by the following aspects: production increase on products of high added value, which require industrialized processes with narrow safety margins [11]; increase of inventories [5]; diversity of distribution routes, change in risk profiles of the supply chain as a result of changes in their business models [9]; population growth that leads to an unplanned urbanization near the industrial sector [12]; the inclusion in the organizational performance of the sustainable development concept [3]; the need to ensure the efficient and optimal allocation of limited resources in processes of evaluation and risk management [12].

On the literature review, the research problem was defined as the lack of a prescriptive theory for analysis of major hazards in logistic activities of storage, processing and distribution of dangerous substances.

The decision making in the logistic processes when hazardous substances are handled requires that the risk is measured and represented by models, maps and indices. These should consider the existing dangers, the vulnerability of the system, the expected physical damage and the possible aggravation of the impact according to social, economic and environmental conditions.

Reference [2, 13] consider that the main objective of the management of technological risks within the logistics process is the search of alternatives to reduce or mitigate the major hazards without eliminating the obtaining of benefits. In this regard, a multicriteria analysis is necessary to manage the uncertainty regarding a threat and the vulnerability of the system. This must be done through a sequence of activities that include the identification of triggering events, prevention and mitigation actions, levels of acceptability, disaster management, governance and transfer.

Despite the importance given by the government, the academic circles and the business sector, Cuba recognizes the lack of a framework that analyzes the complexity of the major technological risks in the supply chains. The absence of a holistic conception and a systemic and continuous improvement approach, which addresses all dimensions of risk management, limits a modification of the situation reflected.

The present research shows a procedure for the management of technological risks in activities of storage and distribution of hazardous substances as support for the decision making process. This document is structured in five sections. In the next section, a research background of the models and indices of evaluation of technological risk, and a discussion about its advantages and limitations is presented. Section 3 proposes a methodology for management of technological risks in logistics processes where hazardous substances are handled. Results and conclusions are presented in section 4 and 5.

RESEARCH BACKGROUND

Several methodologies have been developed to study technological risks in logistics processes. According to different probable risk scenarios and their interaction with the environment, those methodologies have progressed towards a dynamic direction [8].

Technological risk management depends on the measurement of the level of risk associated with the identified hazards. It also depends on the degree of precision with which the variables that condition it and its synergy are determined [11]. The risk profiles should show the existing situation and allow the classification and prioritization of activities.

The choice of risk metrics is critical since it selects the type of information included in the study and legitimizes the results [9]. Consequently, the assessment of risk level must be deployed by various levels of analysis: risk activities, logistics processes and supply chains. Some advantages reported in the reference [3, 4, 11, 13] of use of risk indexes in security management systems are:

- Reducing the complexity of risk management at the company level and make it possible to measure their social and environmental performance. The information is synthesized and expressed by a numerical value including parameters and/or variables of risk management.
- Evaluate and support decisions regarding environmental and social impact allowing the observation of evolution in the time and study trends about disaster situation.
- Fulfillment of accomplish with social and environmental laws.
- Operability of the strategies. It shows the limits for acceptable operations that can lead to better efficiency of process and serve as basis for planning inspections and establishing prevention measures.
- Improvement of performance. It facilitates internal communication and helps to maintain a high degree of awareness about prevention of major accidents. Facilitates the efficient and optimal allocation of limited resources for risk assessment around the classification and prioritization of different scenarios.

Reference [2] states that determining the level of risk requires the use of different mathematical and empirical models. Reference [8] provides an explanatory overview of risk metrics related to the study of major accidents.

At the same time, it shows in most cases these are conditioned to estimate certain variable within the risk assessment process, making it difficult to prioritize the sources of technological risks within a supply chain.

METHODOLOGY TO DETERMINE THE LEVEL OF TECHNOLOGICAL RISK IN LOGISTICS PROCESSES

In this section we will show how to determine the current risk level in the logistics processes. To achieve this goal we will follow the procedure shown in figure 1.

