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RISK ANALYSIS OF COLLISION BETWEEN PASSENGER FERRY AND CHEMICAL TANKER IN THE WESTERN ZONE OF THE BALTIC SEA

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ABSTRACT

This paper presents assumptions and process of the forming of a risk assessment model for collision between a passenger ferry departing from or approaching port of Świnoujście and a chemical tanker carrying a dangerous cargo. In order to assess navigational safety on the basis of data obtained from AIS system, were prepared probabilistic domains of ships, which made it possible to estimate number of navigational incidents as well as their spatial distribution , that consequently allowed to determine potentially dangerous areas. The next phase was formulation of a simulative model intended for the calculating of probability of collision between the ferry and chemical tanker as well as the determining of characteristic scenarios for such collision. This paper presents also an analysis of consequences of the collision with taking into consideration a damage of cargo tanks.

Keywords: safety of navigation, navigational risk, ships domain, ships collisions, simulation methods

Introduction

In view of a large number of narrow passages and shallow waters the Baltic Sea has been always a difficult area for navigation. In spite of investment projects undertaken to improve navigational safety in the Baltic Sea any significant drop in number of navigational incidents has been observed so far. In order to obtain a comprehensive image of navigational safety over the Baltic Sea it is neccessary to have basic information on ship traffic flow. According to HELCOM data, total number of ships moving along certain routes per year exceeds 60 thousand.

To improve navigational safety traffic separation systems are introduced. They organize ship traffic by lowering traffic flow breadth, that is associated with lowering the distance between passing-by ships. In certain areas the distances between passing-by ships drop below a value at which navigational incidents may occur. To estimate size and shape of ship domains for different kinds of encounters as well as to determine a number and spatial distribution of navigational incidents, in this work were examined 4 crossings of main navigational routes in the water area in question and routes of passenger ferries sailing between Świnoujście and Ystad (Fig.1).

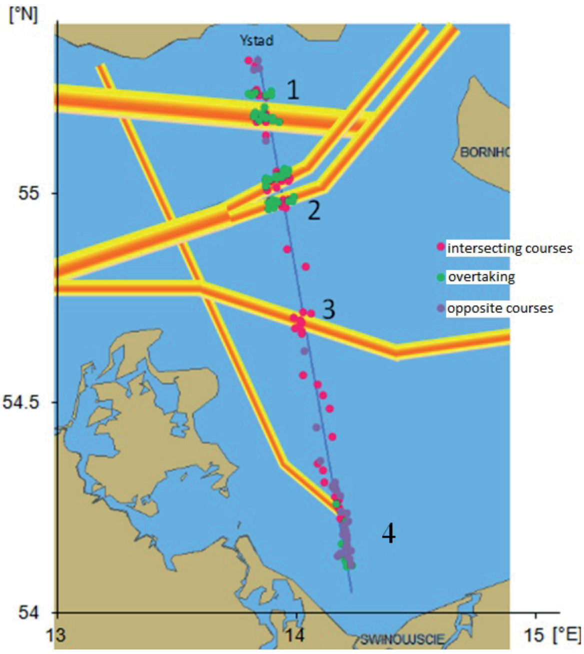

Fig. 1. The investigated water area with depicted points where navigational incidents occurred

Data concerning ship types and shipped cargoes, achieved from AIS system, are limited to the code in which the first digit stands for a type of ship (e.g. 6 – passenger ship, 8 – tanker), and the other digit – a type of shipped cargo:

- 1 –X category
- 2 – Y category
- 3 – Z category
- 4 – OS category

In this work occurrence probability was determined of the most dangerous incident, i.e. collision between a passenger ferry and chemical tanker carrying a dangerous cargo of X category, i.e. noxious liquids which, in case of their discharge to sea, could endanger sea resources or human health [2], and, consequences of such incident were also assessed.

Preliminary assessment of navigational safety

The first phase of this work has consisted in estimation of a number of navigational incidents on the basis of analysis of actual data achieved from AIS system. To this end, for the selected water area probabilistic domains of ships were determined. Ship's domain should be meant as a certain area around the ship whose navigator would like to keep free from other objects either permanent or moving ones. To calculate parameters of the domains the methodology presented in the publication [3] was used. It makes it possible to determine limit distances in which majority of navigators (their number is determined by 1st local maximum of distribution of CPA distances) pass by other ships at different course angles in a given encounter situation. In Fig. 2 detail data dealing with shapes and sizes of the determined domains (marked blue), are presented. Additionally, the same domains, but diminished (marked green) and expanded (marked red) by 25%, are also depicted.

