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Fire Hazards Of Transportation Of Fuels

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ABSTRACT
Hazardous materials are defined to be the substances that can have harmful effects to human, environment and property. These risks exist due to the nature, the hazardous properties or the state of the above materials. Fuels are categorized to flammable hazardous materials, either in the liquid or gas phase. Industrial needs as well as several human activities depend on the daily transportation of fuels. The consequences of road accidents involving fuel fires cannot be compared to the ones of simple collisions in terms of seriousness. Risks involved in transportation because of freight's hazardous properties (flammability, explosivity etc) are probable to give an extended radius to the affected area during a fire accident. A methodology for conducting a fire safety study during transportation of fuels and the basic elements for emergency and security planning are given with some indicative examples for implementation. Different fire hazard identification methods are examined, and mathematical models are implemented for the analysis of consequences of fire incidents. General fire prevention strategies are presented along with the requirements for fire detection and protection. Furthermore, specific measures for implementing the aforementioned strategies are given. Additionally, the first aid fire protection arrangements and equipment along with the necessary emergency and security planning are discussed. Finally, a fire risk management framework for the transportation of fuels have been deployed, in order to facilitate decision makers with a scientific tool for the safe routing of fuels transportation movements.
KEYWORDS—*transportation of fuels; fire risk assessment; hazardous material routing.*

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I. INTRODUCTION

Past fire accidents during transportation of fuels have revealed the high impact of consequences on human life, environment and property. Thermal radiation and overpressure are the main consequences leading to undesired final outcomes in case of fire accidents during transportation involving fuels as a cargo. Therefore, special consideration should be given in the proper planning for ensuring safe transportation of fuels. For these reasons technical codes and regulations have been developed including the European Agreement (ADR) concerning the international carriage of dangerous goods by road [1] and the U.S. Code of Federal Regulation (CFR), title 49, part 172 transportation of hazardous material [2]. Furthermore, several risk analysis methodologies have been developed by the scientific community for identifying fire hazards, estimating frequencies and consequences and finally concluding in appropriate mitigating measures for eliminating fire hazards [3].In the present paper, a methodology is presented for conducting a fire safety study during transportation of fuels, along with the compilation of emergency and security plans. Furthermore, a framework for assessing risks during transportation of fuels and routing vehicles carrying flammable fuels as a cargo is presented.

II. FIRE SAFETY STUDY

A. General Framework

The objective of a fire safety study is to ensure that the existing or proposed fire prevention, detection, protection and fighting measures are appropriate for the specific fire hazard and adequate to meet the extent of potential fires for the subject development. The fire safety study is one element in the safety assurance process. Emergency and security planning is also an important element and its relationship to fire safety arrangements should be clearly dealt with in the study. The principle of a fire safety study is that the fire safety "system" should be based onspecific analysis of hazards and consequences and that the elements of the proposedor existing system should be tested against that analysis. This should always producea better outcome than the application of generalized codes and standards alone.The methodological approach of the fire safety study during transportation of fuels includes the proposed procedure and the steps that should be followed in order to identify potential fire hazards, analyze consequences, develop fire prevention strategies and measures, analyze fire detection and protection requirements, identify specific measures for implementation and specify first aid fire protection arrangements and equipment.

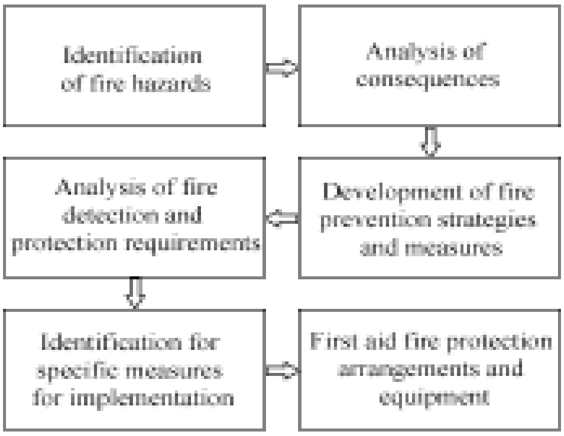

Fig. 1. **Procedure and steps for a fire safety study.**

B. Fire Hazard Identification

The first step in the study involves the identification of all potential fire hazards. The possible internal and external causes of incidents are also identified. The Preliminary Hazard Analysis and Hazard and Operabilitystudy (HAZOP) are used for guidance in the hazard identification process [4]. The methods in the Preliminary Hazard Analysis that are used to identify fire hazard during transportation of fuels include checklists, fault tree analysis and event tree analysis. The checklists include gap analysis and compliance with all relevant regulations. The fault tree analysis is used in order to identify root causes of fire hazards and fault trees display graphically the various combinations of equipment failures and human errors that may lead to the top event [5]. In figure 2 a sample fault tree for the top event Boiling Liquid Expanding Vapor Explosion (BLEVE) is presented.

