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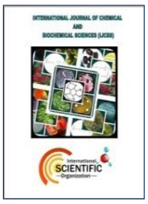

An Integrated Risk Management Strategy for Safer Rail Transport of Hazardous Materials

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Abstract

The possibly hazardous property of chemicals, which causes substantial health hazards and catastrophic accidents, has an impact on the worldwide economic sustainability of rail transportation. Despite the existence of numerous risk assessment models, a more comprehensive approach is required to evaluate additional risk-triggered criteria, especially those result in significant health losses and fatal repercussions, such as vapour cloud explosions. This research proposes a unique risk assessment approach that considers prospective health risk variables and hurdle conditions. Population density, the distance of the route from residential regions and the presence of sensitive individuals who could be at risk for health consequences are instances of potential risk variables. The proposed framework employs the Quantum-inspired Dynamic Bayesian Network-Fuzzy Set Theory (QDBN-FST) to improve accuracy and flexibility in rail transportation risk assessment. Fuzzy Set Theory is used to handle the inherent imprecision and ambiguity in risk assessment. The use of fuzzy logic allows the model to address ambiguity in input data, resulting in a flexible decision-making framework. Fuzzy membership functions assess the degree of uncertainty associated with various risk situations. The use of quantum-inspired computing techniques improves the model's capacity to handle the dynamic and entangled character of risk variables. Meanwhile, fuzzy logic offers a method for navigating through uncertainties and imperfect information. Investigation results in the production of individually dangerous curve and safe separation from the railroad. To assess the model's performance, Tehran appears to be implementing a real rail system for the transportation of gasoline. The findings provide comprehensive insights into risk-adjusted decision-making for the safe transportation of hazardous commodities by rail.

Keywords: Rail Transport, Risk Assessment, Fuzzy Membership Functions, Quantum-inspired Dynamic Bayesian Network-Fuzzy Set Theory (QDBN-FST)

Full-length article **Corresponding Author*, e-mail: shivang.desai24451@paruluniversity.ac.in

1. Introduction

Rail is a successful method of material transportation and processing approximately one million shipments of materials annually. According to statistical data, 10% of the materials were carried by a railway network. Statistics indicate that a sizable portion of hazardous chemicals are transported over the rail network, even though its share of material transportation is reduced [1]. Stability and security are major operational goals of the railway hazardous material transportation system (RDGTS). This is due to the complexity of the RDGTS, which has numerous risk factors that could affect regular operations and intricate relationships between managers and researchers. As a result, a great deal of analytical work is necessary to understand the frequency of instances involving the rail transportation of dangerous goods [2].

Railway represents one of the most secure ways to carry hazardous materials, due to the execution of a thorough safety plan and numerous industry-wide initiatives. There is a chance that multiple railcar disasters could result in spectacular events. An example of a potential disaster connected to hazardous rail shipments involves the accident and explosion of many oil crude rail tank cars at Lac-Megantic, which resulted in irreversible casualties and damages [3]. The sector of the transport market is dominated by relatively large railway operators and highly specialized road transports. The exporters and transport providers are seasoned in DGT, it is a regular occurrence for the employees and they will cease operations if they break the law and endanger their employees and assets. Smaller transport, including part loads and general loads, carry far less, but they can be difficult to manage because the shippers, carriers and terminal employees are not adapted to DG [4].

There is a container to be made for a systems-theory-based method. Analyses should focus on average outcomes without waiting for unfavorable circumstances that lead to learning possibilities to reduce risk. Instead of taking into consideration how the entire system operates, systems-based analysis techniques have, up to now, been used on individual rail system components, including signaling, level crossings, or examinations of particular instances [5]. The transportation of hazardous compounds, or hazmat, by rail has been a major factor in recent decades. Railway transport is among the safest ways to move hazardous materials to several industry initiatives. As intermodal transportation grows at an exponential rate and the utilization of rail-truck combinations to convey chemical develops, the amount of hazardous traffic on railway networks is predicted to expand for the following ten years [6].

To improve the safety of hazardous material rail transport, the objective of the assignment to design and execute a complete risk management approach. For a transportation system to be reliable and secure, this entails evaluating possible risks, determining mitigation strategies and incorporating cutting-edge technologies. Assuring the security of people and the environment by reducing the possibility of events and resulting effects is the objective. The article [7] states that successful management of the RDGTS required a clear as well as efficient approach to accident control and past accident investigation. The works recommend using the combined technique of Failure Trees and Fuzzy D-S Evidence-based reason to analyze the RDGTS accident. The technique can address the issues with information fusion and uncertainties modeling that arise in RDNGTS accident assessment. The findings indicate that the transportation staff's professional abilities and attitudes were the least reliable factor in the lithium battery rail transportation accident.