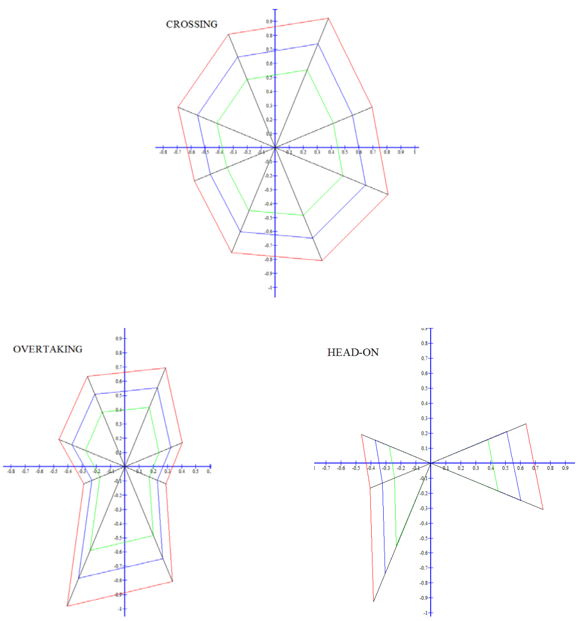

Fig.2. Domains determined for particular types of encounters

The domain determined for encounter on crossing courses is of a shape most close to circle. It shows that both the ships passing before bow of another ship (most often those having priority) and the ships passing behind stern of another ship (most often those giving way) have maintained a comparable passing distance. The largest number for encounters on crossing courses occurred in the sector of 270° ÷ 315° (270 encounters, 20 incidents).

The domain for overtaking is of an elongated shape both in fore and aft part. It results from the fact that for such manoeuvre the points of the closest approach (CPA) occur usually when the overtaking ship is almost on the beam. Most encounters (about 80%) identified as the overtaking, reached CPA before reaching the beam position (270° ÷ 90°).

For encounters on opposite (head-on) courses majority of the closest approach points happened around a on- the-beam position, 80% out of which – when passing port side. However it is rather surprising that as much as 20% of ships passed each other starboard as the Regulation 14 of the International Regulations for Preventing Collisions at Sea [COLREG] states that: if two ships go head to each other in such a way that it causes risk of collision then each of them is to so change its course as to be able to pass port side of the other.

On the basis of the determined domain parameters, number of navigational incidents which happened within one month in the examined water area, was determined for each type of the encounters. The incident (statistical one) was defined as a situation in which ships pass each other at a distance smaller than that determined for a given type of encounter and a given course angle. Detail data on the incidents are presented in Tab. 1

Tab. 1 Incidents between ships in the examined water area

Encounter type	Number of encounters	Number of incidents	Frequency of incidents [1/h]	Occurrence probability of an incident at encounter
Crossing courses	544	59	0.079	0.11
Overtaking	686	55	0.074	0.08
Opposite courses	364	33	0.044	0.09

In Fig. 1 positions of incidents are shown and, additionaly, a type of encounter at which a given incident has happened, is distinguished by a colour. Incidents on crossing courses occurred especially in the places where the route of ferries crosses navigational routes of a high traffic. Incidents during the overtaking occurred close to ports and in the places where routes cross each other. Incidents on opposite courses took place close to ports, that is associated with lowering the traffic flow breadth and, in consequence, lowering the distance between passing ships. The areas most dangerous for navigation, where the highest concentration of incidents was observed, are determined by the following coordinates:

- 55° 10.170'N - 55° 14.598'N and 13° 48.138'E - 13° 53.712'E
- 54° 57.732'N - 55° 03.306'N and 13° 52.926'E - 13° 58.086'E
- 54° 06.678'N - 54° 21.342'N and 14° 05.394'E - 14° 14.160'E

Stochastic model of navigational safety

To calculate occurrence probability of collision between passenger ferry and chemical tanker, a stochastic model of navigational safety assessment, developed by Institute of Sea Traffic Engineering, Maritime University of Szczecin, was implemented. Structure of the model is presented in Fig. 3. The model operates in the deliberately accellerated time flow in order to obtain a statistically sufficient number of scenarios.