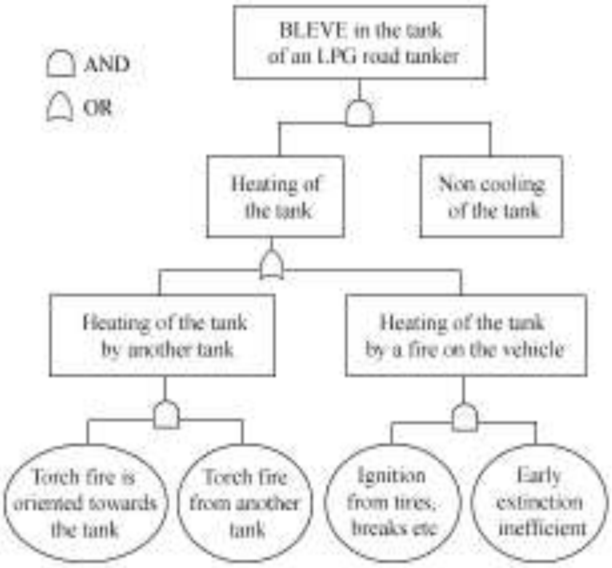

Fig. 2. **Fault tree analysis for a BLEVE from an LPG road tanker.**

The event tree analysis considers the responses of vehicle crew and of safety systems to the initiating event, as well as random effects such as the chance of ignition of a flammable mixture when determining the potential outcomes. An event tree is a graphical representation of the possible outcomes of an incident that results from a selected initiating event. In figure 3 a sample event tree is presented for the initiating event of fuel release during transportation.

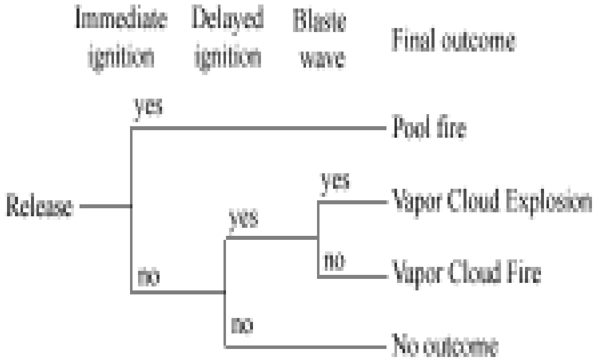

Fig. 3. General event tree for liquid fuels.

The fire hazard identification process should cover the nature of the materials and quantities involved, the nature of hazardous events (such as loss of containment), potential initiating events, ignition sources and so on.

C. Analysis of Consequences of Incidents

Once the fire hazards have been identified, the consequences of fire incidents should be estimated. The consequence analysis should address both direct impacts of incidents and the potential for propagation and secondary incidents. The analysis should relate selected targets such as people, environment and property, to specific time related exposures (heat flux, explosion overpressure and so on). The main outcomes resulting from accidents during transportation of fuels include pool fires, flash fires, vapor cloud explosions and boiling liquid expanding vapor explosions (BLEVEs).

A pool fire is the result of the ignition of a liquid fuel release. Initially, a pool of a certain diameter is formed due to the liquid fuel release, while an ignition source is present to give rise to the formation of the pool fire. The main effect of a pool fire is thermal radiation. The main elements for calculating thermal effects from pool fires are burning rate, pool size, flame geometry (height, tilt and drag), flame surface emitted power, geometric view factor, atmospheric transmissivity and thermal flux [6].

A flash fire results from the ignition of a released flammable cloud in which there is essentially no increase in combustion rate. The main dangers of a flash fire are radiation and direct flame contact. The size of the flammable cloud determines the area of possible flame contact effects. Cloud size depends mainly on dispersion and release conditions. Radiation effects on a target depend on its distance from flames, flame height, flame emissive power, local atmospheric transmissivity and cloud size [7].