The research [8] provided the connection between the functional technique and alternative techniques for preserving the reliability of the transportation method. Considering the purpose of optimizing the management of the environment in railway transport, an innovative method of operation and a model of the system for environmental management have been presented. To detect and assess environmental risks and provide the general guidelines for managing them when transporting hazardous materials by rail and an innovative device has been developed.

cThe study [9] investigated digitization in relation to dangerous goods transportation (DGT). The research was the first examination of the barriers to the use of information and communications technologies for hazardous material transportation. The method combines user-driven innovation (UDI), Bayesian networks and an analytical hierarchical procedure (AHP). The methodology can be easily applied to other industries, which can improve the designing of information and communication technology (ICT) solutions and make it easier to integrate and deploy in both large and small businesses. Using multi-modular ICT solutions, the outcome illustrate a potential hierarchy barrier of two different collaborated schemes for a huge company and a smaller and medium enterprise (SME). The author [10] determined the weights connected to the primary transport risk factor of hazardous materials. A wide range of opinions from professionals were gathered to determine the critical risk factor for the hazardous objects transports. To assess risk factors, the two-level hierarchical framework was created and the modified Delphi technique was used to integrate the expert assessments of the major and minor risk elements. To calculate the major and secondary risk factors relative weights, the Pythagoras fuzzy analytical hierarchy method was employed. An investigation of the recommended decision-making methodology's robustness can be carried out by using sensitivity testing. The article [11] provided the revised system of risk quantification that incorporated the population exposure and imprecise incidence rate in addition to the travel duration. The revised definition accurately captured the erratic character of real-world transportation scenarios. Frank-Wolfe method, piecewise linearization method and genetic algorithm-based methodology were used to solve the model efficiently. Container research was presented using both the latest, bigger network and the recognized Sioux Falls network. In the event that different hazardous kinds were subject to different hazmat tolls, those container researchers provide management insight when it comes to the dual toll policy and incident possibilities.

The research [12] primary operating objective of the RDGTS, the complicated nonlinear dynamical system, was safety. The RDGTS was divided into two states, including safe and risk. Based on an analysis of the data from past RDGTS incidents, the system was in a safe condition until an unexpected dangerous event (or accident cause) occurred and that became the risk state. The term catastrophe or mutation referred to rapid changes in the state of the system and catastrophe theory was the process used to describe the dynamic system's altered state concern. Changes in the system state brought about by a combination of the control components were modeled and explored. The article [13] explores the genesis and dissemination of rail service in cities (RSC) problems and projects the legislation and path of propagation. They prevent and control prepared errors. The URT dangers were defined and categorized using the incident and defect report. When creating the hazards assessment network for the URT, consideration was given to global safety behavior.

The foundation for risk management and URT system control was established by the research outcomes. The author [14] objective was the pandemic change in the supply chain as it affected not only how manufacturers and customers interacted but also the environment. The health crisis reduced sea and air freight capacity halted passenger transportation and had a favorable environmental effect. The research resulted by reminding readers that the epidemic can be shown as the testing ground for subsequent instances and the chance to start the conversation regard an innovative, environmentally friendly, public paradigm of mobility. The article [15] integrated the matter-element model with fuzzy set theory to provide an uncertain fuzzy-matter-element framework for risk assessment. A Work Breakdowns Structure (WBS) and Risks Breakdowns Structure (RBS) risk classification matrices has served as the foundation for the risk assessment index system. The maximum proximity principle was applied to establish the level of the danger matter evaluated furthermore the viability and efficacy of the recommended model was established.

2. Methodology

The initial phase is estimating, under uncertainty, the probability of a chemical material leak and its possible repercussions. The following step indicates that the severity is evaluated. Following that, the estimated health risk for the particular research essential components is modified by defining a severity impact coefficient (SIC).

2.1. Calculating the Consequence Probability: The Modeling of Causes and Consequences

The Bowtie (BT) approach is used in the first step of the cause-and-effects research on material leakage in rail trains. The method, that takes safety barriers into account, is appropriate for determining the causes that affect the incidence of instances and how incidents have consequences. Event Tree Analysis (ET) approaches are closely related to this technique. Experts in safety are consulted at the outset with particular matters pertaining to the past of rail mishaps involving goods of chemical commodities. These perspectives assist in determining the main and secondary events that resulted in the train car leak. Data on the probability of each occurrence arising year is provided. Twenty experts in the fields of safety and railroads are consulted during the process and the fuzzy analytical hierarchy process (FAHP) approach can be used to compute the quantitative probability. It is possible to infer the possibility of occurrence, the types of effects and their probability based on the time and place of the incidence. Fig 1 shows the quantitative risk analysis methodology.

