IDENTIFYING POTENTIAL RISKS CREATED BY STATE JOINT-STOCK COMPANY LATVIJAS DZELZCEĻŠ JELGAVA STATION AND EVALUATING THEIR IMPACT ON ENVIRONMENT, INHABITANTS AND INFRASTRUCTURE

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Abstract. Critically important infrastructure objects play an important role in the national security system by transporting loads, which provide the possibility of developing and working for many national economy sectors. It is very well known that zero risks do not exist, so it is necessary to clearly recognise the hazards and to assess the situation in time in order to plan and, if necessary, minimise potential harmful effects on the environment, economy, etc. The aim of the research is to study the impact of one of the hazards options on the population and identify potential consequences by using situation modelling. When operating rolling stock, there exists a possibility of major accidents that can lead to pollution of the atmosphere, land, water bodies, and damage to human health and may result in fatal outcomes, as well as serious material damage to the environment. The object of the research is located in Jelgava area, on the left bank of the Lielupe, in the territory of Jelgava transport infrastructure, Stacijas street 1A, Jelgava. The analysis of cargo flow shows that the most dangerous substances at the object are liquefied gas, petrol, ammonia. These substances, except ammonia, may serve as the starting stage of a possible accident and create a domino effect with other dangerous cargo situated in the territory of the object, for example, ammonium nitrate. In case of damage to a separate tank the hazard of possible accident at the object increases significantly due to the use of great number of tanks, as well as the possibility of domino effect increases because the tanks are close to each other. The worst variant of an accident is possible for inhabitants in case of south wind when the downtown with plenty of public institutions is affected. Passenger station is also adjacent to the territory of the object; that is why the most dangerous place of origin of the accident at the object directly opposite the station building was selected for the modeling. The results of the research: risks and potential consequences that may arise in one of the options for potential hazards are examined.

Keywords: infrastructure, objects, hazard, effect, substances, accident.

Introduction

Critically important infrastructure objects play an important role in the national security system by transporting loads, which provide the possibility of developing and working for many national economy sectors. It is very well known that zero risks do not exist, so it is necessary to clearly recognise the hazards and to assess the situation in time in order to plan and, if necessary, minimise potential harmful effects on the environment, economy, etc.

The railway infrastructure and the operation of transport involve the storage and transfer of significant quantities of dangerous substances, as well as processing of large amounts of information, carrying out of dangerous technological processes, as well as external natural and anthropogenic hazards that can have an extreme impact on the operation of the facility. Depending on where the source of the hazard is located within the facility – inside the territory, in the rolling stock or outside - internal and external hazards are singled out.

The hazard to the infrastructure facilities and rolling stock is defined as a totality of various individual cases or processes, extreme external natural and anthropogenic impact factors, incorrect actions of personnel, which can be incompliant with the functioning conditions of the facility's technical systems when a definite potential exists capable to lead to an accident or cause a catastrophe.

In order to identify the reasons for a possible accident, a scenario tree was created as the most appropriate for each type of accident while a fault tree will be used in work. In order to identify the causal-effect regularity, the logical graphical method (ETA –Event tree analysis) is used in the paper to identify the possible consequences of railway tank damage and to assess the probability. ETA is an established risk analysis technique to assess likelihood (in a probabilistic context) of an accident [1]. ALOHA 5.4.6. software program developed by the US Federal Services has been used in this modeling of accident consequences. When modeling the consequences of an accident, criteria applied in the world practice are used. The event tree approach was used to show all possible risk scenarios. In order to assess the consequences for humans (traumatism %, toxic impact %), the Gaussian error (Pr - probit) function of the upper limit integration, or so-called *erfc*-function, is used.