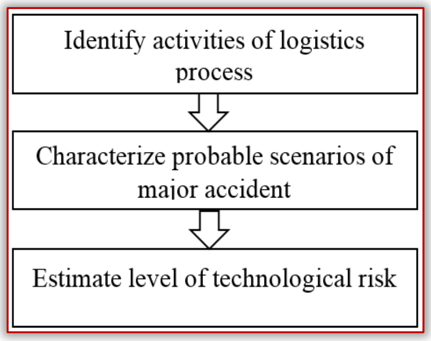

Figure 1. Methodology to determine the level of technological risk

Identify activities of logistics process

This step constitutes the basis to determinate the scenarios of major accident occurrence considering the hazard of technological risk. All activities and relations between different organizations belonging to the supply chain are delimited. Once the flows of existing materials have been analyzed, a unique inventory of hazardous substances is made. This inventory relates all substances with potential to trigger a major accident, causing damage to people (workers and surrounding communities), industrial or public property and environmental components.

The experts will assess the physical-chemical nature of inventoried substances and type of potential damage (explosives, flammable-toxic liquids, and flammable-toxic gases), forms of containment, associated activities (storage, processing, and distribution), possible initiating events, disasters events that can be triggered and routes of propagation.

Characterize probable scenarios of major accident

In this step, the group of experts must establish a sequence of accidents that can be triggered considering the occurrence of an initiating event:

- Spillage of toxic liquids: due to loss of fluid containment, it can generate toxic effects, fires and/or explosions, depending on the nature of the substances.
- Exhaust of gases: due to loss of fluid containment, it can generate toxic effects, fires and/or explosions, depending on the nature of the substances.
- Fire: combustion of multiple forms of the contained or emitted fluids generates harmful thermal radiation, when the substances are flammable.
- Explosion: prior to the emission or after the fire, generates pressure or overpressure waves, and the propagation of projectiles.

The process is supported by the software ALOHA (Areal Locations of Hazardous Atmospheres). This computer program designed for models key hazards-toxicity, flammability, thermal radiation (heat), and overpressure (explosion blast force) - related to chemical releases that result in toxic gas dispersions, fires, and/or explosions. Its chemical library contains information about the physical properties of approximately 1 000 common hazardous chemicals.

ALOHA allows to determinate the radius of affectation in the event of a major accident taking into account: type of substance, form of containment and description of how the chemical is escaping from containment, and weather conditions. The software will display the threat zones in red, orange, and yellow. The red threat zone represents the worst hazard and the orange and yellow threat zones represent areas of decreasing hazard.

Estimate level of technological risk

In this step, the level of technological risk will be assessed in logistics activities. The risk level estimation must quantify the damage caused within the affected radius, delimited in the previous step. A holistic assessment of risk takes into account: 1) the physical damage: number of victims and economic and environmental losses (first-order effects) 2) the conditions related to the social fragility and the resilience lack of communities that favor the occurrence of accident or aggravate the impact of these (second-order effects).

The analytical structure of indicators systems for holistic evaluation of technological risk *(IRT)* in an activity *i* is expressed as the sum for each possible event *e* (fire, explosion, spill, escape), considering their occurrence probability p_e and probable physical consequences C_e within the radius of affectation. It is affected by a coefficient of aggravation of the impact Cai, which depends on conditions of socioeconomic fragility and lack of resilience of the community (equation 1).

$$\mathrm{IRT_i} = (1 + \mathrm{Cai_i}) \sum (\mathrm{p_{ei}} * \mathrm{C_{ei}}) \qquad (1)$$

The consequences respond to the determination of the physical damage before an event e in activity i. This is evaluated using the equation 2.

$$\mathrm{C_{ei}} = \sum_{n=1}^{p} w_{XC_{ne}} * X_{C_{ne}} \qquad (2)$$

where $X_{C_{ne}}$ represents the physical risk factors, $w_{XC_{ne}}$ the weights of these factors and p is the total number of factors to be considered in the calculation. We propose the quantification of victim's number, economic losses and environmental damage, with an equivalent weight.