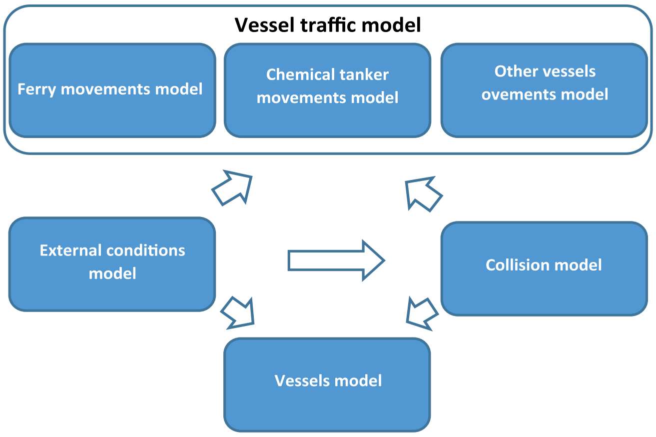

Fig. 3. Schematic diagram of structure of the model for navigational safety assessment

Chemical tankers' traffic model

Traffic of chemical tankers is modelled by means of Poisson's non-homogeneous distribution whose parameters have been determined on the basis of actual data achieved from AIS system. Analysis of the data allowed to determine parameters of navigational routes as well as parameters of distributions describing traffic flow along the routes (a.o. length, draught and speed). The so determined navigational routes are presented in Fig. 4.

Ferries' traffic model

Traffic of ferries is modelled on the basis of an actual sailing schedule of ferries travelling on routes for and from Świnoujście. Ferries' traffic parameters (a.o. speeds, turn points) as well as parameters of the ferries (a.o. values of their length, breadth and draught) are simulated on the basis of actual data taken from their technical documentation and also from AIS system. Differences in time of actual departures of ferries from a port in relation to scheduled ones are taken into account by using a probabilistic model. The model has been developed on the basis of actual observations carried

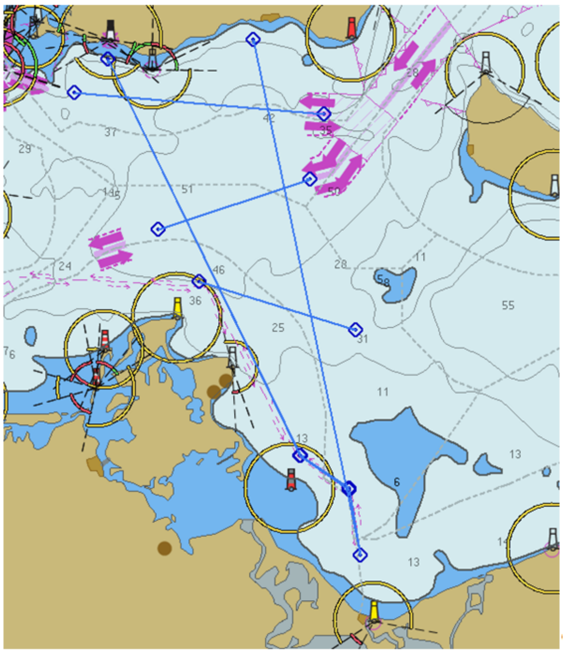

Fig. 4. The modelled navigational routes

out at Ferry Terminal, Świnoujście [6]. The investigations consisted in determination of parameters of a theoretical distribution which allows to simulate delays of ferries or their earlier departures out of port.

The following results were obtained from statistical analysis of the gathered data:

- The mean difference between actual and scheduled departure time of a ferry: 4min
- Maximum difference between actual and scheduled departure time of a ferry: 34 min
- Minimum difference between actual and scheduled departure time of a ferry: -9min (the ferry got away from the pier prior to scheduled time)
- Modal value: 3min
- Standard deviation: 8,2 min

The detail data subjected to statistical analysis are shown on the histogram (Fig. 5.)