2.2. Modeling with QDBN-FST

When modeling consequence instances quantitatively under uncertainty QDBN-FST was used. In order to show a set of random variables in a noncyclic graph, the research used the BN analysis. A conditional probability table (CPT) is used to evaluate the relationships between them. The primary objective of this network is to illustrate nonlinear relationships between parameters. It is composed of nodes, which represent random variables and arcs, which represent potential connections. Equation (1) presents the fundamental tenet of this network, which is Bayes theory. $P\ (A\big/B)$ represents the probabilities of A arising when B is true, while $P\ (B^{S}{}_{T}{}_{X}A)$ is the chance of B occurring when A is true. A and B represent the occurrences and $P\ (B) \neq 0$. In an equivalent manner, $P\ (A)$ *and* $P\ (B)$ represents the marginal probability of A and B. By selecting substance leakage (SK) is the confirmation joint and identifying primary factors influence leak, the network used to establish the most recognizable effects of leak

$$\boldsymbol{P(A|B) = \frac{P(B|A)P(A)}{P(B)}} \qquad (1)$$

2.3. Calculating the Effect of Consequences

2.3.1. Modelling Toxicological Effects)

Numerical intervals are introduced by the fuzzy set theory through verbal expressions or language phrases. The result of a fuzzy collection is a numeric index, which can be developed by first employing fuzzy tools to provide the number of intervals in linguistic codes. The fuzzy inference rules are applied to estimate the numerical output from a linguistic statement, L expressed as a numerical interval. The concept is the foundation of the fuzzy set methodology, which is used to quantify the opinions of experts. The potential health impacts are simulated using fuzzy set theory. Considering that fuzzy rules translate into fuzzy numbers from crisp language variables and defuzzification techniques generate fuzzy output numbers from fuzzy rules. The three input factors were used by the system. The quantity of pollutants spilled, the population's vulnerability rate and the toxicological characteristics of the material emitted. The initial application of the technique was to assess chemical vehicle transportation that affects toxicology. The severity exposure coefficient, which is determined using the aforementioned criteria, is the intended result. The substance's airborne concentration is found using Equation (2).

$$\boldsymbol{v(y,x,h) = \frac{O}{2\pi w\sigma_x\sigma_h} a^{-x^2/2\sigma_x^2}. + \left\{a^{-(h-Z)^2/\sigma_h^2} + a^{-(h-Z)^2/\sigma_h^2}\right\}} \qquad (2)$$

Where σ_x indicates the distribution of the y-axis, σ_h represents distribution of the z-axis, H is respiration point height, h is a substance leakage height, O indicates the output rate of flow at the time of leaks, w demonstrates local wind speed and v denotes the concentration in the air. To evaluate the final two parameters, σ_x and σ_h the interaction, along with the material stability categorization are employed. The exposure levels are divided into multiple groups according to the recommendations of safety, toxicology specialists, as well as factors like age, lifestyle and particular instances, including delivery.

2.3.2. Vapor clouds explosion (VCE) simulations

The Vapor clouds explosion (VCE) of petroleum-based substances leak from rail cars were simulated using the Baker-Strehlow (BS) method. Recent research indicates that the used method can be more accurate than alternative models. The primary explanation for the selection of BS is its ability used to evaluate the pressure of the explosion used in consideration of the variables that affect flame propagation speed and overpressure. The data enables the assessment of fuel reactivity, obstacle density and flame front propagation to determine the explosion blast intensity. The BS approach can ascertain the size of the cloud and assess the explosion's energy. This method is used to calculate the scaled distance by estimating the overpressure and the effective parameter is flame speed. In the leaking liquid state, one can estimate the steam cloud. The quantity of liquid that evaporates quickly and the duration of the inflammable phase that exists, the interval of time between leaks and explosions are multiplied to generate the vapor cloud. In order to determine the volume of vapor released material, the subsequent Equation (3) must first be used, including the mass of the material leak from reservoirs, the density of the vapor material and the substance to oxygen molecule ratios:

$$C(n^3) = \left(\frac{n}{\rho}\right)K \qquad (3)$$

Where K represents the substance-to-molecular oxygen ratio, ρ is the density of the material's vapor (kg/mvl) and n denotes the mass of the object released from the pool (kg). The cloud radius, $K(n)$, can be derived from the cloud volume $C(n^3)$, with the consideration that the hemisphere is calculated using the following Equation:

$$K = \left(\frac{3c}{2\rho}\right)^{1/3} \qquad (4)$$

Fuel reactions (higher, medium, or low reactivity), obstacle density and flame expansions (1D, 2D, or 3D) are used to compute the flame speed (Ni). The material's reactivity is deemed to be the highest and amount the barriers was deemed to be mediums when a flame was allowed to expand in three dimensions. The following equation, on reverse, is used to determine the scaled distance (k'):

$$k' = y\left(\frac{A}{B_e}\right)^{-\left(\frac{1}{3}\right)} \qquad (5)$$

Where $y\ (n)$ is the distance from the explosion's center and $B_e\ (NB_e)$ is the surrounding pressure. Utilizing the following data, density ρ_m (kg/n3), clouds volume C (n3), reaction equilibrium ratios of substance to oxygen (K), heat of combustion ΔZ_v (Ni/kg) and Ni's A is the following formula is used to compute $A\ (Ni)$, or the explosion's total energy Equation (6):

$$A = C\left[\Delta Z_v \times \rho \times \left(\frac{1}{K}\right)\right] \qquad (6)$$

