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Research Article

Stochastic Risk Assessment with Bayesian Networks in Esfahan Refinery

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Received date: April 17, 2023; **Accepted date:** April 25, 2023; **Published date:** May 08, 2023

Citation: Meysam Saeedi (2023), Stochastic Risk Assessment with Bayesian Networks in Esfahan Refinery, *J, Biotechnology and Bioprocessing*, 4(3); **DOI:10.31579/2766-2314/103**

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Abstract

Refineries are among the industrial centers that supply the energy and raw materials to downstream industries. To achieve sustainable development goals, creating appropriate balance between economic and environmental goals has always been the focus of managers and policy makers in the societies. Bayesian Network model has become a robust tool in the field of risk assessment and uncertainty management in refineries. The focus of this research is to prioritizing different units from the point of view of social and ecological aspects for facilitating the decision-making process in the context of waste material treatment in Esfahan refinery in line with the sustainable development goals.

The methodology of this research is based on risk assessment with the aid of Bayesian Networks. To this end, first material flow analysis of the processes procured risk identification, subsequently influence diagram and Bayesian Network structure were designed. After completing conditional probability tables, risk factors were prioritized.

According to the risk assessment results, Fuel unit was classified as the most significant risk factor, whereas Pipelines and Plant air & instrument air system were identified as the most environmentally friendly units.

Key Words: risk assessment; bayesian networks; uncertainty; material flow analysis in refinery; green manufacturing

1.Introduction

According to the International Energy Agency (2018), there is anticipated to be 25% rise in demand for energy consumption by 2040. Currently, a major part of the demand for energy is supplied through fossil fuels, especially oil and gas. The production of oil and gas industries in the vicinity of the sea has a share of 30% of the energy produced in the whole world [1]. A refinery produces large amount of solid, liquid, and gaseous wastes including volatile organic compounds, catalytic residues, heavy metals, oily sludge, and complex structured wastes including PAHs, oil and grease, TDSs, sulfides, ammonia, and nitrates [2]. Furthermore, to overcome global warming implications, it is necessary for different economic sectors in the world to reduce greenhouse gas emissions [3]. Hence, one of the main bottlenecks in oil and gas industry is managing large amounts of waste materials that are produced in various processes.

According to the general framework provided by the US

Environmental Protection Agency, environmental risk assessment is defined as a process that evaluates the adverse ecological effects on ecosystems that are exposed to drivers [4]. According to another definition, environmental risk assessment includes the process of identifying and evaluating potential negative impacts on organisms, humans and societies, which are mainly caused by the release of industrial waste materials and the exposure of organisms and humans to these substances [1]. Risk is defined as the product of the probability of the hazard occurrence and the consequence of the impacts. The main goal of ERA is to analyze the casual relationships between the risk factors and the adverse effects on the ecosystem [5]. BNs are among robust models for making probabilistic conclusions, and the application of these networks is widespread in a wide range of fields such as academic research and development, biological studies, computer games, transportation, urban traffic and vehicle control studies, data processing, medicine, linguistics, psychology, reliability analysis, planning, and meteorological forecasting [7]. In general, BN model is a robust tool due to the very low prediction error and high accuracy, its suitable graphical form, and the ability of combining different types of data sources [8]. Due to the existence of resource limitations in the field of waste management, it is not possible to eliminate the environmental impacts in a refinery concurrently. Dividing a production system into different sub-systems and prioritizing them from the viewpoint of social and ecological adverse effects enables managers and policy makers to make appropriate balance between economic and environmental targets in the planning phase of the manufacturing so that achieving cleaner production and sustainable development objectives facilitated. This research provides a suitable framework for prioritizing different units in line with the sustainable development goals and green manufacturing. Moreover, it is among the few studies in the field of risk assessment with BN, which provides the capability of considering social-ecological aspects as well as water, soil, air, and sound pollution simultaneously or separately. On the other hand, heterogeneous kinds of pollutants which have the potential of releasing into the water, soil, and air environments have been comprehensively considered, thus making it standout.

2.Methodology

A. Study area

The main products of this refinery include petrol, diesel, liquefied gas, and hydrogen. This refinery is located in the Esfahan city in Iran in the geographical coordinates of 51° 29' E and 32° 47' N (Figure 1) and plays a significant role in the supply of country's fuel.

