Application of case-based method to choose scenarios to resolve emergency situations on main gas pipeline

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Abstract. The article is dedicated to application of case-based method in the problem of choosing correct suitable scenarios to resolve emergency situations occurring on main gas pipeline. The result of the work is the algorithm for choosing scenarios with the given level for suitable solutions to resolve emergency situations using base of cases describing emergency situations on main gas pipeline.

Keywords: main gas pipeline, emergency situation, pipeline rapture, case-based method

Uninterrupted consumers supply of natural gas depends on effective and safe operation of Unified Gas Supply System (UGGS) with minimal harmful impact on the environment and exclusion of accidents and losses associated with them. It is necessary to implement methods to locate and resolve emergency situations on the main gas pipeline (MGP). [1, 2]

In short, gas transportation system consists of linear part, compressor station and underground gasholders (sometimes).

On the linear part of the main gas pipeline (MGP), some emergency situations (ES) may occur. Such as [3, 10]:

- drastic change in sensor readings;
- valves malfunction;
- unauthorized rearrangement of valves;
- emergency situations in the management;
- bursting in the linear part of the pipeline;
- ES on the compressor station territory.

Bursting in the linear part of the pipeline is the most dangerous situation. Subsequent leakage of a large gas volume (millions of cubic meters) can lead to human casualties, damage natural resources and the environment, and can pose enormous economic losses. [4, 5]

In the case of bursting of the MGP linear part, it is necessary to determine the location of the gas pipeline rupture (the pipe run and the kilometer), before the elimination of the ES is initiated. Immediately after the rupture detection, it is necessary to start looking for the solution to this problem and a way to resolve this emergency situation.

Scenario generation algorithms for finding solutions in emergency situations make scenarios based on the MGP configuration and the location of the main cranes and jumper cranes, i.e. based only on static data. However, the condition of the MGP changes over time. Opening or closing of the particular pipeline crane may be impossible at a certain time, because the ability of turning the crane depends on the difference in pressure in the pipe sections located before and after this crane (the turn of the crane is impossible if the difference in pressure values exceeds 0.5 kgf / cm^2). Solution or advice to change state of MGP should be proposed to dispatcher as a result of algorithm. Changes of MGP state should be applied through changes of state of cranes (open/close). Short scheme of algorithm is presented in the figure 1.

Different sets of main cranes and jumper cranes are available for opening and closing at different times because of the unstable values of the MGP pressure sensors, in particular, when the pipe run is bursted. Thus, not all scenarios can be available from the set of localization and circumvention scenarios obtained by analyzing the MGP graph.

Turning any crane takes some time. The crane using in specific scenario which is available for rotation at the moment can become unavailable after a certain time, and this moment can occur earlier than the dispatcher will finish the crane turning. After that, this crane can still be unavailable for a certain time (which may be too long in terms of the required speed of elimination of the ES associated with the rupture). In this case, the scenario becomes unsuitable for use. In the article, it’s proposed to represent knowledge in the form of cases as a base of algorithm to form scenarios Case based methods fits well because emergency situations have common signs and have the nature of precedents. General case-based method to find precedents for specific ES was proposed by Buhvalov I.R. and Kokorin A.A. [1]

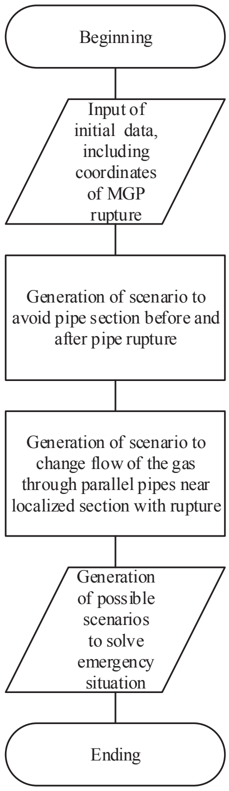

Fig. 1. Short scheme of algorithm to generate scenarios to solve emergency situations

It's necessary to create base of precedents for MGP with specified configuration. Precedents describe emergency situations and actions necessary to resolve that situation.

Specification of precedent *p* contains:

1. array of emergency situations;
2. array of scenarios (advices) describing possible solutions to resolve emergency situations;
3. array of results of applied scenarios.

Specific emergency situation and array of possible scenarios to solve that emergency situation correspond to each precedent *p*.

$$p = \{ES, (\mathrm{C}_i, Sol_i)\}, 1 \le i \le N_{\mathrm{c}},$$

N_{c} – number of possible solutions to resolve scenario.

Base of cases stores known scenarios to solve emergency situations that occured before. The data in base of cases can contain historical data about the results of applying these scenarios as well. The solution proposed in the scenario is considered acceptable if the emergency situation is significantly similar to the precedent.

If emergency situation does not have an acceptable solution in the use case base, it should be eliminated using known algorithms to solve emergency situations. [12, 14]

Descriptions of ES includes information about coordinates of MGP rupture and state of MGP in that moment. State of MGP includes information about state of cranes [7, 11].

It was described algorithm to find acceptable scenarios among a variety of different combinations. The algorithm determines the applicability of scenarios in the conditions of a given ES taking into account various combinations of states on the MGP.

Since it is difficult to determine full compliance of the precedent to this ES, it is necessary to establish following:

1. criteria on which it is possible to determine the coefficient of conformity of a given ES to a particular precedent
2. weights, which determine the degree of significance of the individual elements included in the description of the individual ES
3. the necessary degree of conformity of the ES to the precedent for the correct decision-making on the elimination of the ES

State of the four-way couplings of the MPG determine the signs of an ES. [8] It is necessary to generate a comparison matrix for signs of ES. The number of signs is defined as *n*. The matrix has the size *n x n*.

