Application of AHP for Fuel transportation Environmental impact Assessment in submerged Pipelines

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Abstract— *This study presents an evaluation of associated impacts by leaks in fuel pipelines transportation. Often, the pipelines are built in public and private properties into rural and urban areas. The potential environmental impacts were evaluated using the Analytic Hierarchy Process (AHP). The study was applied for the Billings dam case, located in Brazil. The Expert Choice® software was used as a tool to implement AHP methodology. The evaluated fuels were: oil, natural gas and alcohol-based fuel. Fire, environmental contamination and toxicity were the main evaluation criteria associated with leak impacts. Oil presented the highest associated impact, followed by alcohol-based fuel and natural gas.*

Keywords— ***AHP; environmental impacts; fuels; pipeline.***

I. INTRODUCTION

Among the industries of pipeline transportation, the oil industry is the main benefit; it has vast territorial extensions of installation systems, according to data provided by the security cabinet of the US agency, the National Transportation Safety Board (NTSB, 2002).

The hydrocarbons transport, mainly natural gas, oil and oil products have generated technical challenges, to minimize fuel leaks and environmental impacts due to pipelines issues. Constantly, the oil industry deals with problems resulting by leaks, spills and accidents during stages of exploration, refining, transport and oil (derived products) storage (SANTANA, 2004). In the Brazilian case, studies about impacts mapping of accidents in ducts have been conducted, aiming the use of land. However, there are not literature focusing on the pricing of land uses for later applications, therefore there is a lack of information about pricing issues and their relation with impacts on Billings areas due to pipelines passage (ANP, 2015).

The Billings dam incorporates a system of hydraulic power generation, Henry Borden is a concession area granted to Metropolitan Company of Water and Energy (EMAE). Especially, this area is highly potential demand territory for fuels transport studies, due to the geostrategic location between distribution and reception points of fuels. The easement area of Henry Borden power plant was identified as a protected space through environmental licenses and additional legal requirements. Then, any commercial and industrial activities must be associated with these strict statements. In recent years, the largest oil reservoir was discovered and it was named Pre-salt due to geological location in Brazilian states of Santos (SP) to Plano Alto. Then, a rise of oil production and refining in Brazil are expected, to meet the proposed energetic demands and economic policies with the actual governing. This latter situation has been part of speculation by different sectors of environmental protectionist, that the easement area of Henry Borden is a target of the oil and energy industry (CAPOBIANCO, 2002).

Despite pipeline transportation is considered a safe and reliable way for transporting dangerous and flammable substances, such as oil and gas, there are several factors during the transportation process such as third-party damage, corrosion destruction, design flaws, misuse, among others that could cause leakage and consequently affect social security and environment (GUO et al., 2016).

The fuel transport through pipeline includes a high risk of impact due to failure in the pipeline and subsequent leakage, for both the population and the environmental impacts. Events that take place in population and involved areas after a fuel leak are the assumed impacts of this study.

Analytic Hierarchy Process (AHP) is normally used as a multi-criteria decision-making method and widely used for a sustainable development decision. It was used for instance by De la Fuente et al. (2016) to set weights for a sustainability assessment of sewerage pipe systems, by Dey (2002) in a project feasibility analysis related to oil pipeline in India, by Suganthi (2018) where through AHP method it was possible to set sustainability criteria for a more sustainable development decision, by Guo et al. (2016) in a risk evaluation of long-distance oil and gas transportation pipelines with the intent to minimize leakage or rupture risks of pipelines.

In the event of fuel shedding, the major concern is the possibility of fire with problems of toxicity and pollution on aquifers, for occupied or unoccupied areas. The Billings dam has conservation areas with environmental importance. Then, an evaluation method should be necessary to apply, and so quantifying possible impacts associated with leaks and kind of fuel.

Industrial installations have different piping arrangements and it is considered an efficient way of transport substances, however, it has raised some major concerns in terms of safety, due to frequent accidental gas explosions that caused serious damage, motivated risk assessment of flame propagation and explosion of pipeline fuel transportation (EMAMI et al., 2016)

The importance is mainly focused on the relevance that these areas have because those are part of an energy Hydro-complex (Henry Borden), which in addition to generated energy, supplies water to Metropolitan region of São Paulo (RMSP). The evaluation of consequences through the sensitivity of the areas thus generate greater acceptance by the population both in Brazil and in the world, the potential impacts and mitigating them later, in case of a leakage accident occur on the easement area of the ducts.