The coefficient of aggravation $\mathrm{Cai_i}$ depends on the weighted sum of a set of aggravating factors in the social, economic, ecological, structural, nonstructural and functional perspective; associated with the fragility of community X_{FSi} and the resilience lack of context X_{FRj}, being w_{XFSi} and w_{XFRj} the weights of each factors.

$$\mathrm{Cai} = \sum_{i=1}^{m} (w_{XFSi} * X_{FSi}) + \sum_{j=1}^{n} (w_{XFRj} * X_{FRj}) \qquad (3)$$

The evaluation results of analysis units are presented in terms of relative indexes of physical risk, socioeconomic fragility, resilience lack of and total risk. The set of descriptors used in the multicriteria evaluation corresponds to qualitative or quantitative data that are derived from previous studies, damage scenarios and socio-economic information of the context to be analyzed.

The descriptors proposal was made based on a bibliographic compilation of risk indicators proposed by other methodologies to assess physical risk, socioeconomic fragilities and resilience lack (table 1).

Table 1. Descriptors of socioeconomic fragility and lack of resilience

Perspective	Descriptors	Criteria
Social	Population density	X_{FS}
	Presence of community areas	X_{FS}
	Level of human development	X_{FR}
	Reaction capacity	X_{FR}
	Perception of risk	X_{FS}
Ecological	Vulnerable environmental receptors	X_{FS}
	Reversibility of damage – recovery	X_{FR}
Economic	Potential losses	X_{FS}
	Financial resilience	X_{FR}
	Institutions within the radius of affectation	X_{FS}
Structural	Physical condition of constructions	X_{FS}
	Nearby facilities that handle hazardous substances	X_{FS}
	Protection of facilities	X_{FS}
	Evacuation system	X_{FR}
	Structural reconstruction	X_{FR}
Not structural	Presence of aggravating non-structural units	X_{FS}
	High density traffic routes	X_{FS}
	Non-structural reconstruction	X_{FR}
Functional	Security practice	X_{FR}
	Emergency plans (internal and external)	X_{FR}
	Operability the emergency	X_{FR}
	Firefighting brigades	X_{FR}
	Hospital services	X_{FR}

These descriptors used in holistic risk assessment have different units. To standardize the gross value of the descriptors, transforming them into commensurable values, must be used transformation functions with the pattern shown is Figure 2.

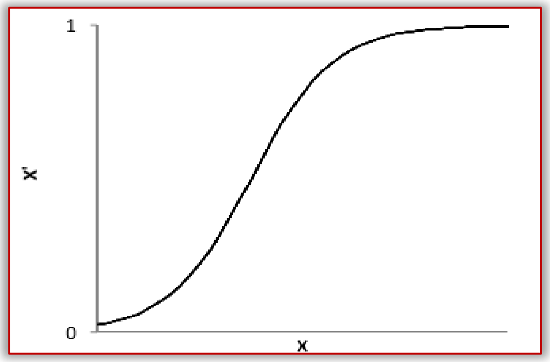

Figure 2: Sigmoidal transformation function for the normalization of risk indicators

The previous function responds to the equation 4.

$$X' = \frac{1}{1 + e^{-\beta\left(\frac{X-m}{M-m} - \mu\right)}} \qquad (4)$$

where,
X: Initial value of the indicator
X': Normalized value of the indicator
e: Base of natural logarithm
β: Parameter - slope of the curve
M: Maximum value of parameters (table 1)
m: Minimum value of parameters (table 1)
μ: Point of inflection of the curve

The parameters valuesused for the transformation of each descriptors are obtained from the reference values established by experts, bibliographic review, observations made in major accidents and examination of descriptor statistics along the chain.