A Vapor Cloud Explosion (VCE) is defined as an explosion occurring outdoors, producing a damaging overpressure. It begins with the release of a large quantity of flammable vaporizing liquid or gas fuel. The main features that are needed to be present in order a VCE to realize are [7]:

- the released fuel must be flammable at the prevailing conditions of pressure and temperature,
- a cloud of the gas phase of the released fuel having sufficient size must form prior to ignition,
- a sufficient amount of cloud must be within the flammable range of the released fuel in order to cause extensive overpressure and
- the flame propagation determines the blast effects produced by the VCE.

A Boiling Liquid Expanding Vapor Explosion (BLEVE) is an explosion resulting from the failure of a vessel containing a liquid fuel at a temperature significantly above its boiling point at normal atmospheric pressure. A BLEVE produces in addition to blast and fragmentation effects, buoyant fireballs whose radiant energy can burn exposed skin and ignite nearby combustible materials. The radiation effects of a fireball depend on the diameter of the fireball, the height of the center of the fireball above its ignition position, the surface-emissive power of the fireball and the duration of combustion.

For the estimation of the thermal radiation intensity (I) versus distance (x), the solid flame model is a safe and conservative approach. This model treats the flame as a solid shape and calculates the radiation which reaches a target at a certain distance to the flame, using a radiation heat transfer calculation incorporating a view factor (F), also called shape factor.

$$I = F * E * \tau \quad (1)$$

The surface emissive power (E) depends on the pressure of the containment before vessel failure (P), while atmospheric transmissivity (τ) decreases with the distance (x).

$$E = 235 * P^{0,39} \quad (2)$$

$$\tau = 1 - 0.056 * \ln x \quad (3)$$

The thermal dose (D) is calculated from the following equation:

$$D = I^{4/3} * t \quad (4)$$

where t is the exposure time.

The safe thermal radiation flux levels are considered to be 31.5 kW/m^2 for buildings and 1.4 kW/m^2 for people as guides in determining an "Acceptable Separation Distance" between a fire consuming combustible liquids or gases and nearby structures and people [8].

For the estimation of overpressure (P_{ov}), the TNT equivalence method is used, which calculates the overpressure at different distances from a vapor cloud explosion [9]. The first stage is to calculate the portion of the release that will volatize and take part in the explosion. The flash fraction (F_{fr}) is given by the following equation:

$$F_{fr} = 1 - \exp(-Cp * DT/L) \quad (5)$$

where $C_p$is the specific heat, DT is the difference between ambient temperature T_a and boiling temperature T_b at standard pressure, and L is the latent heat.

The TNT equivalent (E_{TNT}) is calculated by the following equation:

$$E_{TNT} = M * E_R * 2 * F_{fr} * a \quad (6)$$

where M is the mass released.
For hydrocarbon fuels the energy ratio $E_R$equals 10 and the efficiency factor ais 4%.
Then the scaled distance (R) is calculated by:

$$R = x / E_{TNT}^{1/3} \quad (7)$$

where x is the distance from the point of release.

Finally, the overpressure (P_{ov}) is obtained from specific diagrams of the scaled distance versus the overpressure, and the impulse D_{ov} (dose) is calculated bythe following equation:

$$D_{ov} = P_{ov} * t_{ov} \quad (8)$$

where t_{ov} is the positive phase duration.

D. Fire Protection Strategies and Measures

The basic elements of fire safety during transportation of fuels include appropriate vehicle design and operating procedures. These elements compose the most suitable fire prevention strategy as shown in figure 4. The appropriate vehicle design requirements based on international codes and standards include provisions for electrical equipment and suitable specifications for prevention of fire risks. Each element of the vehicle's electrical equipment should be appropriate for the environment that will be used, based on area classification regarding explosive atmospheres. The electrical equipment of the vehicle consists of the wiring, the batteries and the battery master switch, the permanent energized circuits and the electrical installation situated in the rear of the driver's cab. Furthermore, suitable specifications should be followed for fire risk prevention including the vehicle cab, the fuel tank of the vehicle, the engine, the exhaust system, the endurance braking system and the combustion heater (where appropriate).

Fig. 4. Fire protection strategy.