Lastly, the magnitude of explosion pressure (bar) is calculated by implementing into consideration of the indication diagram, speed of the flame (Ni) and scale distance *(k')*, VCE's fatality probit is calculated using Equation (7) as,

$$X = -77.1 + 6.91I \qquad (7)$$

Here, B is the overpressure (N/m^2) and X is the fatal probability of the VCE. Equation (8), which is used to estimate the chance of VCE fatality or the severity coefficient:

$$Bk(X = 1fY) = \emptyset(Y^D\beta) \qquad (8)$$

Where, the distribution function was denoted by φ.

2.4. Severity Impact Coefficient (SIC)

The density of the population in the area where the risks are released determines the extent of exposure. Accordingly, a sparsely inhabited area is probable to experience less severe accident impacts than a highly populated area. For normalization purposes, an innovative item called SIC is added to Equation (9). Determine the coefficient associated with the nodes with the assistance of the system. A fuzzy system was created to evaluate the toxicological effects and SIC, as shown in Tables 1 and 2.

2.5. Quantitative Evaluation and Assessment of Risk.

The equation is utilized to calculate the quantitative risk, taking into consideration the SIC and chance of the specified parameter. Safety distances are determined by taking the railroad route's coordinates of the SIC into consideration and using the following equation to determine which nodes have the largest geometric mean of SIC.

$$Risk = B \times [GJV \times GG] \qquad (9)$$

An extreme condition can be utilized for perspective as a criterion when measuring and evaluating danger and establishing safe distances, according to safety philosophy. The most serious instances constitute the most hazardous research node and the states of high obstacles are used to determine the safe distances in Algorithm 1.

Algorithm 1: Process of BM-AB

```
function BM_AB_Adaboost(X_train, y_train, T):
N = number of samples
M = number of features
initialize_weights(D, N)
strong_classifier = 0
for t in range(T):
weak_classifier = train_weak_classifier(X_train, y_train, D)
predictions = weak_classifier.predict(X_train)
error = calculate_error(predictions, y_train, D)
alpha = 0.5 * ln((1 - error) / error)
update_weights(D, alpha, predictions, y_train)
strong_classifier += alpha * weak_classifier
return strong_classifier
function train_weak_classifier(X_train, y_train, weights):
function calculate_error(predictions, true_labels, weights):
function update_weights(weights, alpha, predictions, true_labels):
function predict (strong_classifier, X_test):
```

3. Experimental result

This section comprises the outcome of severity estimation for toxicological and VCE modeling and the results of probability prediction based on QDBN-FST and Bowtie outcomes. Finally, it presents the quantitative risk analysis findings.

3.1. Probability Prediction Outcomes

3.1.1. Outcomes for QDBN-FST

Fig 6 illustrates the ET representation associated with the HM leakage and mathematical outcomes provided in Table 3. There have been no major leaks on the examined railway line and there are few reliable statistics on train accidents in the region under examination. The outcomes of existing research are supported by another investigation. There are quantitative chances of pool fire, flash fire, VCE and health damage (per work year) of 3.82 E-2, 2.51 E-3 and 2.51 E-3. Additionally, it is estimated that there is a 6.02 E-4 chance of successful containment per working year.

3.1.2. Outcomes of Bowtie

A number of the major explanations for releasing HM are identified by the BT results as faults in rail car packing, including containers and compartments. Ultimately, the material release has intermediary causes (IC) and root causes (RC). In Table 4, the details of every cause and their classical probability are displayed. The overall ET for HM leakage is displayed in Fig 2. The release of flammable heavy metals can result in a pool of flame in the presence of an instantaneous ignition source. In addition, dispersal of the material can occur if the rescue team fails to act promptly and in certain situations. Any chemical product dispersion, even in the lack of ignition, can result in vapor clouds and health hazards. Vapor condensation explosions (VCEs) are predicted to happen when there is an extension in the combustion along with a crowded environment and flash fire is anticipated in an open-space setting in the absence of sources of delayed ignition. Table 5 represents the Intermediate and basic causes of the BN and BT probability.