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Research results and discussion

The facility is located in the territory of Jelgava town, on the left bank of Lielupe River, in TR zone of Jelgava transport infrastructure area, at 1A Stacijas Street, Jelgava, geographical coordinated according to WGS84 56º38'26" Z latitude, 23º43'56" A longitude. Total ground area of the facility according to www.kadastrs.lv data is 25.9758 ha [2]. The territory examined in the overall risk assessment is of area about 128,839.21m^2. The facility generally consists of two yards: Jelgava I and Jelgava II. Operations carried out in park Jelgava I are train acceptance, dispatch, technical and commercial processing, while tracks of park Jelgava II are intended for train passage. Cargoes processed at Jelgava Station are mainly construction materials, oil products and mineral fertilizers [3]. Jelgava Station processes daily (24 h) average 60 freight trains. Functioning of the facility and related enterprises can be considered as a network consisting of five consecutive service systems: processing of trains after arrival; breaking up of trains; completion of train makeup; processing of trains upon dispatch; train dispatch. Traffic of passenger and freight trains is organized via Jelgava Station. It is established that the volumes of cargoes carried by railway comparing 2017 to 2010 are stable although certain tendencies are observed, such as transportation reduction in oil products and increase in stone coal.

The facility mainly borders the properties of legal entities and natural persons: industrial building development territories in the southern part; mixed downtown development area in the north and west; natural and planted territories eastwards. Dense network of railway tracks constructed in the facility's territory is mainly used for placement of freight carriages. Publicly accessible bridge (Lithuanian highway) crosses the facility's territory to join Stacijas Street and Savienibas Street. The most important objects in the facility's vicinity: passenger railway station, where a big number of people can be accommodated waiting for passenger trains.

The hazard to the infrastructure facilities and rolling stock is defined as a totality of various individual cases or processes, extreme external natural and anthropogenic impact factors, incorrect actions of personnel, which can be incompliant with the functioning conditions of the facility's technical systems when a definite potential exists capable to lead to an accident or cause a catastrophe.

In order to identify the reasons for a possible accident, a scenario tree was created as the most appropriate for each type of accident. The development of the fault tree is based on the causes of potential hazardous events at the facility, which are associated with various hazard factors that may affect the safety of the facility. This fault tree for a facility with identified hazards is shown in Fig. 1. Fault tree analysis is a powerful technique that is widely used for evaluating the system safety and reliability [4]. In order to identify the causal-effect regularity, the logical graphical method (ETA – Event tree analysis) is to identify possible consequences of railway tank damage and to assess the probability.

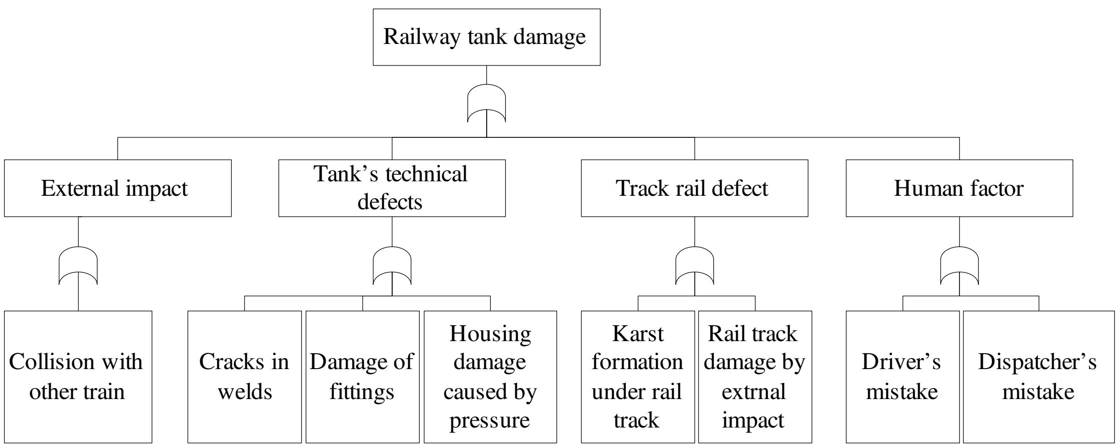

Fig. 1. **Causes of accident with railway tank (fault tree)**

When carrying out the cargo flow analysis, it was found that the most dangerous substances at the facility were liquefied gas, gasoline, ammonia. These substances, with the exception of ammonia, can serve as the starting point for a possible accident and create a domino effect with other dangerous goods located at the facility, such as ammonium nitrate. The risk of a potential accident at the facility in case of a particular tank damage increases significantly since a large number of tanks is used during transportation and the likelihood of domino effect increases as the tanks are positioned close to each other. The worst accident variant for people is possible at the southern wind when the downtown will be affected, where many publicly important institutions are located. The passenger station is also situated next to the facility's territory, therefore, the most dangerous emergency origin at the object was chosen for modeling, located directly opposite the station building.