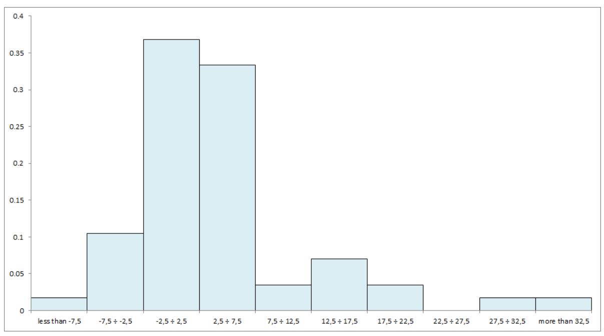

Fig. 5. Histogram of differences between actual and scheduled departure time of ferries from Świnoujście

On the basis of characteristics of the random variable and calculated parameters as well as the developed histogram of the variable, for further analysis theoretical distributions capable of describing the given random variable, have been selected. Analysis of matching of particular distributions has been conducted by means of Kolmogorov-Smirnov test as well as Anderson-Darling test. For both the tests the generalized distribution of extreme values has been found to be best describing differences between actual and scheduled departure time of ferries from Świnoujście.

Model of external conditions

The model makes it possible to simulate many factors which can impact navigational safety, such as: water area depth, wind force and direction, wave height and direction, haze occurrence, day time, hours of sunrise and sunset. Data necessary for calculating parameters of distributions which describe external factors, have been achieved from Polish meteorological stations, navigational charts and own maritime experience of these authors.

Model of collision between ferry and chemical tanker

Simulation of collision of ships has been conducted by means of a statistical model. It neglects several relationships, nevertheless, as it is based on statistical data, the obtained results are close to reality.

Number of ship encounters over the examined water area is the crucial (and simultaneously most difficult to determine) parameter which must be found in order to assess navigational safety. In research on ship traffic systems the use of simulative methods is the most effective approach for determining value of the parameter in question.

Therefore to determine number of ship encounters over the examined water area, has been conducted a simulation experiment where the earlier prepared ship traffic models were implemented. Encounter was defined to be a situation when ships pass by each other at the distance equal to or smaller than the assumed limit value. The limit values were assumed separately for different types of encounters on the basis of analysis of ship's domains (Fig. 2).

The next parameter to be determined in order to estimate navigational safety is a number of actual collisions of ships. The parameter was determined on the basis of analysis of actual data taken from HELCOM database. Only the collisions which happened in open waters of the south zone of the Baltic Sea were taken into consideration. The detail data used in the model are shown in Fig. 6.

The number of ship encounters obtained from the simulation experiment as well as the number of collisions of ships were used for the calculating of conditional probability of collision of ships at their encounter. The calculated values of the probability are presented in Fig. 7.

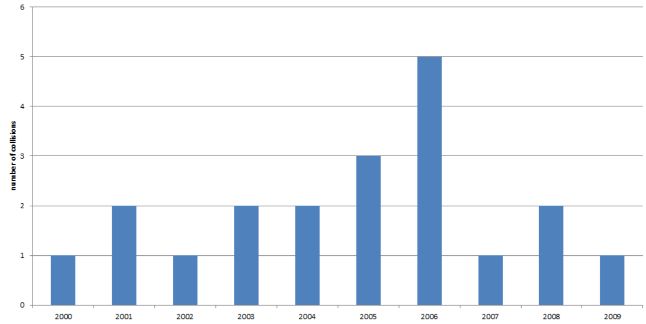

Fig.6 Number of collisions of ships in open waters of the south zone of the Baltic Sea

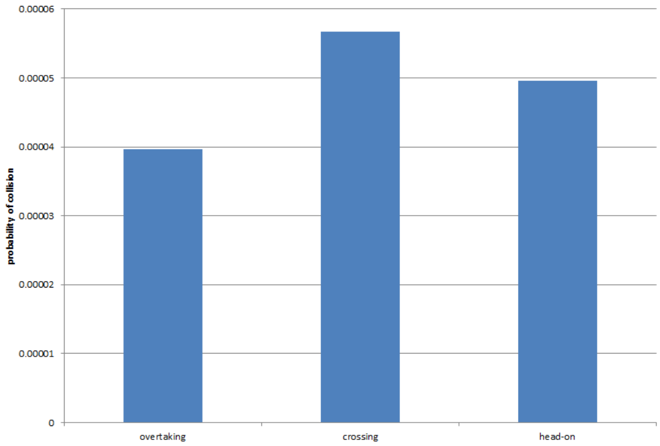

Fig. 7 Calculated values of the ship collision probability for various types of encounters

On determination of the ship collision probability, another simulation experiment was performed. It was aimed at determination of position and parameters describing the probability of collision between the passenger ferry sailing for or from Świnoujście and the chemical tanker carrying dangerous cargo. In order to determine sensitivity of the used model against changes in input parameters, the experiment was conducted for the mean domain based on the data taken from AIS system as well as the expanded domain and diminished one by 25%, respectively (Fig.2). Additionally, influence of simulation step was examined.