The weights of the descriptors represent the relationships of hierarchy (relative importance) in the aggregation process through a multicriteria evaluation. The evaluation of these coefficients is carried out through the analytical hierarchical process (AHP). This is based on the comparison between pairs of descriptors to establish the relative importance (quantitatively). These comparisons generate a matrix that allows to calculate the weight factors and verify the exercise consistency. As a result, we obtain a set of weight factors that are less sensitive to judgment errors.

A network can be generated from a hierarchy by gradually increasing the interconnections. This allows to generate a network, taking into account all existing relationships between levels (perspectives) and between alternatives (descriptors) without assuming the axiom of dependence. At the same time, it generates maps of causal relationships, with a solid mathematical foundation. The figure 3 shows the analytical network modeled in the SuperDecisions software.

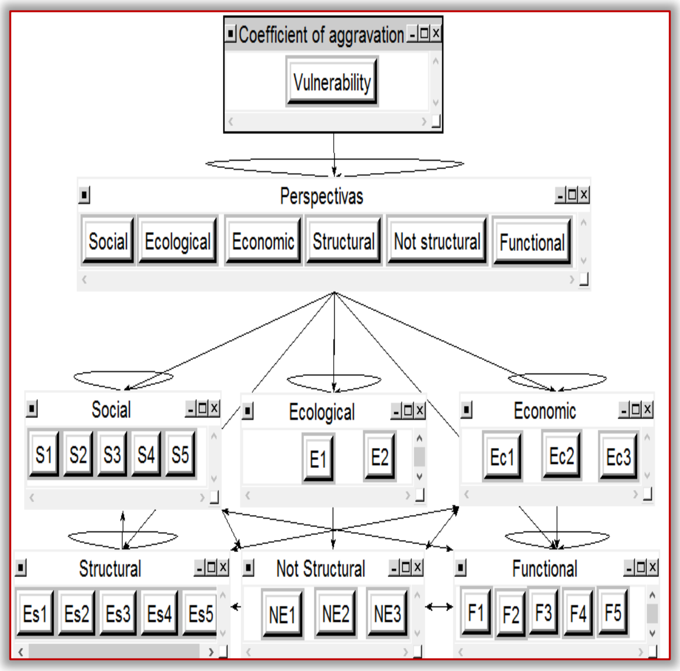

Figure 3: Weight`s network of socioeconomic fragility descriptors and resilience lack descriptors

The table 2 presents the results of application of AHP method.

Table 2: Weight`s coefficients network of socioeconomic fragility descriptors and resilience lack descriptors

Perspective	Weighting coefficient from the perspective	Weighting coefficient	Equivalent Weighting coefficient *WI*
Social	0.240	S1 0.326	0.078
		S2 0.246	0.059
		S3 0.108	0.026
		S4 0.160	0.038
		S5 0.160	0.038
		∑ 1.000	
Ecological	0.124	E1 0.660	0.082
		E2 0.324	0.042
		∑ 1.000	
Economic	0.196	Ec1 0.493	0.098
		Ec2 0.196	0.039
		Ec3 0.311	0.062
		∑ 1.000	
Structural	0.144	Es1 0.215	0.031
		Es2 0.140	0.020
		Es3 0.287	0.041
		Es4 0.252	0.036
		Es5 0.106	0.015
		∑ 1.000	
Not structural	0.078	Ne1 0.493	0.039
		Ne2 0.311	0.024
		Ne3 0.196	0.015
		∑ 1.000	
Functional	0.216	F1 0.326	0.070
		F2 0.143	0.031
		F3 0.212	0.046
		F4 0.108	0.023
		F5 0.212	0.046
		∑ 1.000	
∑	1.000		1.000

RESULTS

In this section the results will be shown according the methodology established in the previous section. This model uses the strategy of multiple explanatory cases in different companies that operate with hazardous substances in the province of Villa Clara. The provincial is subdivided into 13 municipalities, with a total of 124 evaluated facilities.

The inventory of hazardous substances in the province and the evaluation of the activities carried out (storage, processing and distribution) allowed the analysis of 240 potential hazards. The total risk is evaluated in each analysis units as a function of exposure factor, (social, economic and environmental consequences) and the aggravating factor through Equation 1.