B. Material flow

With the aid of process documents of the refinery, the material flow analysis has been performed in order to identify waste materials and potential risks. The investigated units consist of Sour water stripper unit, Steam and electricity unit (DM water system), Water system, Fuel unit, Plant air & Instrument air system, and Pipelines.

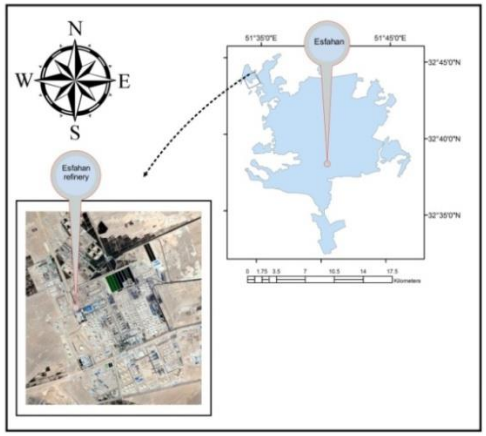

Figure 1: Map of the study area

C.BN design for risk assessment

BN modeling consists of variable definition and node selection, design of network structure, determination of utility function and conditional probability tables, data processing, and probabilistic inference [9]. The required data in this research were collected through the combination of refinery process documents, data sets, and domain knowledge. For this purpose, each unit in the refinery was considered as a subsystem and the required data was collected through pre-designed questionnaires. The average of the aggregated statistical data was considered as the input for the BN model. This research was performed in three phases. In the first phase, relying on experts' opinions, potential risks were identified, afterwards in the second phase of the research, the influence diagram was designed based on the required conditions for BN modeling. In the continuation of the second phase, by determining the conditional probability tables and utility function values, environmental risk assessment modeling was performed by the Netica software, and finally the BN network model related to the risk assessment presented. At the end of the second phase, the risks were prioritized. In the third phase, some solutions were procured to reduce the risk levels. BN is a kind of graphical model where the nodes specify variables and the relationship between variables is specified by arcs. Nodes with output arcs are entitled parent nodes and nodes with input arcs are called child nodes. These conditional distributions are determined by experimental data, statistical models, simulation, and previous studies. The arcs connected between nodes represent dependencies, and the intensity of causal relationships is expressed by conditional probabilities. For each child node, conditional probability distributions are assigned to the different permutations of the parent nodes' states. It is not possible to create loops in these models, feature of these models is the possibility of drawing conclusions in such a way that the parent node is fixed to the desirable value, thereafter the value of the different states of the child nodes is computed based on Bayes' law. Consequently, BNs have capabilities such as specifying the most important variables that cause a specific value of the parent node, and vice versa determining the sensitivity of the parent node to the variables pertaining to the child nodes in the network. First, variables of the model were defined, and subsequently influence diagram were designed by means of domain knowledge. The design of influence diagram is based on some basic variables namely Air, Soil, Water, and Noise pollution which represent physicochemical environment and make direct relation between the risk factors and social-biological environments; whereas Human health, Plants and wild life, and Habitats represent social and biological environments. However, the risk numbers has been defined based on product of probability and consequence nodes that located upside of the hierarchical structure (see Figure 2).

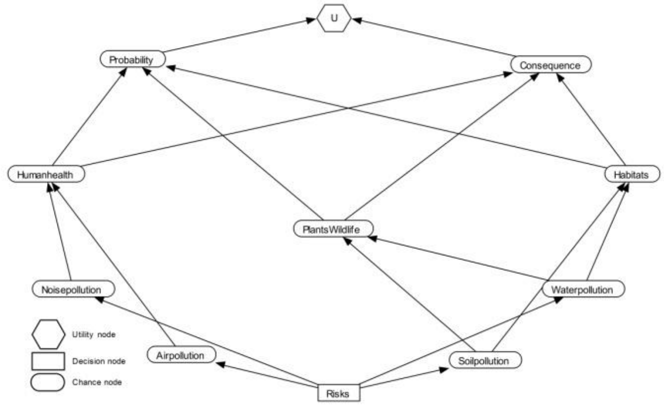

Figure 2: Influence diagram

For designing BN structure, Water pollution, Soil pollution, Air pollution, Noise pollution, Consequence, and Probability nodes have been defined as chance nodes with high and low states. Nodes Habitats, Plants and wild life, and Human health also have been considered as chance nodes, but with satisfactory and poor states. After identifying the risks, different states related to the decision node were also defined in the BN structure. Table 1 shows the characteristics of different nodes in the BN structure.