Results

On collection and implementation of all necessary statistical data, was performed a simulation experiment aimed at determination of a number and spatial distribution of simulated incidents and accidents. Additionally, influence of settings on operation of the model was investigated. In the presented experiment 100 iterations were performed for each initial setting. One iteration covered duration of one year. As the statistical frequency of collisions appeared extermely low it was necessary to conduct an additional experiment covering a much greater number of iterations. 1000 iterations were done to determine frequency and distribution of collisions. The detail results obtained from the experiment are presented in Fig. 8 and Tab. 2. The model operated in the deliberately accelerated time to make it possible to achieve statistically stable results.

Tab. 2. Results of the simulation experiment

Step of simulation [min]	Size of domain [%]	Number of iterations	Number of incidents	Change	Number of collisions	Mean time between collisions
1	100	100	111243	The reference quantity	0	-
3	100	100	67799	-39%	0	-
5	100	100	56201	-49%	0	-
1	75	100	84890	-24%	0	-
1	125	100	136904	+23%	0	-
1	100	1000	-	-	7	142.8 years

Assessment of consequences of collision between passenger ferry and chemical tanker carrying dangerous cargo

In ship traffic engineering navigational risk is expressed in the form of product of occurrence probability of an accident and its consequences. Depending on a way in which the consequences are formulated, the following can be distinguished:

- the navigational risk for which accident consequences are expressed by physical indices calculated on the basis of mathematical description of accident dynamics ,

- the economic risk for which accident consequences are expressed by cost borne as a result of the accident.

In this work the consequences have been expressed by a volume of damaged structural material determined on the basis of energy absorbed during collision of ships.

One of the first, but still commonly used, statistical relationship which makes it possible to assess consequences of ship collisions is that proposed by Minorsky V. [4].

O the basis of an analysis of 26 ship colissions a relationship between volume of damaged structural material and energy of ship collisions, was established (Fig.8). The relationship is expressed as follows:

$$E = 47{,}09\ R_T + 32{,}37\ [MJ] \tag{1}$$

where:
E – energy absorbed during collision [MJ]
R_T – total volume of damaged structural material of both colliding ships [m^3]

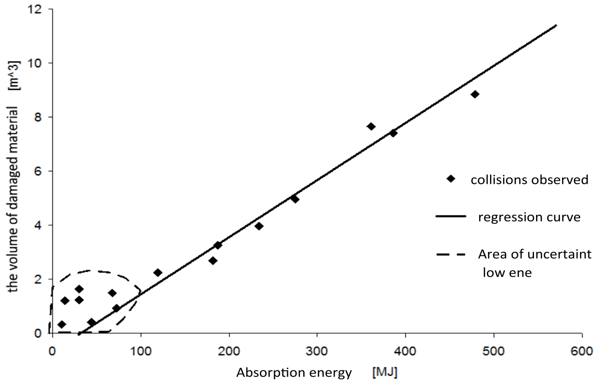

Fig. 8. Relationship between absorbed energy and volume of damaged structural material

In the presented work only one collision scenario was analyzed. In its subsequent phases should be developed a method allowing to investigate influence of changes in ship parameters and other significant factors on consequences resulting form collisions between a passenger ferry and chemical tanker.

For the presented analysis the following parameters were assumed:

- The collision happens under 90° angle between a passenger ferry of a size close to that of m/f Polonia and a chemical tanker carrying ammonia, on approach to port of Świnoujście.
- The chemical tanker's parameters: LOA = 129 m, B = 17.8 m, T = 8.6 m, V = 16.5 kn, total capacity - 8600m^3, 3 tanks of about 3000 m^3 each (Fig. 9).
- The passenger ferry's parameters (based on those of m/f Polonia): LOA = 170 m, B = 28.0 m, T = 6.0 m, V = 20 kn, number of passengers - 918 (of crew members - 82).
- Encounter parameters: of the chemical tanker: COG = 270°, V = 12 kn, of the ferry: COG = 000°, V = 8 kn (speed reduced after a failed anti-collision maneouvre).
- Description of the accident: as a result of navigotional errors done by both officers of the watch, the ferry run into the middle part of the chemical tanker causing damage of a cargo tank amidships.