The figure 4 shows the results of the evaluation carried out in companies located in Villa Clara, divided by municipalities. In this the possible radio of affectation is delimited, and the evaluation of the level of risk is expressed in low, medium and high scale (green, yellow and red). When comparing the results of technological risk in four possible scenarios of major accident, it is observed that Santa Clara municipalities have the highest technological risk index. On the other hand, the municipalities of Quemado de Güines, Camajuaní and Ranchuelo are those exposed to a lower level of technological risk. The figure 4-7 shows the affectation radio of different possible accident.

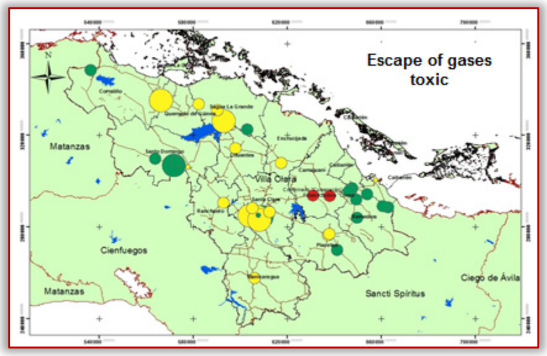

Figure 4: Radio of affectation and level risk. Exhaust of toxic gases[4]

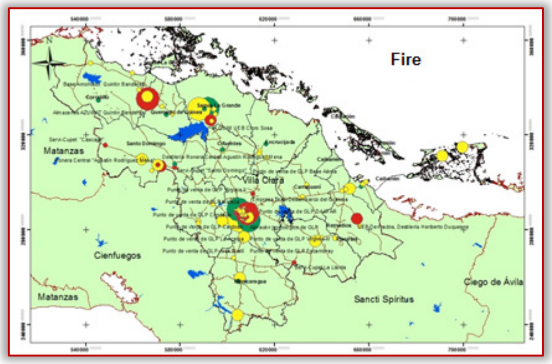

Figure 5: Radio of affectation and level risk. Fire [4]

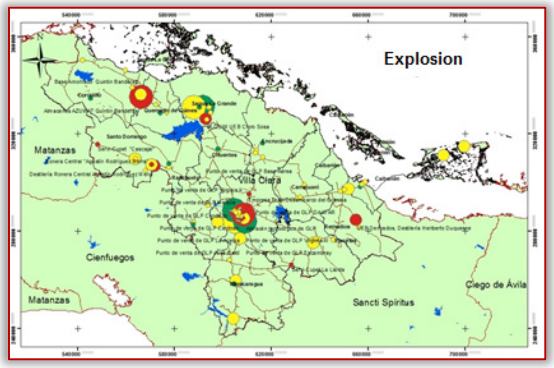

Figure 6: Radio of affectation and level risk. Explosion [4]

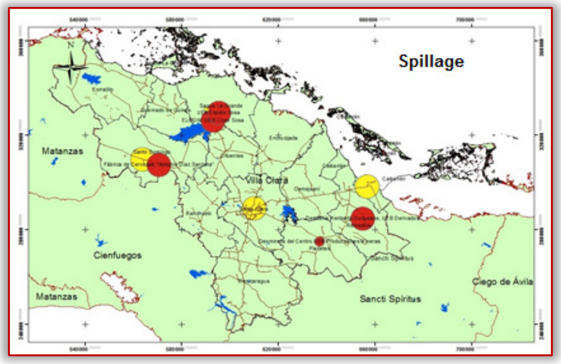

Figure 7: Radio of affectation and level risk. Spillage [4]

This research takes as case study the logistics network in Fuel Trading Company of Villa Clara. This logistics network includes the Fuel Trading Company and the technological warehouse of liquefied petroleum gas (LPG), 53 gas station, 11 stores the sell gas (LPG). These analyzed entities constitute fuel storage and sale centers. This logistics network includes a total of 22 routes by highways and 2 routes by railways.