The railway infrastructure and the operation of transport involve the storage and transfer of significant quantities of dangerous substances, as well as processing of large amounts of information, carrying out of dangerous technological processes, as well as external natural and anthropogenic hazards that can have an extreme impact on the operation of the facility. Depending on where the source of the hazard is located within the facility – inside the territory, in the rolling stock or outside - internal and external hazards are singled out.

Internal threats to the infrastructure facilities and rolling stock are initiated by dangerous processes of which potential is determined by the following basic factors:

- chemical composition of masses and substances, biological and radioactive substances located in the facility's territory (storage or transportation);
- amount of energy present at the facility;
- amounts of incoming and outgoing information flow at the facility.

Operational loads on elements, exposure to aggressive chemical environments, radiation, control system failures are also referred to internal hazards. Much of the internal threat is also related to the human factor (staff errors, non-compliance with regulations).

External hazards include hazard factors of which impact is associated with dangerous causes of natural and technogenic events (processes) that occur outside the facility. Such events can be extreme meteorological conditions, such as strong wind, rain, earthquake, as well as technogenic accidents at nearby infrastructure facilities. The main source of external risk can also be an unrestricted free human access to the facility's infrastructure so that the facility can serve as a target for a terrorist act, potential consequences of which will be considered in the course of this work.

ALOHA 5.4.6. software program developed by the US Federal Services has been used in this modeling of accident consequences (for calculation of spread of explosive, toxic concentrations, for determination of spread of explosion wave caused overpressure and for the estimated fire impact). Thus, there may be a situation where the results of already previous modelling are different, which is possible because every new version of ALOHA software is accompanied by data of in-depth study on the behavior of potentially leaked substances under certain conditions.

When modelling the consequences of an accident, criteria applied in the world practice are used. The event tree approach was used to show all possible risk scenarios. From the specifics of the facility, it can be stated that the main physiological and biological hazards to humans are: baric effects (vapour explosions, thermal radiation or heat emission – spill fires, fireball, jet fires); mechanical effects upon destruction of structures from overpressure and other reasons; toxic effects when hazardous substance gets into human body. It is known that the same impact (amount of substance, dose of thermal radiation or pressure impulse) leads to different degrees of consequences for different people, thus, the factors of influence on human body are of probabilistic nature. Therefore, in order to assess the consequences for humans (traumatism %, toxic impact %), the Gaussian error (Pr - probit) function of the upper limit integration, or so-called erfc-function, will be used.

Area of accident with liquefied hydrocarbon gases (hereinafter referred to as LHCG) with a gas flown from tanks can reach up to 2500 m^2 and can extend to 250 m in length. When the tank with LHCG gets in the area of the impact of the jet fire, pressure therein rapidly increases, the safety valves are not capable to discharge the entire gas and after 16-25 minutes a dangerous collapse of the tank subjected to dangerous effects is expected, creating an explosion and throwing away the flame within the distance up to 150 m, thus generating new fire sources within the radius of 150 m as well as a fireball of 120-150 m diameter. Fragments of exploded tank can be thrown over the distance up to 150 m, in some cases up to 450 m. Sometimes, as a result of the explosion, the tank can be torn off from its frame and moved to within the distance up to 80 m. Explosion of one LHCG-filled railway tank increases the existing fire area up to 160 m2 depending on the terrain of the accident site. The fire spreads most rapidly when LHCG leaks as a result of an accident, when the tanks roll over and damages occur resulting in a fire area of up to 10,000 m^2. After the area of leakage, the combustion spreads not only to the nearest trains, but also to warehouses, administration buildings and, in some cases, to the buildings of the nearest district.