Furthermore, safe work practices including observance of standards, codes and regulations, as well as company policies andprocedures, all have important bearing on fire safety and should be explicitlyaddressed.Procedures and practices regarding transportation of fuels should at least include the following:

- procedures for compliance with the requirements governing the identification of fuels being transported,
- company's practice in taking account, when purchasing means of transport, of any special requirements in connection with the fuels being transported,
- procedures for checking the equipment used in connection with the carriage, loading or unloading of fuels,
- proper training of the company's employees, including the changes to the regulations, and the maintenance of records of such training,
- implementation of proper emergency procedures in the event of any accident or incident that may affect fire safety during carriage, loading or unloading of fuels,
- investigating and, where appropriate, preparing reports on serious fires recorded during carriage, loading or unloading of fuels,
- implementation of appropriate measures to avoid the recurrence of minor or serious fires,
- account taken of the legal prescriptions and special requirements associated with the carriage of fuels in the choice and use of sub-contractors or third parties,
- verification that employees involved in the carriage, loading or unloading of fuels have detailed operational procedures and instructions,
- introduction of measures to increase awareness of the fire risks inherent in the carriage, loading and unloading of fuels,
- implementation of verification procedures to ensure the presence on board the means of transport of the documents and safety equipment which must accompany transport and the compliance of such documents and equipment with the regulations,
- implementation of verification procedures to ensure compliance with the requirements governing loading and unloading,
- existence of an up to date security plan.

Finally, emergency plans and procedures are an important part of fire prevention.Appropriate and early action can prevent small incidents developing into serioussituations and can limit the scale and extent of the impact of incidents. Thedevelopment or analysis of fire prevention strategies and measures should therefore beintegrated with emergency planning.

E. *Fire Detection and Protection Measures*

Given the selected fire prevention strategy, the necessary requirements for fire detection and protection are selected. These requirements include the detection of pre-conditions for fire and the recognition of the appropriate physical protection measures.

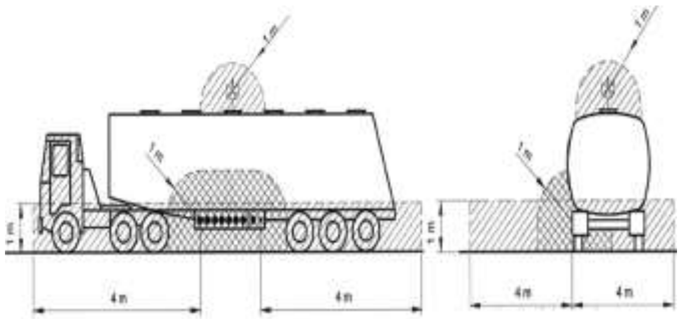

Fig. 5. Typical hazardous area classification of a road tanker during unloading.

In figure 5 the hazardous areas, where a flammable atmosphere is most likely to be present during unloading, are shown [10]. Therefore, proper arrangements should be made in order to ensure that no ignition sources will be present at these areas, as well as all electrical equipment located in these areas meet the necessary requirements. Furthermore, in order to minimize potential release of flammable fuels from the breathing device in the top of the road tanker, proper arrangements for unloading in a closed circuits should be established and appropriate procedures should be followed. Finally, a good electrical connection from the vehicle chassis to the earth shall be established before tanks are filled or emptied. In addition, the rate of filling shall be limited in order to avoid the development of electrostatic charges.

F. Mitigating Measures

Based on the fire prevention strategy and the requirement analysis for fire prevention and protection, specific measures are identified. As mentioned beforehand, these measures include proper vehicle design focusing on electrical equipment protection and prevention of fire risks. The minimum specifications of vehicle's electrical equipment include:

- Wiring: the size of the conductors shall be large enough to avoid overheating. Conductors shall be adequately insulated. All circuits shall be protected by fuses or automatic circuit breakers (except specific connections). Cables shall be securely fastened and positioned in such a way that the conductors are adequately protected against mechanical and thermal stresses.
- Batteries: the battery terminals shall be electrically insulated or covered by an insulating battery box cover. If the batteries are not located under the engine bonnet, they shall be fitted in a vented box.
- Battery master switch: a switch for breaking the electrical circuits shall be placed as close to the battery as practicable. If a single pole switch is used it shall be placed in the supply lead and not in the earth lead. A control device to facilitate the disconnecting and reconnecting functions of the switch shall be installed in the driver's cab. It shall be readily accessible to the driver and be distinctively marked. It shall be protected against inadvertent operation by either adding a protective cover by using a dual movement control device or by other suitable means.
- Permanently energized circuits: Those parts of the electrical installation including the leads which shall remain energized when the battery switch is open, shall be suitable for use in hazardous areas, according to area classification regarding explosive atmospheres.
- Electrical installation situated in the rear of the driver's cab: The wiring located to the rear of the driver's cab shall be protected against impact, abrasion and chafing during normal vehicle operation. Lamp bulbs with a screw cap shall not be used. Electrical connections between motor vehicles and trailers shall have a protection degree IP54 and be designed to prevent accidental disconnection.

The appropriate mitigating measures for fire risk prevention include among others:

- Vehicle cab: unless the driver's cab is made of material which are not readily flammable, a shield made of metal or other suitable material of the same width as the tank shall be fitted at the rear of the cab. Any windows in the rear of the cab or in the shield shall be hermetically closed and made of fire-resistant safety glass with fire-resistance frames. Furthermore, there shall be a clear space of not less than 15cm between the tank and the cab or the shield.
- Fuel tanks: in the event of any leakage from the fuel tank supplying the engine, the fuel shall drain to the ground without coming into contact with hot parts of the vehicle or the load. Fuel tanks containing petrol shall be equipped with an effective flame trap at the filler opening or with a closure enabling the opening to be kept hermetically sealed.
- The engine propelling the vehicle shall be so equipped and situated to avoid any danger to the load through heating or ignition.

- The exhaust system (including the exhaust pipes) shall be so directed or protected to avoid any danger to the load through heating or ignition. Parts of the exhaust system situated directly below the fuel tank (diesel) shall have a clearance of at least 100 mm or be protected by a thermal shield.
- Vehicles equipped with endurance braking systems emitting high temperatures placed behind the rear wall of the driver's cab shall be equipped with a thermal shield securely fixed and located between this system and the tank or load so as to avoid any heating, even local, of the tank wall or the load. In addition, the thermal shield shall protect the braking system against any outflow or leakage, even accidental, of the load. For instance, a protection including a twin-shell shield shall be considered satisfactory.
- The combustion heaters and their exhaust gas routing shall be designed, located, protected or covered so as to prevent any unacceptable risk of heating or ignition of the load. The combustion heaters shall be put out of operation automatically when stopping the vehicle engine and when starting up of a feed pump on the motor vehicle for the dangerous goods carried. The combustion heater shall only be switched on manually and combustion heaters with gaseous fuels are not permitted.

  Also, other proposed mitigating measures and procedures for eliminating fire hazards identified during the preliminary hazard analysis may include:
- Earthing of vehicles: Tanks made of metal or of fibre-reinforced plastics material shall be linked to the chassis by means of at least one good electrical connection. Any metal contact capable of causing electrochemical corrosion shall be avoided.
- Stability of tank-vehicles: the overall width of the ground-level bearing surface (distance between the outer points of contact with the ground of the right-hand tyre and the left-hand tyre of the same axle) shall be at least equal to 90% of the height of the centre of gravity of the laden tank-vehicle.
- Rear protection of vehicles: A bumper sufficiently resistant to rear impact shall be fitted over the full width of the tank at the rear of the vehicle. There shall be a clearance of at least 100 mm between the rear wall of the tank and the rear of the bumper.
- Personnel training: members of the vehicle crew shall know how to use the fire-fighting appliances.
- Portable equipment: the portable lighting apparatus used shall not exhibit any metal surface liable to produce sparks.
- Use of naked flame: Smoking shall be prohibited during handling operations in the vicinity of vehicles and inside the vehicles.
- Parking: no vehicles carrying fuels may be parked without the parking brakes being applied. Trailers without braking devices shall be restrained from moving by applying at least one wheel chock.
- Fire extinguishers: transport units carrying fuels shall be equipped with specified number of portable fire extinguisher suitable for certain inflammability classes for dealing with engine or cab fires, as well as fuel cargo fires in its initial stages only if these fires do not pose a direct threat for the vehicle crew life.

  Finally, an initial and periodic inspections of vehicles transporting fuels should be planned, performing a set of inspections and tests in order to ensure proper functionality of all critical safety equipment and devices of the vehicle [11, 12].