The highest risk index in storage activities is in the storage area from the Fuel Trading Company, and the most dangerous route is the RFC-02 route corresponding to the transportation of fuel by trains from the Camilo Cienfuegos Refinery in Cienfuegos, to warehouse of the Fuel Trading Company in Santa Clara. This route crosses the center of the town of Cruces, which increases the index of associated vulnerability factor. These results are shown in figure 8 and 9 of technological risk level.

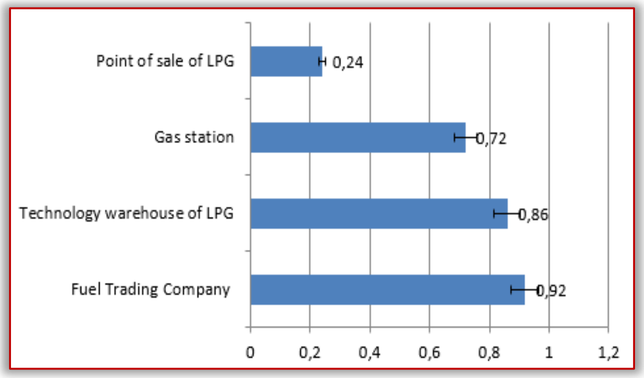

Figure 8: Technological risk index in storage activities [4]

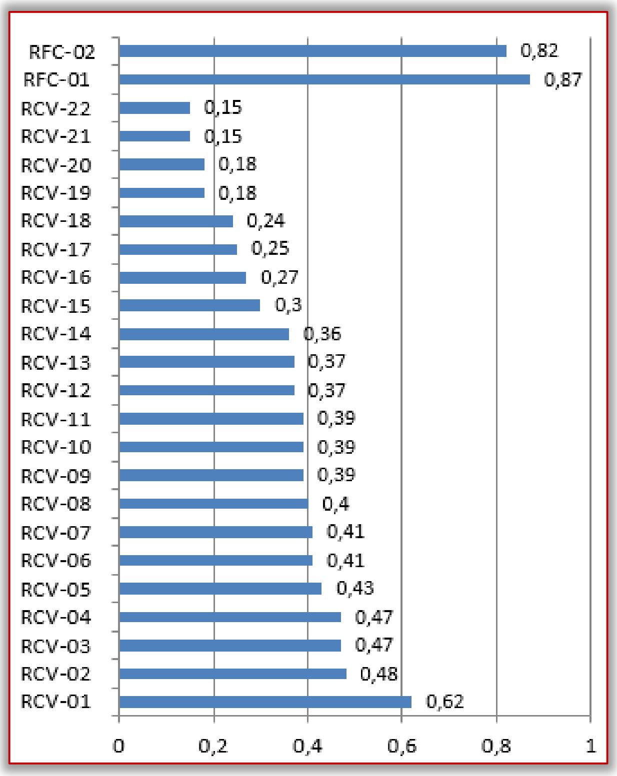

Figure 9: Technological risk index by distribution route [4]

This analysis allows us to index those logistic activities that constitute a major danger in their execution, being necessary to establish disaster prevention and mitigation measures.

CONCLUSIONS

The proposed technological risk index considers the effect of existing physical risk given the occurrence of a destabilizing event, as well as the worsening of the impact due to socioeconomic conditions and the resilience lack of the involved area. It provides a scientific basis for risk-based approach and the development of a proactive culture of prevention, improvement and protection.

The indexing of the technological areas and plants depends on existing risk level in the occurrence of major technological accidents. At same time, facilitates the documentation of involved processes in risk management and decision making for the planning of preventive actions.

The analysis of technological risk level in storage and transport activities supports the decision making process. This analysis is based on the characterization and hierarchization of storage areas and distribution routes of greater danger. The application of the procedure allows the reorientation of the organizational efforts and guarantees an approach of continuous improvement.

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