The following parameters were adopted for modelling of liquefied petroleum gas leakage:

Dangerous cargo is propane transported in a tank, model 15-1200, volume 55.7 m^3. Pressure in fittings 2 MPa, filling factor 85 %. Ambient temperature is + 20ºC, temperature of substance in fittings is the same. The calculation was made for the worst weather conditions, wind speed 1 $m \cdot s^{-1}$. Atmospheric stratification class – F. Leakage takes place on concrete, leakage location is a free horizontal area. Emergency liquidation time and leakage time make up 3600 seconds.

Probability of realization of accident scenarios according to the created event tree "Complete destruction of tank containing liquid under pressure" with the assigned numbers of scenarios is presented in Table 1.

Table 1

Event tree realization probability of "Complete tank destruction"

Scenario No.	Complete tank destruction	(Tank with overpressure)		
		P- Probability	*Z* – Branch probability (total)	Total probability of realization $(P \cdot Z) \cdot year^{-1}$
C1	Hazardous substance leakage within unconfined area	$5 \cdot 10^{-7} \cdot year^{-1}$	0.608	$3.0 \cdot 10^{-7}$
C2	Pool fire		0.592	$2.9 \cdot 10^{-7}$
C3	Vapour cloud formation in the area, toxic threat		0.608	$3.0 \cdot 10^{-7}$
C4	Fire, inflammation		0.09216	$4.6 \cdot 10^{-8}$
C5	Vapour cloud explosion		0.013824	$6.9 \cdot 10^{-9}$
C6	Fireball		0.1408	$7.0 \cdot 10^{-8}$
C7	Pool fire, late ignition, without vapour cloud		0.16896	$8.4 \cdot 10^{-8}$

Upon complete destruction of a tank containing LHCG (most dangerous scenario), possible further escalation of the emergency situation can take place in accordance with the following basic scenarios:

- inflammation of LHCG leak with fireball formation or pool fire;
- formation of explosive cloud (in case of zero wind) with subsequent explosion or fire/inflammation;
- cloud dissipation (as a result of wind) without inflammation.

It should be noted that C1, C2 and C3 accident scenarios have the highest probability.

Probability of realization of accident scenarios in accordance with the constructed event tree "Partial destruction of tank containing liquid under pressure" with the assigned scenario numbers is presented in Table 2.

In the scenario with partial tank collapse, a variation appears with a possible jet fire and this is the second most significant scenario after dissipation without inflammation. It should be noted that growth in the diameter of the damage increases the likelihood of jet fire. Thus, at initial leakage less than 1 $kg \cdot s^{-1}$ the conditional probability will amount to 0.005, while with an increase in the leakage up to 50 $kg \cdot s^{-1}$ the conditional probability of jet fire will rise up to 0.20.

It has been found that LHCG accident is accompanied by the process of overheated liquid boiling and formation of cooled aerosol drops, liquid phase leakage onto the ground surface, outflow, boiling and evaporation from the place of leakage. Upon intensive mixing with air, dissipation of LHCG droplet cloud is possible, as well as formation of primary and secondary gas cloud. In the leakage location, if it contains a source of ignition, there can take place ignition of a gas cloud and/or liquid phase, pool fire and vapour cloud fire, overpressure, and heat radiation impact on people and other objects. If the mass of the leakage exceeds 1 ton, the combustion can turn into a fire. In this case, a cloud saturated with LHCG vapours and incapable to detonate extensively, burns along the perimeter and spreads upwards taking on the shape of a mushroom, in the "stipe" of which strong convective processes occur that can suck up various objects, ignite them and throw them away over long distances, thus increasing the risk of injuries from flying objects. In all situations, the main danger within the nearest distances is the development of the accident with the formation of a fireball, while at farther distances - the combustion of the vapour cloud with formation of overpressure.