Citizen perceptions or beliefs about the benefits and risks of a project, such as fuel transport pipeline or offshore oil drilling, are typically important predictors of acceptance or opposition. Citizen acceptance can be associated with perceptions of economic benefits and opposition can be associated with perceptions of local environmental risks, such as the Exxon-Valdez oil spill in 1989 (AXSEN, 2014).The introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper.

II. METHODOLOGY

In the evaluation case of the generated impact is necessary to consider each involved fuel, physical and chemical properties associated with fire probability, pollution and toxicity of selected fuels. The classification considerations of consequences based on a review of environmental and social studies, determining caused impacts by fuel spills events.

The AHP method is one of the first developed methods in the area of discrete multi-criteria decisions, created by Professor Thomas Saaty (1980). In this method the decision problem is divided into hierarchical levels, easing its understanding and evaluation. According to Costa (2002), this method is based on the three-step of analytical thinking:

Hierarchies Construction: For the application of this methodology it is necessary that criteria and alternatives can be structured hierarchically.

Defining priorities: This principle is needed to judge pairwise elements of a hierarchy level associated to an upper level, a matrix of judgment comparison is made between the elements using the basic scale of Saaty ranking (from 1 to 9).

Logic consistency: The decision-maker can establish relationships between objects or ideas. Consistency is presented if they are consistent, such that they relate to each other and their relations show consistency.

There are influencing variables that directly impact identification, which are: leak area, leakage time until being interrupted, and fuel type. It was used an input orientation that seeks to minimize input values for the same production of output, avoiding the problem to have a large number of Decision Making Units, according to Silva et al. (2019). Finally, the criteria for the evaluation of potential impacts were identified.

- Fire;
- Toxicity;
- Environmental contamination.

The fuels associated with impacts are analyzed by their physicochemical properties related to each fuel (oil, alcohol and gas natural), as the main objective to determine the potential associated environmental damage.

The choice of physicochemical properties was done per event or result.

For fire, the properties are inflammability, vapor pressure, solubility and concentration (flammability limits) are shown in Figure 1. If a substance is flammable, it

generates risk and hazard of conflagration if it has a higher vapor pressure, it will generate a fire hazard in comparison to other compounds with lower vapor pressure. If it is not soluble, the substance will remain on the surface, which creates a fire hazard. If these three properties are presented in the same substance, it will be more likely to have the risk of fire and conflagration. In the case of a substance having two or one of the properties presented above, the fire threat will be lower, depending on the importance of the associated property for the development of a fire.
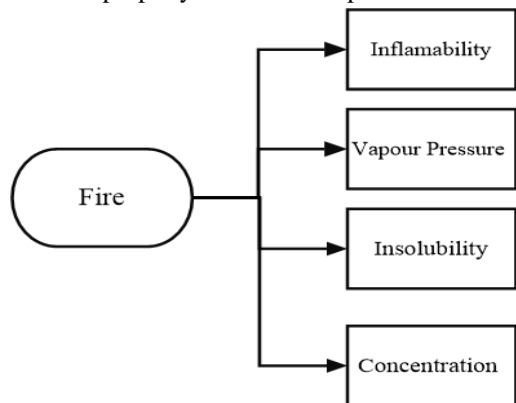

Fig. 1: Physicochemical properties of fuels associated with fire

For toxicity, the properties are: Eco toxicity, mobility in soil, human toxicity, degradability and solubility shown in Figure 2. The above properties illustrate that if a substance has high mobility in soil and is a toxic substance if it is spilled will pollute and contaminate as well. Regarding the existence of deposits of groundwater, this will increase environmental impacts. The degradability as a chosen property represents the time of life of this substance, can be degradable or biodegradable, according to the established parameters, as mitigation the impact generated on the areas will be lower.
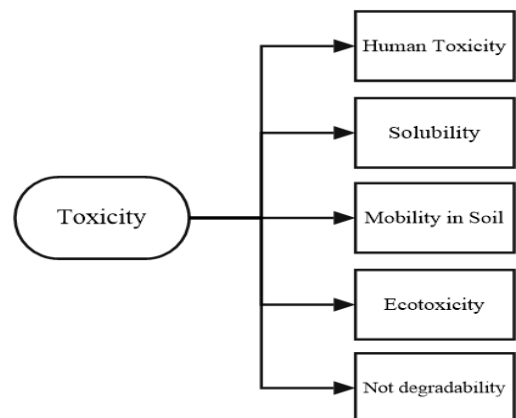

