SIMULATION APPROACH FOR ACCIDENT CONSEQUENCES AND IINSURANCE RATING ASSESSMENT FOR MAIN GAS PIPELINES: ENVIRONMENTAL ASPECTS

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Abstract

The paper presents some recent results that are connected with the simulation approach applied to risk analysis and compensation of main gas pipelines in Russia. A general scheme of accident consequences assessment algorithm is shown. The scheme includes different types of accidents (gas releases, fires, explosions). Environmental (air, water, ground, forest) and population damages are evaluated, including economic losses. Special interest is focused on forest fires. Environmental insurance is rated in the frameworks of solvency theory. The general structure of the computer complex ECOS is presented. The program includes database material (accident statistics, techno-economical features, environmental characteristics, etc.), an accident consequences model, an insurance rating model, and special user's software. Some results of numerical investigation applied on "Gazprom" companies in Russia are discussed.

1. Introduction

The main gas pipelines (MGPL) are a very important part of the industry infrastructure of Russia. The export of natural gas to western European countries by MGPL is an effective source of hard currency income, particularly given the current economic situation in Russia. Natural gas is clean energy carrier. At the same time, in accordance with statistics, accidents in MGPLs are rather frequent events, leading to material and economic losses. Potentially, wide-scale catastrophes with severe consequences in population and environment are possible.

The total length of MGPL in Russia is about 144 000 km. This energy system is operated very intensively. The possibility of accidents is connected with a number of reasons [1]:

- MGPL development and concentration;
- diameter of pipelines (more than 1020 mm) and gas pressure (more than 55 Bar) increasing;

- a large share of pipelines have been in operation more than 20 years.

Accidental gas releases are stochastic, non-control process. Potential damage of accidents is connected with toxic substances of transported gas, fires, and explosions. Material and economic losses can appear both in MGPL owners and third parties. To protect third parties against casualty and property loss, a Federal Law "On safety of industrial Objects" was passed in 1998. The Law introduced a procedure on risk identification, assessment, and management with application to industrial objects and systems. In addition, the Law mandated compulsory third party liability insurance. As a consequence, the Law established that owners or operators of potentially hazardous objects should buy insurance policies before getting an operator's license. It was a very progressive step to construct legislation background for the developing economy. Nevertheless, the law and corresponding legislation acts gave only mainframes for risk management, particularly in insurance. Only three levels of liability limits (loss limits covering by insurance) have been introduced in spite of a wide range of hazardous objects. A simple approach has been used for the rating of corresponding insurance tariffs. Such an approach might be an necessary to develop methods and models for assessment of potential losses (maximal, average, distribution) and insurance premiums in connection with a national insurance market capacity.

Statistics of the insurance market in Russia for last few years show a high rate of development in spite of the financial crisis in August 1998. During 1999, the number of small companies was reduced, with some of them being absorbed by larger ones. As experts assess, the number of companies will stabilize at about one thousand in the year 2000. Shares of the property and liability insurance premiums almost doubled during 1999.

As mentioned above, one of the most important problems is connected with loss compensation caused by accidents in MGPL, particularly connected with population and environment. For three years (1996-1999), special studies in this area were done in the laboratory of Energy Systems, Institute of Russian Academy of Sciences (Irkutsk). In the frameworks of the investigations, accident statistics in MGPL for 18 years have been analyzed, and the methods and models for material and economical losses have been summarized and advanced. Results of the studies have shown the possibility of using some simple models to evaluate accident consequences. In addition, the results included mathematical models for insurance tariffs assessment on the background of the Monte-Carlo method.

This paper presents a general view of interconnected mathematical models for assessment of a wide range of consequences caused by different types of accidents in MGPL and the evaluation of financial behavior of insurance companies. Based on the background of the models listed above, special computer software called ECOS has been designed. The paper gives a general structure and the main features of the program. Some results of numerical investigations applied on specific MGPLs in Russia are presented.

2. Mathematical Models

Generally, a structure of environmental losses is complicated and strongly depends on sitting, technical parameters, etc. Components of environmental loss used in this study are briefly described in the paper. Assessment of economic losses is connected with evaluation of scale and the severity of an accident's material consequences. The background of the assessment in the study was the modeling of different accidental chains using a simulation approach. The general scheme of an accident model is presented in fig.1.