Table 2

Event tree realization probability of "Partial tank destruction"

Scenario No.	**Lasting pouring from tank through opening that corresponds to largest connection**	**(Tank with overpressure)**		
		P-Probability	*Z* – Branch probability (total)	Total probability of realization $(P\cdot Z)\cdot year^{-1}$
C8	Jet fire	$5\cdot10^{-7}$ year^{-1}	0.03	$1.5\cdot10^{-8}$
C9	Pool fire, instant inflammation		0.015	$7.5\cdot10^{-9}$
C10	Vapour cloud formation in the area, toxic threat		0.7004	$3.5\cdot10^{-7}$
C11	Fire ignition		0.0071	$3.5\cdot10^{-9}$
C12	Vapour cloud explosion		0.0107	$5.3\cdot10^{-9}$
C13	Fireball		0.105	$5.2\cdot10^{-8}$
C14	Pool fire, late inflammation		0.13	$6.5\cdot10^{-8}$

The facility's individual risk estimate is included in order to feature the overall risk situation. Outcomes of hazardous the facilities individual risk are applicable for characterization of overall risk level of the facility and the endangered area as well as for zoning of the territory development. The individual risk assessment includes the total probability of possible accident scenarios at the facility of causing human death when being at a particular place in relation to the facility.

Individual risk is a probability that an individual dies as a result of an accident when being at a particular geographical point in relation to a hazardous facility.

Individual risk is evaluated in accordance with formula (1):

$$R_i = Q_p\cdot Q(A_i), \tag{1}$$

where Q_p – conditional probability of getting injury upon realization of logic scheme I branch;
$Q(A_i)$ – conditional probability of scenario realization upon realization of logic scheme branch (event tree).

Individual risk for humans is only estimated for the worst event scenarios (C5, C6, C12 and C13), see Table 3 for the results.

Table 3

Individual risk for humans for worst event scenarios

Scenario No.	**Distance, m**	**kPa**	**kW·m^{-2}**	Q_p	$Q(A_i)$	**Individual risk, *R* year^{-1}**
C5	126	55	-	$6.9\cdot10^{-9}$	0.5	$3.45\cdot10^{-9}$
	172	24	-		0.01	$6.9\cdot10^{-11}$
	346	6.89	-		0	0
C6	181	-	37	$7.0\cdot10^{-8}$	0.07	$4.9\cdot10^{-9}$
C12	126	55	-	$5.3\cdot10^{-9}$	0.5	$2.65\cdot10^{-9}$
	172	24	-		0.01	$5.3\cdot10^{-11}$
	346	6.89	-		0	0
C13	181	-	37	$5.2\cdot10^{-8}$	0.07	$3.64\cdot10^{-9}$

In 2017, guidelines have been developed in Latvia for planning of safety distances and determination of the use of territory around industrial accident risk facilities "Guidelines for Determination of the Minimum Safety Distance and Territory Usage and Building Restrictions in Territorial Planning Documents for Industrial Emergency Risk Objects" [5], where the individual risk level is used as the basic criterion for spatial planning. The risk levels around the facility's territory are recommended in these guidelines. As a result, it has been established that the level of risk associated with the leakage of LHCG is sufficient and that no additional measures are necessary, but the social risk will have possibly to be assessed in order to locate other facilities depending on their use.

In accordance with the methodology "Methodical Recommendations for Estimations of Fatalities in Technological Emergencies" [6], the maximum number of victims was calculated for explosion with LHCG and the domino effect in case when more tanks are damaged. According to the methodological data, the facility belongs to the Category IIIE of facilities wherein 200 to 1000 tons of LHCG may be located. According to the data of the methodology, the total lethal area is S_{let} = 3.38 ha, area of sanitary losses S_{an} = 33.8 ha [7]. The number of people in both zones was calculated by formulas (2), (3):

$$N_{let} = c \cdot k_{let} * S_{let}; \quad (2)$$

$$N_{san} = c \cdot k_{san} * S_{san}; \quad (3)$$

where c – population density;
it may be assumed that $k_{let} = S_{let;}$ $k_{san} = S_{san}$.

Since in case of explosion and heat radiation a part of the town is affected where low-storey buildings and a park are located, but no public buildings except the health centre and railway station, then c = 40.

N_{let} = 40·3.38 = 135 people; N_{san} = 40·33.8 = 1352. Since for accidents with LHCG the coefficient is 1, these values correspond to the number of lethal cases and sanitary losses. The number of injured persons will be 135, lethal cases – 1352, and total number of people suffered in case of LHCG explosion and heat radiation will be 1487. Regularity of total number of suffered people corresponds to the data of "Major Accident Hazard Bureau", where the ratio between the number of suffered people and the number of lethal cases is 1:10 [8].