Node	Node type in ID	Node states	Node type in hierarchical structure
Utility	Utility node	-	Goal
Consequence	Chance node	Low-high	Criteria
Probability	Chance node	Low-high	Criteria
Effect on habitats	Chance node	Poor-Satisfactory	Subcriteria-Level 1
Effect on plants and wild-life	Chance node	Poor-Satisfactory	Subcriteria-Level 1
Water pollution	Chance node	Low-high	Subcriteria-Level 2
Soil pollution	Chance node	Low-high	Subcriteria-Level 2
Air pollution	Chance node	Low-high	Subcriteria-Level 2
Noise pollution	Chance node	Low-high	Subcriteria-Level 2
Risk factors	Decision node	Steam and electricity unit • Plant air & Instrument air system • Water system • Sour water stripper unit • Pipelines • Fuel system	Alternatives

Table 1: Characteristics of nodes in the BN structure for risk assessment

The values of the utility function were determined according to the all-possible permutations of the risk descriptors namely the probability of occurrence and the severity of the effect. If the permutation of probability and consequence nodes is high and high, respectively, the utility function take the value of 1; in the case of low and low, the value of the utility function is 0.1; in the case of high and low, the value has been onsidered 0.6, and finally, if it is in the form of low and high The value of the function has been defined 0.7.

Determination of conditional probability distributions was performed by means of designing some questionnaires.

Questionnaires related to Noise pollution node were completed by ten Hygiene, Safety and Environment experts in different units identified as risk factors in the refinery.

In these questionnaires, they were asked to answer the question "During an eight-hour shift, how longare you exposed to unpleasant noise due to the specific unit processes?". Next, the collected data was converted into the percentage scale and the values of the high state corresponding to the CPD of noise pollution node were obtained. Data related to CPD of Air pollution node were obtained with the aid of recorded data in HSE air monitoring systems. The data pertaining to ten days from the time period of February to March 2021 were selected as sample. These data represent the time period in which the HSE air monitoring systems were in alert mode in a minute time scale and the air pollution condition exceeds the occupational standard limits. Similar to the Noise pollution node, the obtained data were converted into percentage scale, subsequently high state values corresponding to the CPD of Air pollution node obtained. Thereafter all data averaged and procured the input data for the conditional probability tables in the model. CPDs of Water and Soil pollution nodes also went through the same procedures as Sound and Air pollution nodes.

3.Results

A. Identified risks

In this section, the potential risks of each unit are presented.

•Sour water stripper unit

Possibility of releasing $NH_3(g)$ and $H_2S(g)$ into the atmosphere by the Sour water stripper unit tank; Incineration of $NH_3(g)$ and $H_2S(g)$ generated in the tank (incineration takes place in the furnace in the sulfur recycling and solidification unit); Incineration of NH3(g) and H2S(g) generated in the separator tower and drainage chamber leads to the release of NO2(g) and SO2(g); and the discharge of sour water residues containing NH3(aq), H2S(aq) and hydrocarbons(l) from the purification tank into the sea, are among the adverse effects of this unit.

•Steam and electricity unit, DM water system

The possibility of releasing water contaminated with spent caustic, polystyrene resins, and sludge into the sea are the most significant implications of this unit.

•Water system

The possibility of seawater contamination with oil by-products from the residue water pond, and the emission of VOCs in the atmosphere comprise the negative side-effects of this unit.

•Fuel unit

The NOx(g), CO(g), and CO2(g) emissions to the atmosphere by furnaces, boilers, and turbines have been considered as the most important potential impacts of this unit.

•Plant air & Instrument air system

Noise pollution by the compressor is the main implication of this unit. People who are exposed to sound more than 85 decibels on a daily basis are at the risk of hearing loss [10]. Also, unusual noise stimulate disturbances in heart rate, cholesterol level, uric acid level, metabolism, and weight [11].