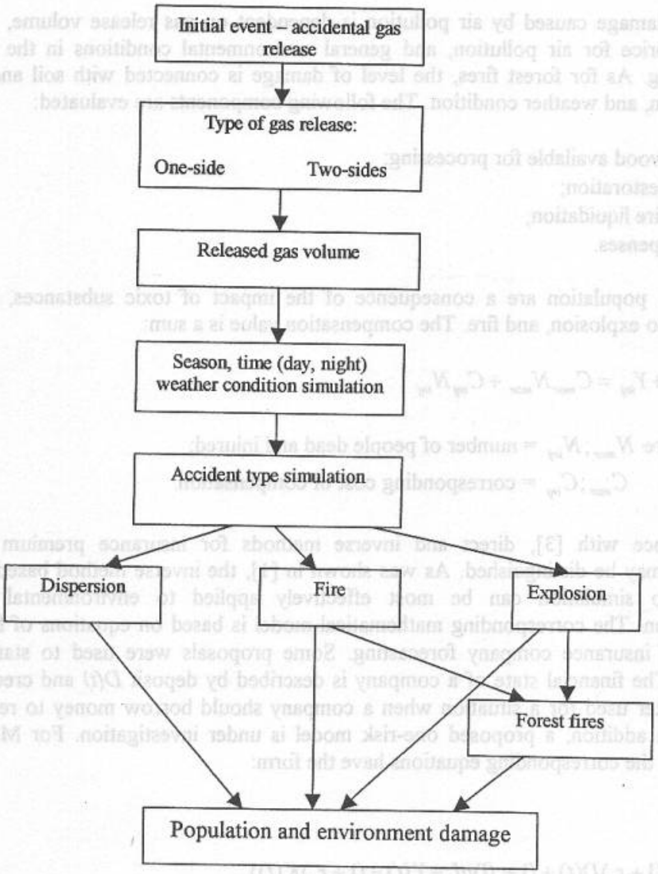

Fig.1. General scheme of the simulation model of an MGPL accident.

By the model, both environmental and population impacts are assessed. Consequences of the accident are evaluated on the background of statistics (frequency of events, gas release distribution function) and simulating atmospheric condition. Damage of environmental components (air, water, soil, forest, etc.) is evaluated by the algorithm's mixed normative state's instructions and the engineering methods. The description of the methods and the proven acceptability of simplification are presented in [2]. As shown, the main loss is connected with air pollution and forest fires, therefore these components of environmental loss are evaluated in the model in the most detail.

Economic damage caused by air pollution is dependent on gas release volume, specific normative price for air pollution, and general environmental conditions in the area of MGPL siting. As for forest fires, the level of damage is connected with soil and forest types, season, and weather condition. The following components are evaluated:

- cost of wood available for processing;
- cost of restoration;
- cost of fire liquidation;
- other expenses.

Damages in population are a consequence of the impact of toxic substances, thermal effects due to explosion, and fire. The compensation value is a sum:

$$Y_{pop} = Y_{mor} + Y_{inj} = C_{mor}N_{mor} + C_{inj}N_{inj} \quad (1)$$

where $N_{mor}; N_{inj}$ = number of people dead and injured;

$C_{mor}; C_{inj}$ = corresponding cost of compensation.

In accordance with [3], direct and inverse methods for insurance premium (tariff) calculation may be distinguished. As was shown in [1], the inverse method based on the Monte-Carlo simulation can be most effectively applied to environmental impact compensation. The corresponding mathematical model is based on equations of financial behavior of insurance company forecasting. Some proposals were used to state these equations. The financial state of a company is described by deposit *D(t)* and credit *K(t)*, with the latter used for a situation when a company should borrow money to recover a solvency. In addition, a proposed one-risk model is under investigation. For MGPL as risk objects, the corresponding equations have the form:

<u>deposit</u>

$$D(t+1) = \{(1+r_1)D(t) + (1-\beta)aL - Y(t) - (1+r_2)K(t)\}_+ \quad (2)$$

credit

$$K(t+1)=\{(1+r_2)K(t)-(1-\beta)aL+Y(t)-D(t)\}_+ \qquad (3)$$

In equations (2) and (3) the following definitions were used:

a – specific insurance tariff, rubl/year/km;
β - loadings share;
L – length of MGPL;
$Y(t)$ – total loss covered by insurance company;
$r_1;r_2$ - deposit and credit interest rates.

The expression $\{\ldots\}_+$ means that the algebraic sum in the brackets is calculated only in the case of positive value.