One element of this matix e_{ij} is defined as:

$$\begin{cases} e_{ij} = \dfrac{d_j}{d_i}, (i \neq e_k) \wedge (j \neq e_k) \\ e_{ij} = 0, (i = e_k) \vee (j = e_k) \end{cases}$$

e_k – four-way coupling on which rupture occurred, d_i and d_j – distance from four-way coupling i and j to four-way coupling e_k.

To calculate the weight that determines the degree of significance of the elements, the following formula is used:

$$w_i = \frac{\sum_{j=0}^{N-1} e_{ij}}{N-1},$$

N – count of four-way couplings, j – number of the element.

When choosing a certain precedent, it is necessary that the four-way coupling indicated in the description of the use case correspond to the four-way coupling corresponding to the rupture given in the description of the specific ES. It is also necessary that the states of the cranes on the MGP match states defined in the description of the use case.

It is necessary to define coefficient k_c ($0 \le k_c \le 1$) which determines the required degree of correspondence of the ES to the precedent.

After determining the coefficient of compliance, the matrix elements of the MPG and a set of use cases and ES – tests are conducted to determine the most appropriate precedent for each given ES. [9, 13] For each of the test results it is necessary to check that the degree of compliance is above the minimum of specified degree of compliance.

The correspondence of an element to a use case is defined as

$$g_i = \begin{cases} 1, if\ state\ of\ cranes\ correspond\ to\ the\ precedent \\ 0, if\ state\ of\ cranes\ do\ not\ correspond\ to\ the\ precedent \end{cases}$$

The degree of applicability of the precedent is calculated using the following formula:

$$p = \frac{\sum_{i=0}^{N-1} w_i g_i}{\sum_{i=0}^{N-1} w_i}, i \neq e_k,$$

g_i– value of element i, w_i – weight of the element, N – count of elements – four-way couplings.

The degree of applicability of the use case base is calculated as:

$$\bar{p} = \frac{\sum_{i=1}^{M_{ES}} p_i}{N},$$

M_{ES} – count of ES, p_i – degree of applicability of the precedent for ES i.

Additional restrictions are:

$$\bar{p} \ge k_c$$
$$\bar{p} - a * \delta(p_i) \ge \bar{p}$$

a – coefficient determined from the results of the experiment; $\delta(p_i)$ – standard deviation.

$$\delta(p_i) = \sqrt{\frac{\sum_{i=1}^{N} (\bar{p} - p_i)^2}{N}}$$

To choose precedent applicable to specific ES from the precedents database it is necessary to perform steps:

1. Set initial value of degree of applicability $p = 0$
2. Pick precedent from the database.

3. Check if precedent fully correspond to ES or is last in database then go to step 6, if not – go to step 4.
4. Calculate degree of compliance of current precedent to specific ES
5. Check if calculated value is more than current value of *p*, then assign calculated value to *p* and go to step 2
6. If found precedent correspond to ES fully, then result is that precedent. If some precedents was found then result is a set of precedents. If no precedents found dispatcher should be notified that solutions should be found using other algorithms.

After all calculations have been performed, it is necessary to rank the found suitable precedents by the degree of compliance for a specific ES.

Experiments were performed using the scheme of the existing MGP to test the algorithm. Figure 2 shows the graph of the dependency of degree of compliance of use-case database to the number of precedents.

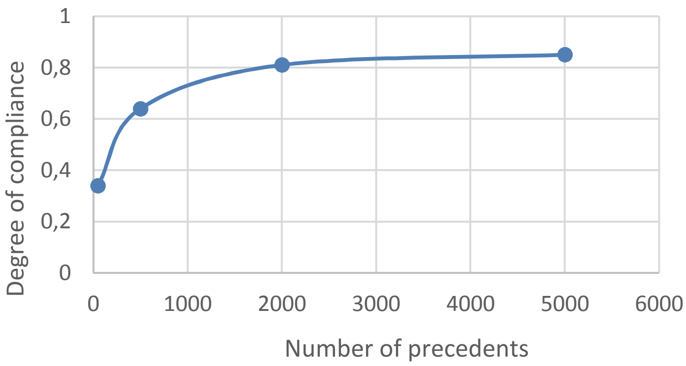

Fig. 2. Graph of the dependency of degree of compliance of use-case database to the number of precedents

Figure 3 shows a graph of the dependence of the root-mean-square deviation to the number of precedents.

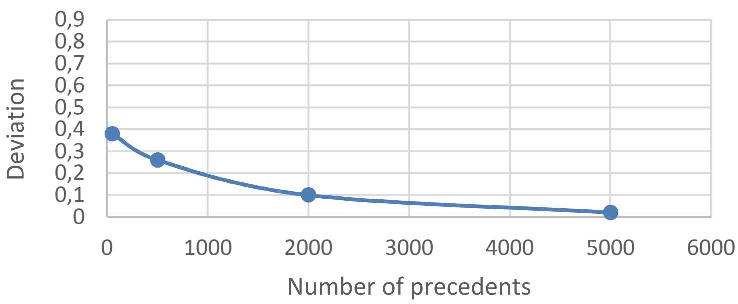

Fig. 3. Graph of the dependence of the root-mean-square deviation to the number of precedents

The graphs show that with the increase in the number of precedents defined in the database the value of the degree of correspondence increases, and the scatter of values for various ES decreases.

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