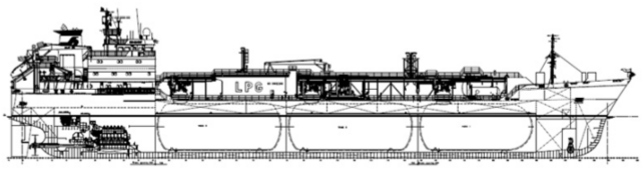

Fig. 9. The analyzed chemical tanker of 8600m^3 capacity

Collision energy was calculated by using the PIANC method [5]. The following results were obtained for further analysis:

The ships' collision energy E = 137,1 MJ

The volume of damaged structural material R_T = 2.3 m^3

The radius of damaged area of ship's hull, (assumed spherical) r= 1.7 m

The diameter of damaged area of cargo tank d = 0.2m

To determine tank damage consequences, was applied the software ALOHA® which has been made cost-free accessible by two US agencies: EPA (Environmental Protection Agency) and NOAA (National Oceanic and Atmospheric Administration) [1].The software makes it possible to determine contamination zones as a result of a leakage of dangerous substances of various types. The following assumptions were done:

- The coordinates of place of the collision: $\varphi=53^0$ 57.0'N, $\lambda=14^0$ 16.6'E (approach to Świnoujście)
- The chemical substance parameters; name: ammonia, molecular mass: 17.03 g/mol, AEGL-1 (60min) = 30ppm, AEGL-2 (60 min) = 160 ppm, AEGL-3 (60 min) = = 1100 ppm.
- The weather conditions: easterly wind of the speed = 15 kn (abt. 7,7m/s)
- The leakage parameters; tank capacity: 3000 m^3, tank filling: 98%, circular damages of 0,2 m diameter, at 8,77 m level above the tank bottom, leakage in the form of two-phase mixture of gas and aerosol.

Fig. 10 shows spatial distribution of contamination of various intensity. Exposure levels (AEGL - Acute Exposure Guideline Levels) are defined to be a quantity of a chemical substance (in ppm) and exposure time which cause:

- AEGL-1 – feeling of discomfort
- AEGL-2 – serious and long-lasting negative consequences to health or leading to the worsening of capability to escape
- AEGL-3 – hazard for life or death

As clearly results from Fig. 10, in case of an unfavourable wind direction, not only ferry passengers and crews of the ships but also inhabitants of coastal dwellings can be exposed to serious consequences, including death. Staying within the zones (marked in the figure) for 60 min or longer may be hazardous to life or even lead to death (AEGL – 3 level– maked red, AEGL – 2 level – marked orange). At an unfavourable wind direction such hazard may concern a major part of Heringsdorf (Ahlbeck district) in which about 3500 inhabitants live.

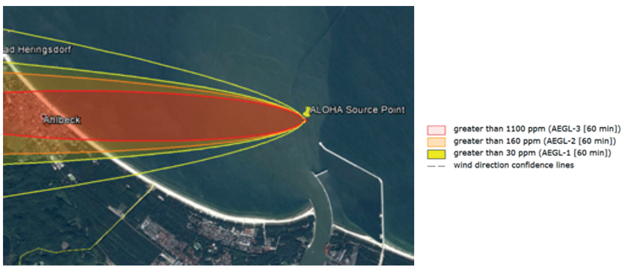

Fig. 10. AEGL level zones after a theoretical leakage of ammonia from the examined chemical tanker on approach to port of Świnoujście

Conclusions

This paper presents an analysis of consequences of a collision between passenger ferry and chemical tanker carrying dangerous substance. Despite the calculated probability of such collision is very low (one collision for about 150 years), its probable serious consequences may impair not only persons on board the ships which suffered the collision but also inhabitants of coastal dwelling places. For this reason hazard to such accidents should be investigated in detail , that would allow to undertake appropriate preventive actions.

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