3. Computer Complex ECOS

The algorithms described above were used to design the computer software ECOS. The complex included the following parts:

- data bases;
- the block of accident consequences assessment;
- the block of insurance features evaluation;
- user's interface.

The general structure of listed components interconnection is presented in fig.2.

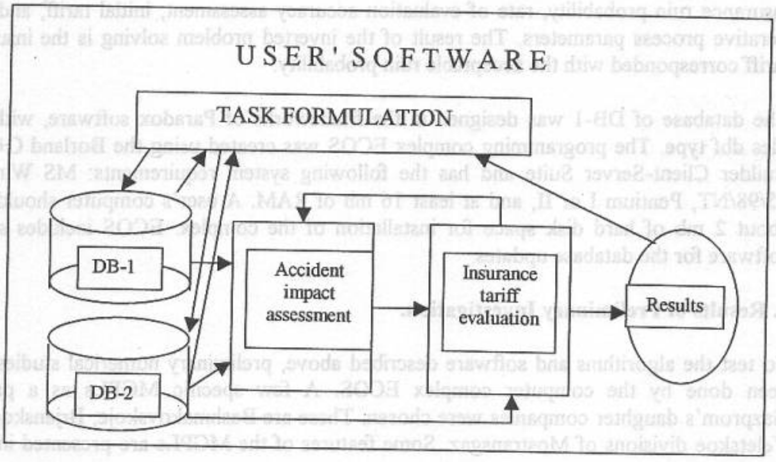

Fig. 2. General scheme of main components of "ECOS" interconnection.

There are two databases key to the software. The first one (DB-1 in fig.2) is connected with specific technical, economical, and accident statistics for different MGPLs. Input data that remain the same for any MGPLs is sited in DB-2. The corresponding information is stored in a separate file and is divided into three parts:

- technical parameters;
- environmental data;
- economical characteristics.

Both databases (DB-1 and DB-2) read, edit, and sort content data. After choosing a task, the data are loaded from the databases in accordance with the type of task.

The results of calculations by the first block of the ECOS (accident impact assessment) are the distribution function of economical damage, represented as a histogram. The program allows one to explore the histogram in the graphical mode.

The program ECOS allows users to solve both straight (assessment of environmental insurance ruin probability with the given tariff) and inverse problems (iterative evaluation of minimal acceptable tariff with the given level of ruin probability).

If the straight problem is in progress, the user enters a valid insurance tariff and the insurance company initial reserve. The straight problem occupies minimum resources of the computer and is useful for a damage histogram evaluation.

In the case of the inverted problem, a user must determine an MGPL, acceptable level of insurance ruin probability, rate of evaluation accuracy assessment, initial tariff, and main iterative process parameters. The result of the inverted problem solving is the insurance tariff corresponded with the acceptable ruin probability.

The database of DB-1 was designed in the frameworks of Paradox software, with data files dbf type. The programming complex ECOS was created using the Borland C++ 3.0 Builder Client-Server Suite and has the following system requirements: MS Windows 95/98/NT, Pentium I or II, and at least 16 mb of RAM. A user's computer should have about 2 mb of hard disk space for installation of the complex. ECOS includes special software for the database updates.

4. Results of Preliminary Investigation.

To test the algorithms and software described above, preliminary numerical studies have been done by the computer complex ECOS. A few specific MGPLs as a part of Gazprom's daughter companies were chosen. These are Bashmakovskoje, Brjanskoe, and Yeletskoe divisions of Mostransgaz. Some features of the MGPLs are presented in table 1.

Table 1. Characteristics of MGPL under investigation.

Division	Specific frequency of accident (event/year/km)	Length of MGPL (km)
Bashmakovskoje	0.000476	476
Brjanskoe	0.000357	623
Yeletskoe	0.000078	712

The histogram of released gas volume per accident distribution was used for simulation of accident consequences. Numerical volumes of the histogram are a result of about two decades of statistics from Mostransgaz. The histogram of the distribution is shown in fig.3.