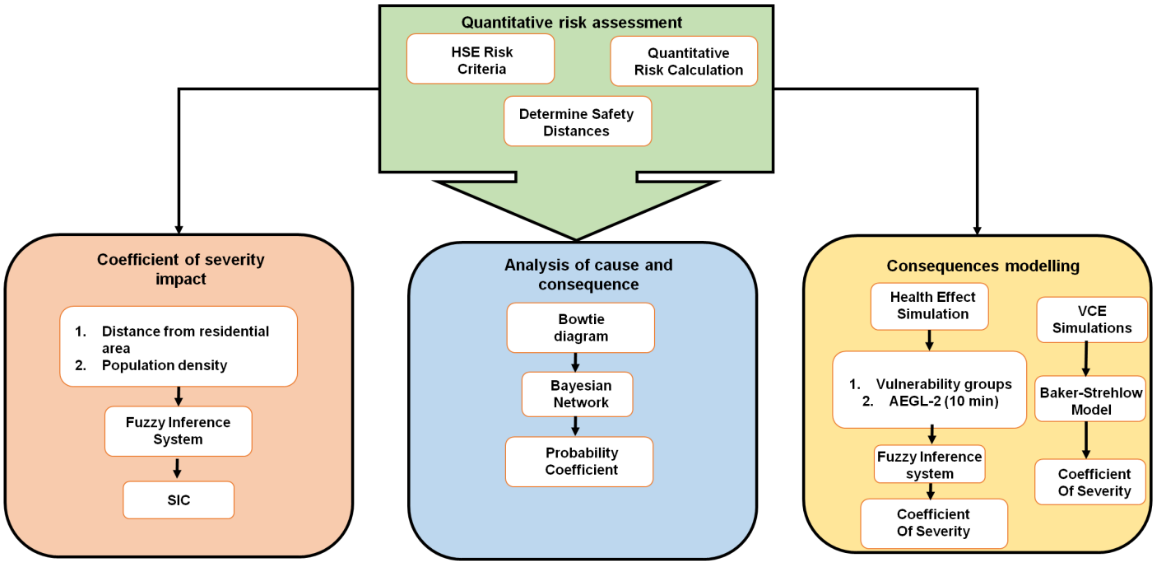


Figure 1. Quantitative Risk Analysis Methodology [Source: author]

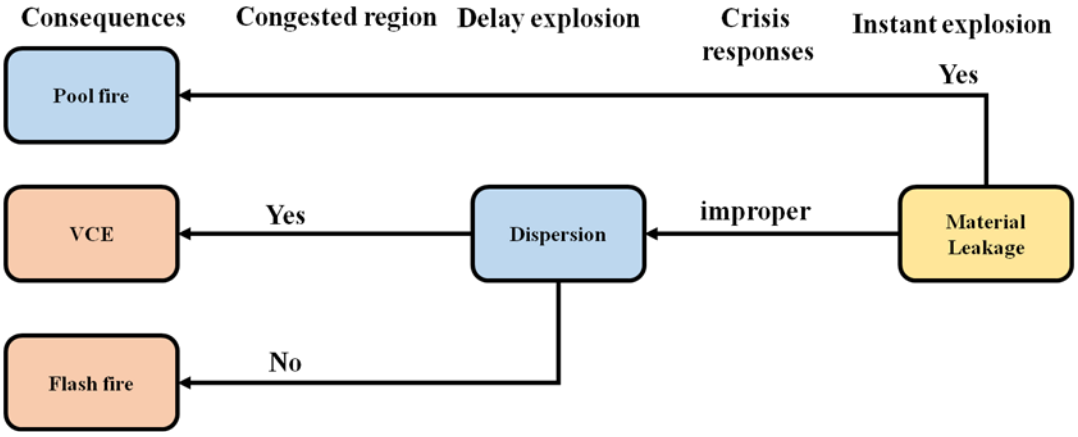


Figure 2. Event Tree Structure (Source: Author)

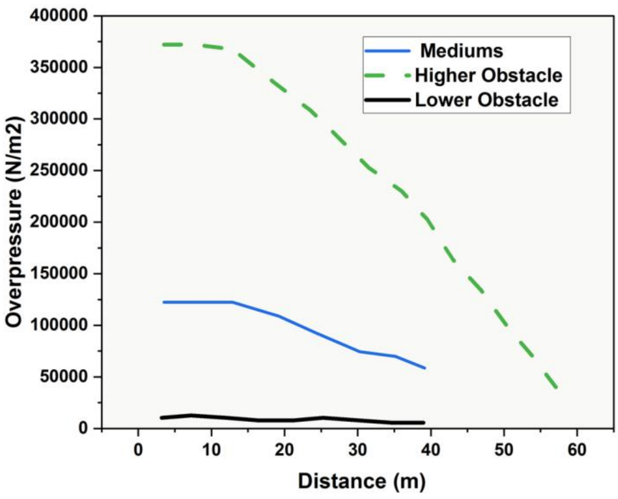


Figure 3. Overpressure on VCE (Source: Author)