G. First Aid Fire Protection Arrangements

In case of fire, the first actions for preventing escalation are of high importance. The necessary first aid fire protection arrangements and equipment include provision of portable fire extinguishers, provision of warning signs and training of vehicle crew.

Each vehicle transporting fuels should be equipped with a minimum number of fire extinguishers. At least one fire extinguisher of a minimum capacity of 2kg should be available for engine or cab fires, while at least two fire extinguishers of a total minimum capacity of 12kg should be available in the cargo area. The extinguishing agents shall be such that they are not liable to release toxic gases into the driver's cab or under the influence of the heat of the fire. The portable fire extinguishers shall be fitted with a seal verifying that they have not been used. They shall bear a mark of compliance with all relevant standards and an inscription at least indicating the date (month, year) of the next recurrent inspection or of the maximum permissible period of time, as applicable. The fire extinguishers shall be subjected to periodic inspections in order to guarantee their functional safety. The fire extinguishers shall be installed on the transport units in a way that they are easily accessible to the vehicle crew. The installation shall be carried out in such a way that the fire extinguishers shall be protected against effects of the weather so that their operational safety is not affected.

Also, proper placarding signs and labels for the fuel class being transported should be located on the vehicle. Orange placards indicating the fuel UN number along with the fuel hazard identification number should be located in the front and the rear part of the vehicle. Hazard labels indicating the hazard category of the fuel (flammable liquid, liquefied flammable gas etc) should be located at the rear and both sides of the vehicle.

Furthermore, specific instructions for handling emergency situations such as releases of fuels and subsequent fires after ignition are provided to the vehicle crew in writing. Vehicle crew should be properly trained in order to implement these instruction in writing properly and on time, in order to avoid escalation of undesired consequences.

III. EMERGENCY AND SECURITY PLANNING

A. Emergency Planning

An effective response to a road transport emergency is essential to eliminate the hazards and lessen their impact of an incident occur. An emergency plan is looking at the actions and initiatives that need to be developed prior to any such incident [13]. It is critical to the success of any transport emergency response that an appropriate emergency organization structure is set up. All personnel who are members of the emergency response team must be well trained and competent to handle the situation in as professional a manner as possible. A typical organization structure consists of the emergency controller, the emergency coordinator, the company spokesperson and the emergency response team.

In order to better handle different types of emergencies, incidents and emergency situations can be divided into three severity levels. The first level includes minor road incidents where there is no damage and the situation is unlikely to escalate. The second level includes serious incidents such as tanker rollover, transported fuel spill or serious vehicle collision with multiple injuries. Finally, the third level includes serious incidents that could potentially escalate into a disastrous emergency situation, such as a large pool fire or a boiling liquid expanding vapor explosion.

The necessary actions that should be followed in case of an emergency include:

- report accident by driver or public,
- receive report by supervisor or public emergency services,
- confirm preliminary accident information,
- assess the emergency level in order to proceed to further actions,
- in case of serious incidents (level 3) isolate the area with an initial protective action zone,
- set up emergency control center at a safe distance and up wind from the incident scene,
- deal with fire or spill (put out the fire, stop the spill, transfer the released fuel),
- evacuate the area if needed based on the assessment of possible consequences,
- provide first aid at the scene and transfer injured people to the hospital,
- recover the area and the vehicle in order to give the road back to traffic.

B. Security Planning

High consequence dangerous goods are those which have the potential for misuse in a terrorist event and which may, as a result, produce serious consequences such as mass casualties, mass destruction or mass socio-economic disruption. Liquid and liquefied flammable fuels transported in tank with a capacity of more than 3000 lt are considered to be high consequence dangerous goods.All participants in the logistic chain of the transportation of fuels characterized to have high consequences, shall adopt, implement and comply with a security plan that addresses at least the following elements:

- specific allocation of responsibilities for security to competent and qualified persons with appropriate authority to carry out their responsibilities,
- records of dangerous goods or types of dangerous goods concerned,
- review of current operations and assessment of security risks, including any stops necessary to the transport operation, the keeping of dangerous goods in the vehicle, tank or container before, during and after the journey and the intermediate temporary storage of dangerous goods during the course of intermodal transfer or transshipment between units as appropriate,
- clear statement of measures that are to be taken to reduce security risks, commensurate with the responsibilities and duties of the participant, including training, security policies, operating practices, equipment and resources that are to be used to reduce security risks,
- effective and up to date procedures for reporting and dealing with security threats, breaches of security or security incidents,
- procedures for the evaluation and testing of security plans and procedures for periodic review and update of the plans,
- measures to ensure the physical security of transport information contained in the security plan, and
- measures to ensure that the distribution of information relating to the transport operation contained in the security plan is limited to those who need to have it.