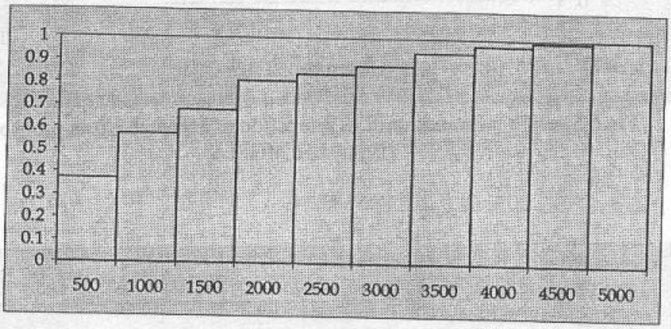

Fig.3. Distribution of accidental gas release volume (thousands of cubic meters).

The inverse task was solved to assess minimal specific insurance tariffs (rubls/year/km) for different levels of acceptable probability of bankruptcy. It is well-known that for developed countries ruin probability level is less than 0.1%, but for Russia this characteristic might be higher (by a few percent) because of the developing stage of national economics. Calculations were run for a wide range of ruin probability to study the behavior of specific tariffs as a function of ruin probability for different MGPLs. Results of these investigations are presented in figs. 4-6.

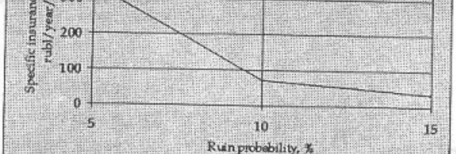

Fig. 4. Specific insurance tariff as a function of acceptable ruin probability (Bashmakovskoje MGPL).

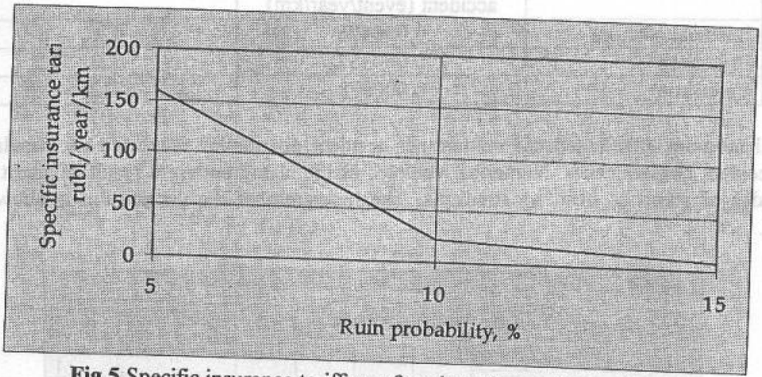

Fig.5 Specific insurance tariff as a function of acceptable ruin probability (Brjanskoe MGPL).

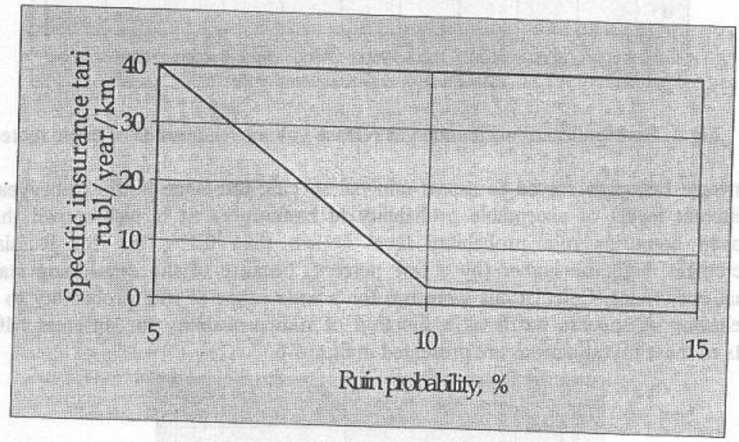

Fig.6. Specific insurance tariff as a function of acceptable ruin probability (Yeletskoe MGPL).

The results of this investigation show a good interconnection between initial data and output information. Mathematical models express the main features of environmental impact and can be used for insurance tariff evaluation applied to different MGPLs in Russia.

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References

1. Lesnykh V.V. et al. Environmental insurance of gas industry objects: methodological, modeling and information aspects. Novosibirsk, Nauka, 1998, - 138 p. (in Russian)
2. Srafanova E.Yu., Lesnykh V.V., Lesnykh A.V. Emphasizing of regional features in the design of programming complex for environmental insurance efficiency assessment applying on gas industry objects. / Regional aspects of risk analysis and management: national and international experience. Irkutsk, ISEM, 2000, pp.114-123 (in Russian).
3. Lesnykh V.V. A compensation system of damage caused by accidents at energy objects: problems, methods, models // Safety Science, 30 (1998) 107-113.