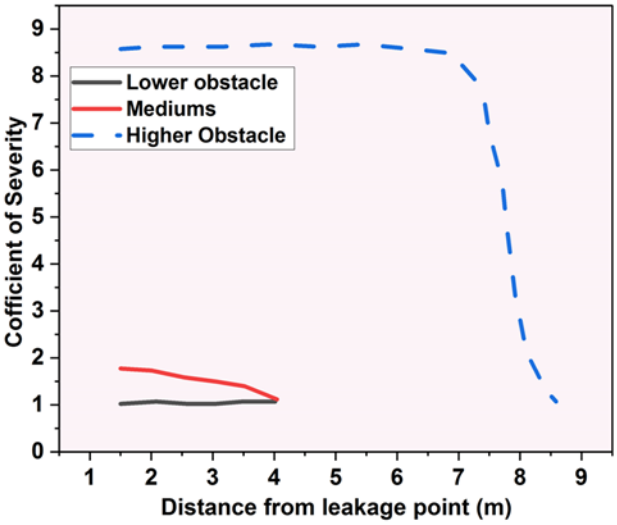
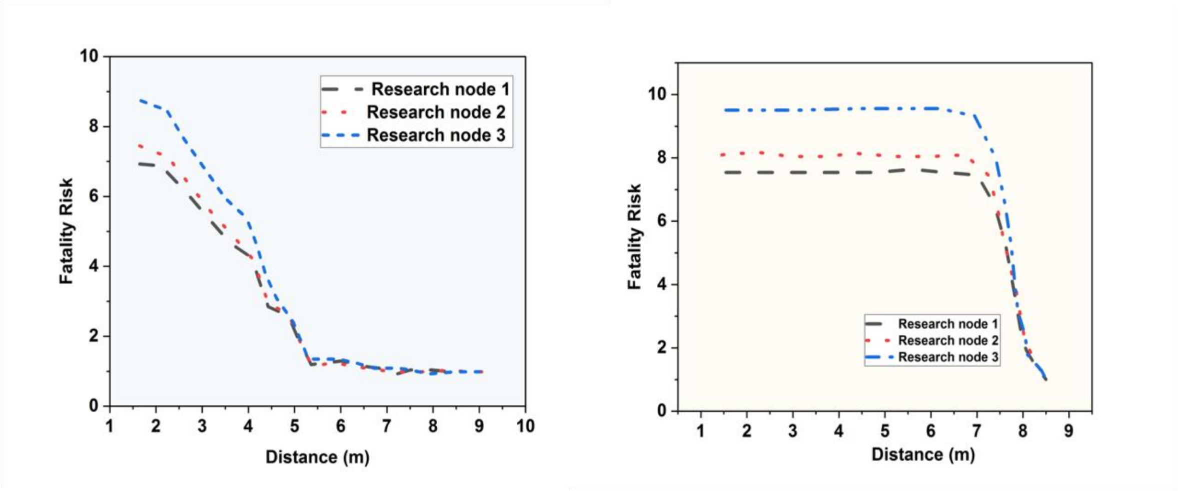


Figure 4. Coefficient of severity on VCE (Source: Author)



(a) Individual VCE severity

(b) Individual VCE risk

Figure 5. Individual VCE severity (a) and risk (b) (Source: Author)

Table 1. Toxicological consequences of fuzzy system (Source: Author)

Factor Level	Airborne concentration	Age-based vulnerability category	AEGL-2 (10 minutes)	Hazardous Consequences	LS*
1)	<IDLH of objects	35 - 55	500 - 100	Moderate- low	ml
2)	<NOAEL of objects	19 - 35	Greater than 1000	Low	l

3)	>Lethal dose of objects			High	h
4)	<Lethal dose of objects	Sensitive set <132>74	Less than 100	High-Moderate	hm