Fig. 2: Physicochemical properties of fuels associated with toxicity

For environmental contamination, the properties are density, degradability, solubility and mobility in soil

shown in Figure 3. In this case, the physical properties represent better the potential damage on these ecosystems. A substance that is soluble in water, which has high mobility in soil, low density and low degradability, it is the substance that can cause higher damage on the ecosystem due to the difficulty to remove it from these areas. Presence and permanence in water and land will be higher compared to other substances.
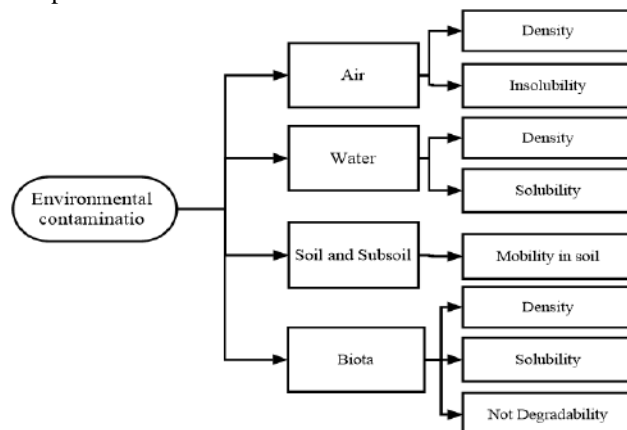

Fig. 3: Physicochemical properties of fuels associated to environmental contamination

2.1 Construction of hierarchies

The existence of a decision hierarchy is the main point of AHP, for the application of this methodology, it is necessary that criteria and alternative can be structured hierarchically. The first level corresponds to the general purpose of the issue, the second and third levels are the criteria and the alternatives.

The complete impact assessment represents the hierarchy for leadership levels of criteria, identified and defined by impacts of fuel spillage on the easement areas.

The hierarchy spreadsheet was constructed on four levels, considering the variables in the problem analysis, as shown in Figure 4 according to Saaty (1991).

Level 1: In this level, is located the goal of the evaluation (Fuel with highest associated impact);

Level 2: This refers, primarily to defined criteria to the evaluation of fuel with highest associated impact as a fire, toxicity and environmental contaminations;

Level 3: In this level, takes place the detailing sub criteria of the previous level (Figure 1, 2 and 3);

Level 4: This level is the lowest in the hierarchical spreadsheet decision and shows the goal fuels (oil, ethanol and gas) in this study.
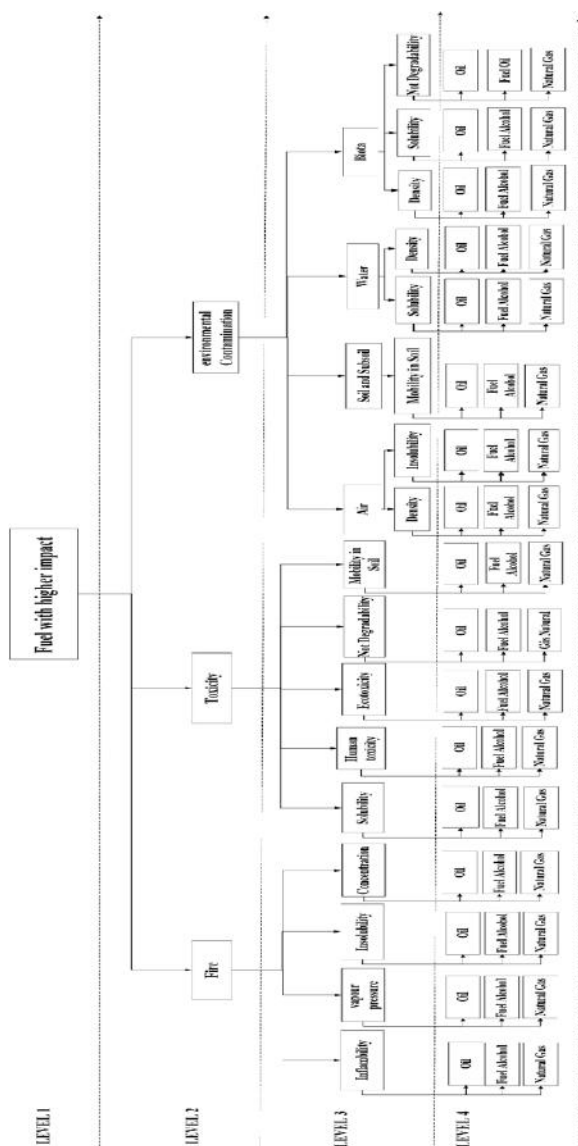
Fig.4: Hierarchical spreadsheet of the associate impact of spillage fuels

2.2 Comparison matrix of scale

The comparison stage needed to be carried out between the established criteria showed in the spreadsheet. Before this stage, was performed a meeting with a specialized group integrated by EMAE experienced analysts on environmental management and sustainability.

