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Applying Indexing Method to District Heating Network Risk Assessment by Using GIS

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Abstract: *This scientific paper explains applying indexing method to district heating network risk assessment by using GIS. To determine efficiently the level of risk for each section of the district heating network modified program for steady state simulation SimNet SSV Heat was used. The method for adapting the assessment of the risk of a district heating network and the example of an assessment of the actual heat distribution network of a tree structure are described. The adaptive method for assessing the risks of district heating network has been based on the extended Muhlbauer method. Knowledge of the level of risk for individual sections of the district heating network allows for planning and carrying out maintenance work during the heating season. It allows to take action that minimizes and in some cases eliminates interruptions in the supply of heat to network customers.*

Keywords: *risk analyses, risk management, district heating network*

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I. Introduction

GIS (Geographical Information System) [1] is a tool for collecting, analysing, and presenting data on objects in terms of their geographic location on Earth. Digital maps have free navigation, allowing you to move and create new objects by scaling. The information is stored in the database, allowing you to store, update and access other users. Depending on the requirements, users have access to the appropriate base levels, which are visualized in the form of maps. For heating networks GIS is a system for storing information in the form of vectors, points and graphical representation of objects in 2D space, i.e. on maps containing heating network elements. GIS works with databases stored in the heating system for business trans-actions such as the invoicing base, accounting reports for current equity investments, and net-work updates. The district heating network of any topological structure may be represented as a graph or mathematical object, consisting of a set of nodes and a set of edges connecting some of these nodes. The Graph, therefore indicates a graphical representation of the relationship between nodes and edges. The graph G = (V, E) consists set of objects V = {v_1, v_2, ...} called nodes and set E = {e_1, e_2, ...} whose elements are called edges. The edge is marked by an unordered pair of nodes (v_i, v_j). In turn, the edge e_k with an ordered pair of nodes (v_i, v_j). is called a branch. v_i-nodes connected with n_j,, are called edges.

A network node is a point at which one of the following conditions is met:
- Meet 3 pipes - tee,
- There are 2 pipes of different diameters,
- The pipe changes the technology of execution - the network running over the surface of the terraces, pre-insulated network, canal network,
- A non-linear element is installed.

Non-linear elements in the heat district heating network are:
- Power plant for district heating network,
- Heat storage,
- Network pumping station,
- Valve,
- Compensator,
- Heat Exchangers station.

Non-linear elements are represented by ordered pairs of nodes (V_x, V_y),
where: V_x - input node, output node - V_y.
In turn, the district heating district line is the pipeline section described by the start node, end node, diameter, length, type of material and absolute roughness.

Linking to GIS enables you to locate each element of a centralized heating network according to your city plan and latitude, unambiguously assigning latitude and longitude. The described heat distribution network diagram is linked to databases describing the current state of the technical components. The proper description of the district heating network schedule, ie the Network Section, contains the following information:
• Type of media: water / steam,
• Network type: mains / return line,
• Technology: channel / preinsulated,
• Material (roughness) and diameter, conduit thickness,
• Type of insulation, thickness, heat transfer coefficient,
• Type of environment: pipe in the ground, pipe over the ground.
The length of a section and its location in the geographical space describe the coordinates of the beginning and the end of the graph branch. Using simulation software for the district heating network, as a result of simulation calculations, we obtain the following network parameters:
• Flow temperature at the inlet and outlet,
• Heat losses on the network segment,
• Flow rate of heating water in the section,
• Height of inlet and outlet pressure.
This gives you detailed information on the quality of the district heating network.

This article presents a comprehensive computer simulation program for the SimNet Heat SSV from Fluid Systems company [4], which allows analysing and assessing the risk level of the components of the heat network. The risk assessment of the heat distribution network is limited to assessing the risk of individual sections of the district heating network graphs There-fore, each branch with a specific geometry and performance parameters is individually evaluated in the power and return networks. The influence of nonlinear elements is taken into ac-count when evaluating the sections directly related to the element, for example, the compensator is evaluated in the section of the heat network that is connected to the compensator. The method for adapting the assessment of the risk of a district heating network and the example of an assessment of the actual heat distribution network of a tree structure are as follows.

II. Adaptive Method of Risk Assessment of District Heating Network

The adaptive method for assessing the risks of district heating network has been based on the extended Muhlbauer method [3,5]. The Muhlbauer method is a method of qualitative and quantitative methods. It is based on the point evaluation of selected parameters affecting the district heating network risk for four indexes:
- damage caused by a third part,
- damage caused by corrosion,
- damage caused by faulty design,
- damage caused by incorrect operations.

The level of risk is lower than number of points is greater. Figure 1 shows a flowchart of an adaptive risk assessment method for district heating networks.