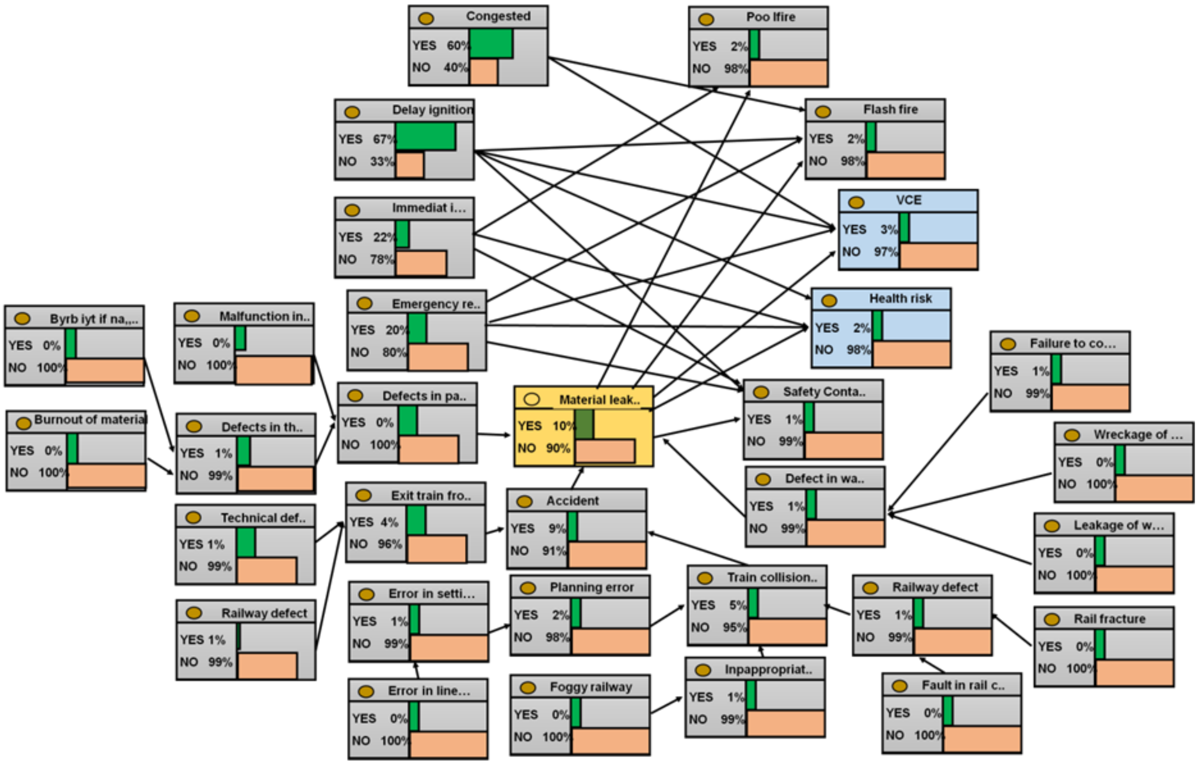


Figure 6. Model of fuel leakage using a Bayesian network (Source: Author)

Table 2. Coefficient of SIC of fuzzy system (Source: Author)

Factor Level	No. of people in 2500 m^2	Route distance to residential points	Critical points	SIC**	LT*
1)	Less than 11	Greater than 41`	0	Low	l
2)	11 - 51	31 - 41	2	Moderate- low	ml
3)	51 - 101	21 - 31	3 and 4	High-Moderate	hm
4)	Greater than 101	Less than 21	4 Greater than	High	h

Table 3. Rail cars with consequences and barriers(Source: Author)

Barrier	**Probability (work year)**	**Consequences**	**Probability of BT (work year)**	**BN probability (work year)**
Immediate ignition	6.72E-1	VCE	1.51 E-3	3.82E-2
Delay ignition	2.23E-1	Pool fire	7.93E-3	2.51E-3
Overcrowded region	6.02E-1	Safe Containment	3.82E-3	6.02E-4
Material flow	1.19E-2	Flash fire	1.02E-3	2.51E-3

Table 4. Rail cars with consequences and barriers(Source: Author)

Material	Gasoline
IDLH (g/n^3)	39.25
Reliability class	Relatively stable
Reactivity level	High
Lc50 (g/n^3)	301
Volume (n^3)	66
Heat combustion (ni/kg)	46.6

Table 5. Intermediate and basic causes in the BN and BT probability (Source: Author)

Conditions	BT possibility (annually)	BN possibility (annually)
Fundamental Conditions		
Broken wheels	9.00 E-4	7.03 E-3
Deliberate fault on the train	3.02 E-3	2.80 E-2
Rail connection fault	3.02 E-3	2.73 E-2
Inexperience of the machinist	9.00 E-3	7.91 E-2
Fracture of the rails	5.01 E-*3*	4.41 E-*2*
Rail cars Connection Failure	8.00 E-3	7.00 E-2
Rail crash with another rail	2.01 E-*5*	2.01 E-*5*
Foggy railroad	7.00 E-*3*	2.71 E-*2*
Dirty railroad	7.02 E-*3*	6.02 E-*2*
Intermediary Conditions		
Packaging material Defects	3.42 *E-6*	2.01 E-*5*
Rail collision with another rail	8.18 *E-2*	6.98 E-*1*
Accidents	2.07 *E-1*	9.95 E-*2*
Train exiting the rails	4.62 *E-2*	4.08 E-*2*
Rail car body Defect	2.51 *E-2*	2.30 E-1
Railway defects	7.03 E-4	2.07 E-3
Technical fault rail	2.01 E-3	9.61 E-2
Development mistake	2.51 E-2	2.28 E-1
Unintentional mistake on droppings on the rail	2.83 E-2	2.56 E-1
Train wheel flaws	5.82 E-6	2.02 E-6

Table 6: Severity Estimation of Various Age Groups (Source: Author)

Collectives	**Category Of Vulnerability (Age)**	**Severity Estimation**
i.	18–34	0.09
ii.	35–54	0.14
iii.	11 to 17 and 55 to 74	0.4
iv.	people with underlying illnesses and pregnant women: $\geq 75\ and\ \leq 10$	0.7

3.2. Severity Estimation Outcomes

3.2.1. Results of Toxicological Modelling

At the dispersion area, the airborne concentration of petrol vapor is 0.07 g/m^3 according to the distribution and categorizations in the sets of fuzzy. It should be mentioned that this quantity is little, which is why the fuzzy system classifies it as the L level. This concentration is lower than the gasoline's toxicological indices. Using the FL, further cases are examined in relation to the population's ages and the toxicological properties of petrol. The outcomes of the instance analysis utilizing this method are displayed in Table 6. It appears that the AEGL-2 level petrol and that neither AEGL-2 nor the no observable adverse effect level (NOAEL) for petrol are accessible. Based on the findings, if petrol is released, the vapor concentration will be less than the NOAEL. As a result, the quantity deficit at the leaking point has no effect on the radius in different sections. The graph shows that as one gets farther away from the leaking point, the exposure severity gets less severe. Hence, the exposure coefficient will ascertain an individual's vulnerability.