The judgment and its importance of an alternative over other ones was made subjectively, converting these judgments in numeric values, using a scale from 1 to 9 points as the AHP method indicates. Where 1 denotes equal importance and 9 denotes high degree of favoritism of an alternative over another.

The group of analysts made the comparison of levels 2 and 3 of the hierarchical spreadsheet of the associated impact of spillage fuels. The judgments of the last

spreadsheet level were made from the comparison of numerical and qualitative values of the physicochemical properties of fuels (natural gas, oil and fuel alcohol) chosen for this analysis.

It was discussed that, fire is a consequence which represents the lowest impact on the easement areas. This consequence could be controlled by authorities, can be controlled by the carrier by means of a closure valve or finally with a stop in the operation. The toxicity, as well known, affect aquatic life and the ground. One of the most important uses of the dam is the water supply associated with the generation of energy through the energy complex Henry Borden. An area affected by fuel spillage prevents largely these activities (water supply and power generation which) according to the information revealed by EMAE, these leads to many problems for that the impacts of toxicity has the major value. Table 1 presents an example of how should be made the comparison matrices between each level, in this case, this matrix is the comparison matrix of level 2 of the spreadsheet.

Table 1: Comparison Matrix of level 2

MATRIX A	Fire	Toxicity	Environmental Contamination
Fire	1	1/3	1/3
Toxicity	3	1	1
Environmental Contamination	3	1	1

This treatment of judgments for each case of the matrices is performed in the same manner. Regarding the needed calculation to confirm the consistency of judgments in the decision-making group, it is specified that these are made by software EXPERT CHOICE®. The manual method for obtaining a measure of the consistency of judgment values may be performed according to the equations present in the Analytic Hierarchy Process (AHP).

After the development of these steps and obtaining a fewer judgments consistency than 0.10 as specified, the numerical values obtained of the final criteria are reliable, which is summarized with the inexistence of judgments inconsistencies between themselves. In this stage of the process, it is the moment to justify and analyze the results presented by AHP.

III. RESULTS AND DISCUSSION

The three main consequences of fuel leakage (level 2 of hierarchy) are presented.

3.1 Fire

It was argued, that of the three consequences, the fire can generate on the areas the less impact. This event is an unusual event on those areas due to moisture that they present, the risk of explosion is not present. Moreover, it can be easily controlled by authorities due to constant monitoring. Environmentally speaking, the damage can be of great importance and magnitude, as in the case of the event happening in protected environmental areas, the destruction of typical vegetation could lead to several changes in ecosystems. Nevertheless, for the fire to reach this magnitude it needs proper conflagration conditions and a long time of conflagration.

The software presents a concentration (inflammability limits) as the property with the highest influence on to generate fire, it has a numerical value of 0.607, followed by igniting with a 0.243 value, fuel vapor pressure with 0.101 and insolubility with 0.049 value.

3.2 Toxicity

The toxicity affects aquatic life and terrestrial life. After a chemical leak (fuel) the seriousness of consequence is directly related to the type and amount of leaked fuel. The possibility of death for inhalation incident or consumption of the substance is big both for animals and for the general population.

The high impact index is due to different dam uses Billings, as a water supply associated with the generation of energy through the Henry Borden energy complex. An affected area with shedding needs degradation and cleaning treatments, both for the soil as the water, depending on the affected area may or may not be recovered in its entirety.

The toxicity, according to the values obtained by the EXPERT CHOICE®, the property of human toxicity represents the most important property to quantify a toxicity event with an associated value of 0.482. The eco-toxicity is in second place with a value of 0.218.

3.3 Environmental Contamination

Contamination is a consequence that affects ecosystems and wildlife. The degree of severity depends on the fuel type and the amount leaked, but the consequences may lead to animals' death. The study focused on the criterion of environmental contamination, it was divided into four types of environments that may be affected, according to the discussion with the decision-maker group these ambient are: soil and subsoil, water, air and biota.

The properties of environmental contamination event are defined by affectation areas: biota, soil and subsoil, air and water. The values obtained by evaluation in the software are shown in Table 2, it is seen that the areas with the highest affectation in the case of leakage, are water and soil, with numerical values of 0.560 and 0.249, respectively. For other affectation areas, the biota (0.095) and the air (0.095) had low values of influence of environmental contamination.