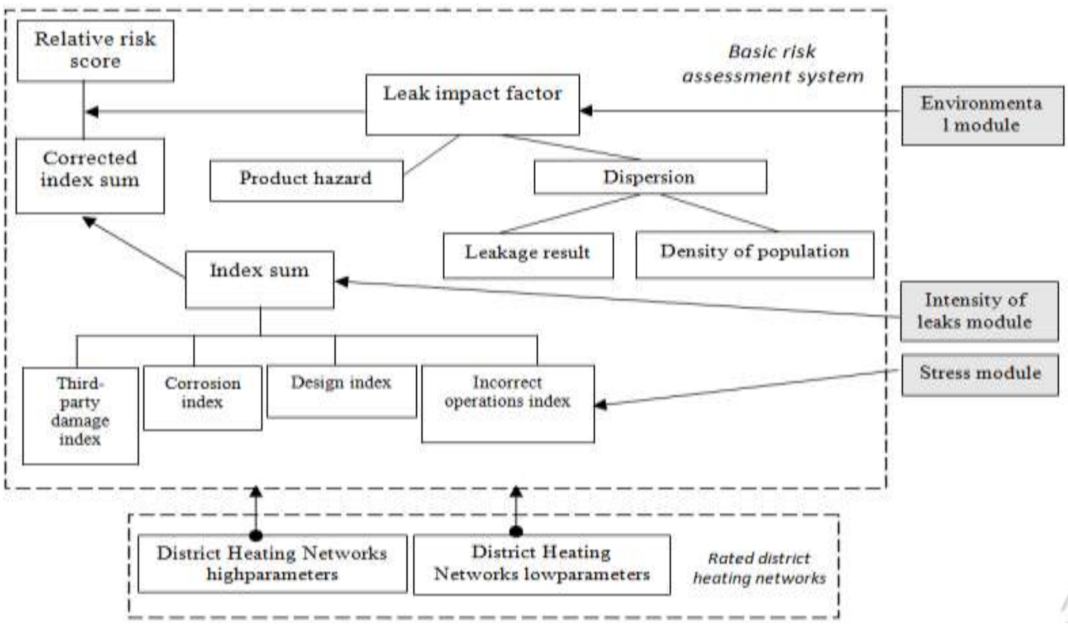

Fig. 1 Flowchart of adaptive method of risk assessment of district heating network

The pipeline evaluated is divided into a series of homogeneous sections, each of which is further evaluated. Uniformity can be obtained e.g. through the same year of section construction, diameter, homogeneous area, etc.
Parameters describing episodes are divided into:
· Attribution - at which the value of the operator is not affected by its activities,
· Preventive - where the value of the operator can be affected by the course of your business.
All stages of the generation and operation of the district heating network: from design through construction to operation are taken for evaluation. In the operation phase, influence of external environment and interference of third parties are calculated. The rating is for all sections and non-linear elements of district heating network. The GIS environment allows unambiguous localisation in the field of the analysed network section. As mentioned earlier, the district heating network is evaluated in the group of four basic indexes:
1. Third-party damage (intentional or sabotage or unintentional e.g. during construction works),
2. Corrosion (natural processes occurring in the external and internal environment of the steel pipe),
3. Design,
4. Incorrect operation (unintended bugs in operation).
The maximum total score for the four indicators is 400, with 100 points for each indicator being analysed. This is a subjective score proposed by W.K. Muhlbauer [3,5].

An unusual expansion factor changes by introducing a stress module. This allows for the inclusion of stressful working conditions of employees and their impact on the quality of work. This is an element of evaluation, which is introduced when stress occurs and is therefore called the adaptive method. The second module, if needed, is a leak history module.

It takes into account the changes of rating for sections of the district heating network that are prone to frequent failures. To maintain impartiality, the district heating network assessment is evaluated by the choice of the most up-to-date response. The factors taken into account in valuation and assessments are based on the expertise and experience of the appraiser. Depending on the design and operating conditions of the network, the evaluation may be changed at the request of the evaluator who presents the proposed adaptation method.
Below, the flowcharts show the breakdown of points into subgroups in the basic assessment of the four indexes.
Figure 2 Third-Party Damage Index
Figure 3 Corrosion Index
Figure 4 Design Index
Figure 5 Incorrect Operations Index