Carriers, consignors and consignees should co-operate with each other and with competent authorities to exchange threat information, apply appropriate security measures and respond to security incidents [14].

IV. RISK MANAGEMENT AND VEHICLE ROUTING

A. Fire Risk Management Framework

The necessary data for conducting a fire risk assessment for the transportation of fuels are derived from the traveling risk source, the transportation network and the impact area as shown in figure 6. Fire risk assessment during transport of fuels is structured as a process resulting from the interaction between the vehicle or traveling risk source, the transportation network and the impact area [15].

The vehicle or traveling risk source is characterized by the probability (P) of an outcome (i), such as fire or explosion, which, in case of an accident, depends on the type of fuel (f) being carried.

The transportation network can be considered and viewed as a graph G = (M, A) formed by the node set N_M and arc set N_A and a certain amount of shipments of some fuels (f) that are made yearly from node O (origin) to node D (destination). Also, the transportation route can be viewed as a linear risk source, since a release can occur at any point. This means that each point of the route can be considered as a point risk source. All arcs (A) can be divided into a number of links (N_l), each link (l) having the same properties across its length.

The impact area is characterized by population distribution and meteorological conditions. Population distribution can be made with accuracy by dividing the impact area into: (i) zones of polygonal shape, where people may be considered uniformly distributed with a density depending on the area being an urban, a suburban or a rural one, (ii) roads, where people are linearly distributed, (iii) centers of aggregated population (CAP) e.g. schools, hospitals and commercial sites, where people can be considered as clustered. Also, population distribution takes into account that people can be indoors at the occurrence of a release, sheltered from the accident consequences. Meteorological conditions are divided into N_k pairs of atmospheric stability class – wind speed. Also, the wind probability density distribution $p_{wind}(j,k,\theta)$ is the wind rise in the impact area, for each meteorological condition k and seasonal situation j. The angle θ is used to mark a generic wind direction.

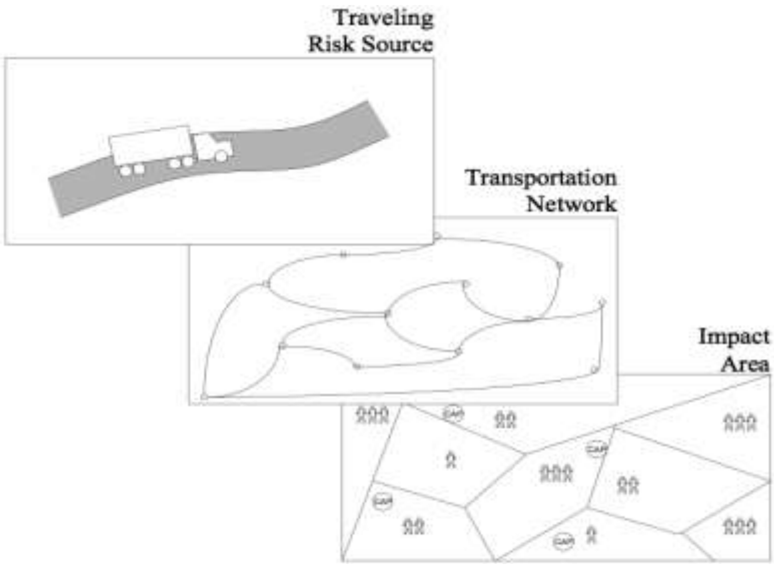

Fig. 6. **Interaction between data sources for fire risk assessment of transportation of fuels.**

B. Risk Source Release Model

Release assessment involves quantifying the extent to which a risk source releases risk agents into the human environment. In transportation of fuels the frequency of an outcome – fire, explosion – during an accident is the above mentioned measurement. The frequency ($f_{i,j,f}$) of an outcome (i) from an incident of fuel (f) transportation at seasonal situation (j) can be calculated by the following equation.

$$f_{i,j,f} = f_{inc,j,f} * P_{i,f} \quad (9)$$

where $P_{i,f}$ is the probability of an outcome (i) from an incident of transportation of a fuel (f).