According to the data of the State Fire and Rescue Service Recommendations 2018, Table 3 "Risk Criteria for Possible Consequences of Hazard", the current level of risk for a person is assessed as a significant S3, because in case of a more severe accident the number of people affected at C2 point: max. is 1352, and C1 fatalities – 135. Environmental damages Vi1, damage to ecosystem S1, time required for environmental recovery and remediation works from 1 to 15 years.

Conclusions, proposals, recommendations

Summarizing the results of the estimate of risks existing in the territory of the facility, depending on the nature of the threat, it is possible to visually look at the existing danger areas where people are most at risk in case of an accident.

Assessing the risk, there is an opportunity to increase safety in the vicinity of the facility. It should be done by taking the necessary measures to reduce the flow of inhabitants within the territory of the facility, for example, by building a fence around it. In addition, one of possible safety measures in order to minimize the risk for inhabitants would be organization of railway freight transit traffic via the town only for transit cargoes or also standing of tanks outside the town territory; however, the individual risk assessment analysis demonstrated that the existing safety level at the station is adequate, corresponds to the safety standards established in Europe, for example, in the Netherlands, i.e. the minimum risk level is 10^{-6}, and in this case such risk level is within the norm limits. As a result, special measures to increase safety are not necessary; however, upon occurrence of an accident the consequences will be catastrophic, which is demonstrated also by the social risk estimate. Accidents with LHCG are featured by a high concentration of LHCG within a small area, large burning areas, rapid flame spread (5-10 m/s) with a risk of formation of explosive zones, possibility of explosion, deformation and complete destruction of tanks, possible flying of structures within the distance 100 to 300 m, time of burning (for leakage cases) up to 3-5 days.

As an additional measure, it should be mentioned that the town needs to establish its own early warning system since the activation of the civil protection system takes quite a long time - up to 2 hours – which is very long in case of an emergency situation. The early warning system may consist of emergency notification equipment sirens, loudspeakers, telephones, GSM messages, which can be used in accordance with the municipal civil protection plan. It has been found that a person, who has not received a special training on how to act in case of emergency situation, will not be able to make optimal decisions and act adequately in a particular situation. It is especially difficult to expect correct human decisions, if there are no clear situations associated with the risk fields and undetermined human reaction to one or more hazard factors. Due to the abovementioned facts that may potentially develop it is necessary to evaluate the need for deployment of infrastructure associated with the operation of the passenger railway station, as well as the necessity to construct new public facilities in the potentially endangered area.

Emergency situations with dangerous cargoes can affect other dangerous cargoes, thus deteriorating the situation and creating a domino effect at the facility, in which case it is necessary to be guided by the greatest distances.

In 2017, guidelines have been developed in Latvia for planning of safety distances and determination of the use of territory around industrial accident risk facilities “Guidelines for Determination of the Minimum Safety Distance and Territory Usage and Building Restrictions in Territorial Planning Documents for Industrial Emergency Risk Objects”, where the individual risk level is used as the basic criterion for spatial planning. The risk levels around the facility’s territory are recommended in these guidelines. As a result, it has been established that the level of risk associated with leakage of hazardous substances is sufficient and that no additional measures are necessary in order to locate other facilities depending on their use, while the social risk will have possibly to be assessed.

It is necessary to develop a new civil protection plan for the facility, which was not done by the day of drafting this document, because according to the Cabinet of Ministers Regulation No. 568 of 11.09.2018 “List of increased danger objects” and annex thereto it is classified as “A” category increased danger object. Thus, according to Section 14, Paragraph 2, Clause 1 of the Law on Civil Protection and Disaster Management, “Category A object of increased danger - an object, which due to effects of different factors, can cause a national disaster or significant harm to the safety of people, the environment and property”, thus, based on the Cabinet of Ministers Regulation No. 658 of 07.11.2017 “Regulations on the Structure of Civil Protection Plans and the Information to be therein Included”, the Facility in accordance with the requirements of the Regulations shall develop the Civil Protection Plan.

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