In Table 2 it is summarized and explained the mentioned values obtained by AHP above. It can be evident that the fire has a value of 0.146 and the lowest impact, compared with the toxicity and contamination event with 0.429 impact value for each one.

Table 2 - Impact assessment associated with the leak

Consequence	Impact
Fire	0.146
Toxicity	0.429
Environmental Contamination	0.429
-Air	0.095
-Soil and subsoil	0.249
-Water	0.560
-Biota	0.095

The next table presents the final values obtained by EXPERT CHOICE® software, regarding the goal of the AHP (associated fuel with the highest impact)

The evaluation by AHP shows that oil has an associated impact value of 0.390, while the fuel ethanol has a value of 0.361 and the natural gas obtained a value of 0.249, presenting the lowest value. The oil has a higher potential impact related to ethanol-based fuel. Natural gas despite of their clear potential fire, it is the fuel that could generate less impact in case of leakage.

This analysis is presented by the judgments based on the significance of impacts on the areas in the Billings reservoir. Depending on the study focus and the importance provided to each of the criteria, the final values obtained may differ.

Finally, Table 3 shows the fuel impact on associated values to be transported. In this table, the fuel with the highest impact value is the oil with a value of 0.390 followed by the alcohol fuel having a value of 0.360 and finally the natural gas with a value of 0.249 as the fuel with less impact associated of the three studied fuels.

Table 3: Fuel with highest associated impact

Fuel	Impact
Oil	0.390
Alcohol-based fuel	0.361
Natural gas	0.249

The toxicity caused by the amount of leaked gas depends directly on pressure, heat and transported flow (ROSENBAUM, 2011). If the gas leak does not generate fire or explosion, the impact of toxicity on the affected areas will be higher due to the concentration of leaked gas in the áreas. Leaks can occur in inaccessible places where emergency operations are not to be effected. These leaks also can occur in different scenarios. In rural areas, as in environments with the presence of protected areas, damage or final impact will depend directly to the place where the leak occurs and the amount of leaked fuel. In water, natural gas tends to go over the surface, where it will dissipate in the air, causing a low concentration. Previously mentioned, natural gas has a low potential for contamination and low potential for toxicity because, in contact with the environment, it dissipates. That is the reason for the lowest potential impact of natural gas compared to fuel ethanol and oil.

The main damage caused by oil leaks is contamination, fire and toxicity. The oil affects the soil, groundwater, water and air environments, due to the properties that the oil has (vapor pressure, density, flammability, insolubility) (BONVICINI, 2015).

Oil spills result in significant contamination in relation to other fuels, due to the persistence of oil in water and land. According to works conducted the toxicity caused by contamination is high due to toxic compounds (polycyclic aromatic and other compounds present in the oil) (TRONCZYNSKY, 2004).

The alcohol may be degraded rapidly, its toxicity in human and environment depends on the leaked quantity and the area where the leak occurs. The dilution factor in water is an important factor to determine the degree of contamination, toxicity and pollution. Generally, fuel ethanol does not generate toxicity and pollution problems. It is necessary a large amount of ethanol to generate impact. Alcohol has a strong affinity with to potentiate fire, in reason of their concentration limits are low compared to natural gas. It is toxic with high solubility and mobility in soil, which also represents a high potential to reach any areas even if the leakage occurred in only one area. This is what allows that alcohol has a potential medium impact compared to natural gas and oil.

IV.   CONCLUSION

The criteria and sub-criteria evaluated showed oil as fuel with the highest potential impact in a ratio of 1.57 times, regarding the natural gas that presented the lowest impact. The fuel alcohol presents a high impact on the potential areas, but a minor impact generated compared to oil, having a ratio of 1.45 times higher referred to natural

gas. Natural gas is considered, among the three fuels, the lowest potential impact on the areas to be affected. In this study, the toxicity, polluting and inflammable power of oil was evidenced. Alcohol has power as the combustible oil and natural gas, but due to its ability to generate the media toxicity and contamination; this appears as a fuel with lower associated impact. In the case of natural gas, the only event that was able to identify is the average potential fire making this a fuel with low associated risk compared to other fuels.

From these results, it can be concluded that the AHP has shown its ability to deal with problems involving both quantitative and qualitative variables. The evaluation of the environmental issues surrounding the fuel type, the properties associated with these fuels, among other multi-criteria components scenario where the AHP has satisfactorily responded to such demands. It is necessary to verify the importance of the available data for the criteria evaluation. Not only the quantity and quality of data to be relevant, so was the way the information was translated into the values for the criteria.

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