•Pipelines

Leakage from pipelines, tanks and pressure control valves is considered as the negative effect of the pipelines.

B. Prioritizing risks

By entering conditional probability values in CPTs, BN was created (Figure 3). Based on the results obtained from the decision node, which includes the expected value of the risk factors mentioned in the decision node of the BN, the risk factors were prioritized. The utility variable expresses the negative effect of different risks, so that higher values indicate more negative impacts and have a higher rank in prioritization. The classification of risks has been done by considering the expected value of the risk factors in the decision node according to the categories illustrated in

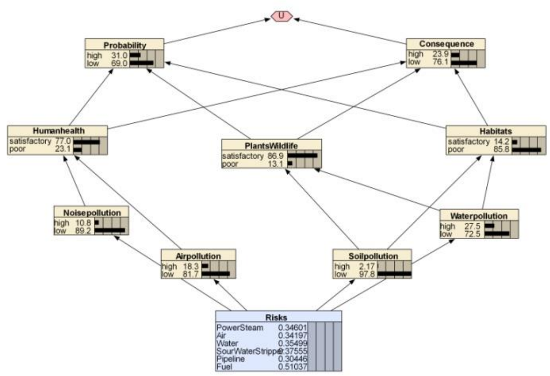

Figure 3:BN for environmental risk assessment

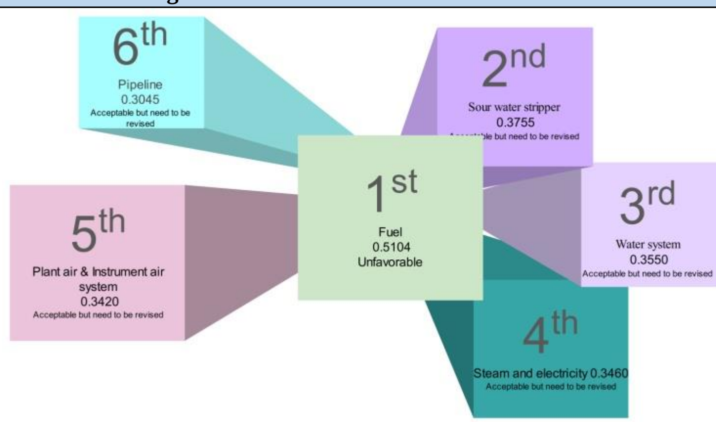

Figure 4: Prioritizing the risk factors

Figure 4. If the risk number is more than 0.75, the risk is placed in the category of unacceptable, 0.5 - 0.75 unfavorable, 0.25 - 0.5 acceptable but need to be revised, and less than 0.25 is classified as acceptable. As shown in Figure 4, the risk factor of Fuel unit with expected value of 0.51037 was recognized as the dominant risk factor in the risk assessment model and was placed in the category of

unfavorable risks. The risk factors of Sour water stripper unit, Water system, Steam and electricity unit, Plant air & Instrument air system, and Pipeline with expected values of 0.37555, 0.36302, 0.35499, 0.34601, 34197, 0.30446 were classified as the acceptable but need to be revised risks.

4.Conclusion

In this research, with the aim of providing a framework for achieving clean production and sustainable development goals, BN model was used for Esfahan refinery risk assessment. According to the obtained results from the risk assessment model, Fuel unit was determined as unfavorable risk, whereas Sour water stripper, Sulfur recycling and solidification, Water system, Steam and electricity, Plant air & Instrument air system, and Pipelines were placed in the category of acceptable risks. Attaining sustainable development goals in refinery necessitates appropriate resource management and the design of efficient waste treatment systems. The results of BN model and sensitivity analysis facilitated sustainable development goals achievement in Esfahan refinery by introducing preference of the refinery units when it comes to the paralyzing impacts of the wastes on the environment and the design of instrumental waste systems. Furthermore, these results provided a framework for managers and policy makers in decision making process based on their predetermined environmental targets and in line with sustainable development goals regarding the extinguishing environmental adverse effects.

The Conflict of Interests Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors acknowledge Esfahan refinery personnel who facilitated study of the refinery process.

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DOI:10.31579/2766-2314/103

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