The frequency ($f_{inc,j,f}$) of an incident (inc) of transportation of a fuel (f) at seasonal situation (j) depends on the length (L_l) of the link, the number ($V_{l,j}$) of vehicles passing through link l, the fraction ($x_{l,j,f}$) of vehicles carrying the fuel (f) and the expected frequency ($f_{exp,j,l}$) of an incident on link 1 and at seasonal situation j [6].

$$f_{inc,j,f} = f_{exp,j,f} * L_l * V_{l,j} * x_{l,j,f} \quad (10)$$

The probability ($P_{i,f}$) of an outcome (i) from the transportation of a fuel (f) can be calculated through event tree analysis, as described above.

C. Exposure Model

Exposure assessment is the process of measuring the dose of risk agents received by population. Thermal radiation and overpressure have been modeled for the calculation of the total dose which an individual receives at a certain distance.The estimation of the thermal radiation intensity and overpressure have been presented briefly beforehand.

D. Consequence Model

Consequence assessment is the process of describing and quantifying the relationship between exposures to a risk agent and the adverse health consequences that result from such exposures. The probit equation is used for the calculation of fatalities from exposures to certain amounts of doses from thermal radiation and overpressure.

$$Pr = -a + b * \ln(dose) \quad (11)$$

Values for constants a and b for each consequence are given in table 5 [16].

TABLE I. PROBIT EQUATION CONSTANTS

Consequence	Dose	a	b
Thermal radiation	$I^{4/3}$ □ t	14.9	2.56
Overpressure	P □ t	46.1	4.82

E. Fire Risk Estimates

Risk estimation, also referred to as risk characterization, is the final step in risk assessment. Its goal is to produce measures for the fire risks that are being assessed. The measures are usually referred to as indices of risk. Typically, risk indices are simple numbers selected to characterize some important aspect of the risk. For the estimation of risks involved during transportation of fuels, the individual and societal risk indices are used.

Individual Risk is the frequency at which an individual may be expected to sustain a given level of harm from the realization of specified hazards [17]. It is used to estimate the risk of a hypothetical "average" individual as a function of distance from the hazard.

Societal Risk is the relationship between frequency and the number of people suffering from a specified level of harm in a given population from the realization of specified hazards [17]. Societal Risk is usually expressed in the form of cumulative F-N curves, which are plots of the cumulative frequency (F(n)) of N or more people receiving the specified level of harm per year, against the number of people (N) receiving the specified level of harm. F-N curves are usually plotted on a log-log scale. In the calculation of societal risk, it is usual for the specified level of harm to be a fatality. Unlike in the calculation of individual risk, the number of people exposed to the risk is taken into account in the calculation of societal risk. Once both the frequency, f_i, and the number of fatalities, n_i, has been calculated for each event, it is possible to estimate the societal risk.

According to the fire risk acceptance criteria specific routes may be pose intolerable risks for the public and therefore transportation of fuels from these routes should not be allowed. Two or more alternative routes should be compared in terms of fire risk estimates and proper cost benefit analysis should be conducted in order to conclude on the optimum path for transporting fuels under acceptable safety levels in combination with the necessary additional mitigation measures.

V. DISCUSSION

The aforementioned methodological approach for conducting a fire safety study during transportation of fuels is based on international best practice on fire safety, as well as international codes and regulations regarding the safe transportation of hazardous materials. The use of well recognized methodologies by the chemical industry for hazard identification has been proved to be also effective for identification of fire hazards during transportation of fuels. Consequence analysis and modeling of fire scenarios resulting from accident during transportation of fuels is one of the main parts of the fire risk management process. On the other hand, frequency analysis is based mainly on road accident rates of the particular road network. Finally the risk management general framework has been implemented for the development of the fire risk management for the assessment of fire risks during transportation of fuels, which is a sound justified decision support tool to be used by decision makers in the process of selecting the safest routes for the transportation of fuels.

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Nikolaos Vagiokas "Fire Hazards Of Transportation Of Fuels." The International Journal of Engineering and Science (IJES) 7.7 (2018): 38-48