3.2.2. Results of VCE Modelling

Fig 3 illustrates the calculated explosion radius of the rail car. This shows that, depending on the distance of the source of explosion, VCE is the cause of the overpressure in three states of barriers. The graph demonstrates that the VCE pressure in the condition of "high obstructions" differs greatly from that of other states. When the leaking point is three meters away, the VCE pressure in the given conditions is 3.73 bars for the medium and low barrier; it is 1.21 bars and 0.11 bars. In Fig 4, the VCE coefficient of severity is illustrated. This graphic illustrates the 100% (coefficient of severity = 1) probability of death in the VCE-exposed population in the state with the highest barriers with a distance of up to 35m from the point of explosion. Based on a severity coefficient of 0.1, the exposed population has a 10% chance of dying in the medium obstacles state. The chance of dying at any distance drops to zero in the lower obstacle condition (coefficient of severity = 0).

3.3. Results of quantitative risk analysis (QRA)

Equation (8) is used to calculate the individual quantified risk in assessing the safety and health consequences based on the outcomes of BN, healthiness, protection models and the identified SIC. The full outcomes of quantified Toxicological risk evaluations and VCE are displayed in Fig 5 and 6. Age group 4 and node five were utilized to estimate the secure construction distance. An individual seriousness three meters from the leaking source, Figure A shows that the likelihood of a VCE-related death is 8.49 E-3 every work year. As shown in Figure B, the working annual individual risk of dying from a VCE at three meters from the location of leak is 8.48 E-2. The medium density state's anomalous trends of declining danger with distance are taken into consideration by the resource diagrams utilized in the BS method.

4. Discussion

This research uses the Quantum-inspired Dynamic Bayesian Network-Fuzzy Set Theory (QDBN-FST) systems to conduct a QRA on the Risk Management approach for safer rail transport of hazardous materials. Quantify the chance of combustion spill and its potential consequences, including toxicological effects and collision-generated energy, the QDBN is employed. The proposed model, QDBN-FST, can be a proper method for increasing the probability of the conclusions derived from consequences analyses. Large and complicated data processing can provide difficulties for Bayesian systems [16] in safer rail transportation, which can result in computational inefficiencies. Compared to the BN technique [17], our proposed method demonstrates that the contemplated discontinuous interactions among important factors supply improved accuracy. The results of the investigation support the hypothesis that stress and combustion heat are directly correlated and our research showed a stable relationship between the probability of dying and the distance traveled from the place of the explosion. The fuzzy set theory, according to community groups' sensitivity and the airborne concentration estimation equations, is applied in this research [18].

Every influencing aspect was taken into consideration when developing a fuzzy framework for modeling the toxicological outcomes. The proposed research analysis reveals that human factors possess a direct impact on the speed of technical failure of gear and the rate of defects in the equipment's maintenance has a direct impact on the rail transports' brake and wheel systems. With an excellent degree of monitoring and protection, this system is recognized as a more secure technological rail transport component and this research, the root causes and potential BN repercussions [19] are examined. This increased the precision of probability estimation and employed a Bayesian framework to predict rail incidents. Implementing an integrated risk management model is essential for improving the security of hazardous material rail transportation. Proactive methods such as extensive risk assessments, innovative monitoring systems and emergency response procedures are incorporated into this technique. Through the integration of these components, the plan requires reducing the possible impact of incidents, assuring the safe transportation of hazardous resources [20] as well as protecting the environment and public safety.

5. Conclusion

The execution of a comprehensive QDBN-FST risk management technique is essential for assuring the security of hazardous material transport on rail. The dangers connected to the transport of hazardous goods can be decreased through preventive measures, utilizing technology and encouraging cooperation between stakeholders. This method not only increases safety but also improves the rail transport system's overall resilience and sustainability. Incorporating modern innovations similar to artificial intelligence and Internet of Things sensors, An Integrated Risk Management Strategy for Safer Rail Transport of Hazardous Materials will expand predictive analytics in the future. It will be essential to implement improved communication protocols, real-time monitoring tools and stakeholder collaboration. The development that addresses evolving hazards and regulatory frameworks ensures that the method is robust and flexible in the evolving hazardous material transportation instance.

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