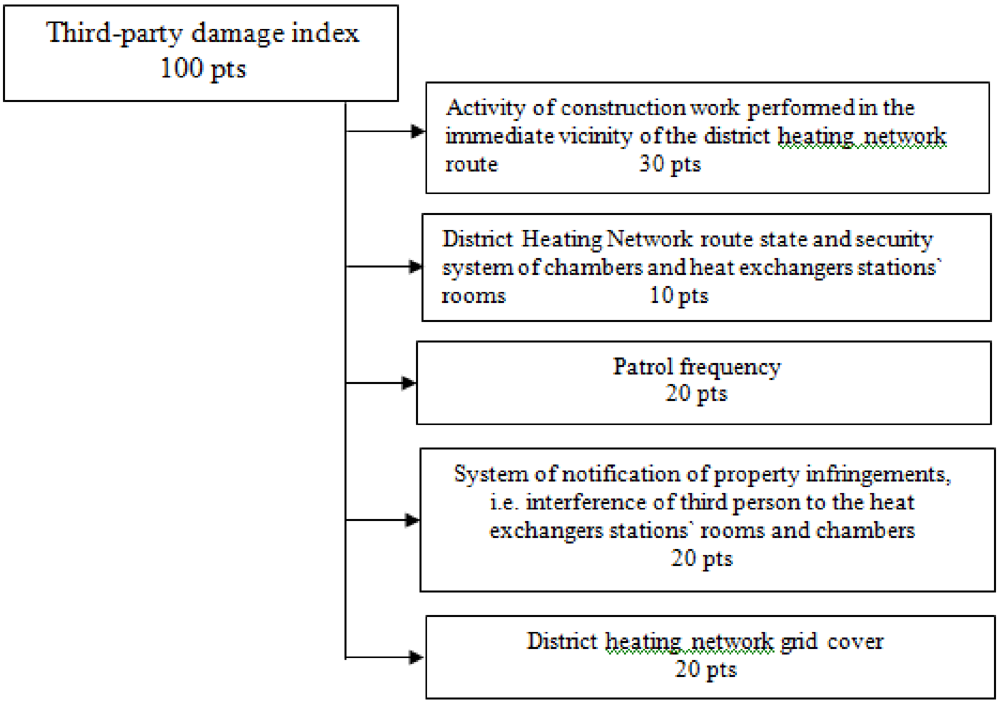

Fig.2 Flowchart of third-party damage index

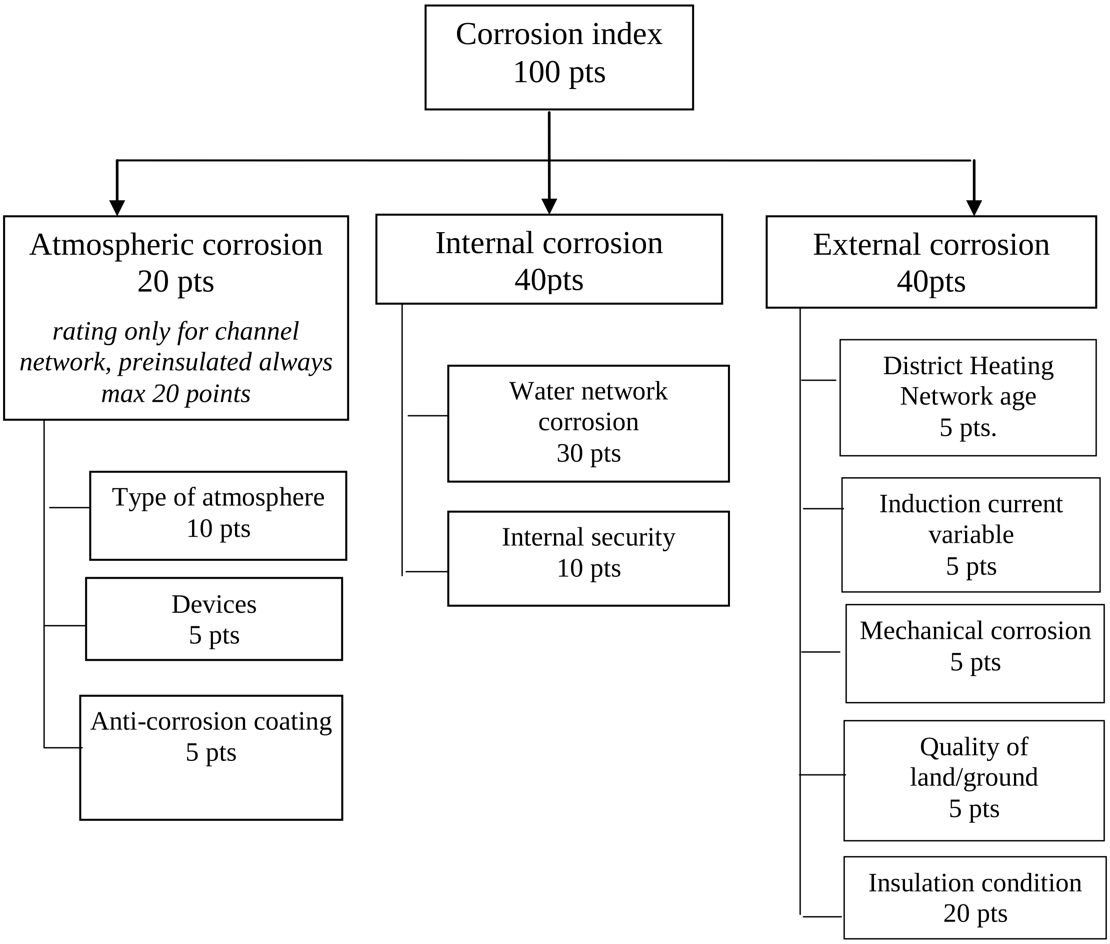

Fig. 3 Flowchart of corrosion index

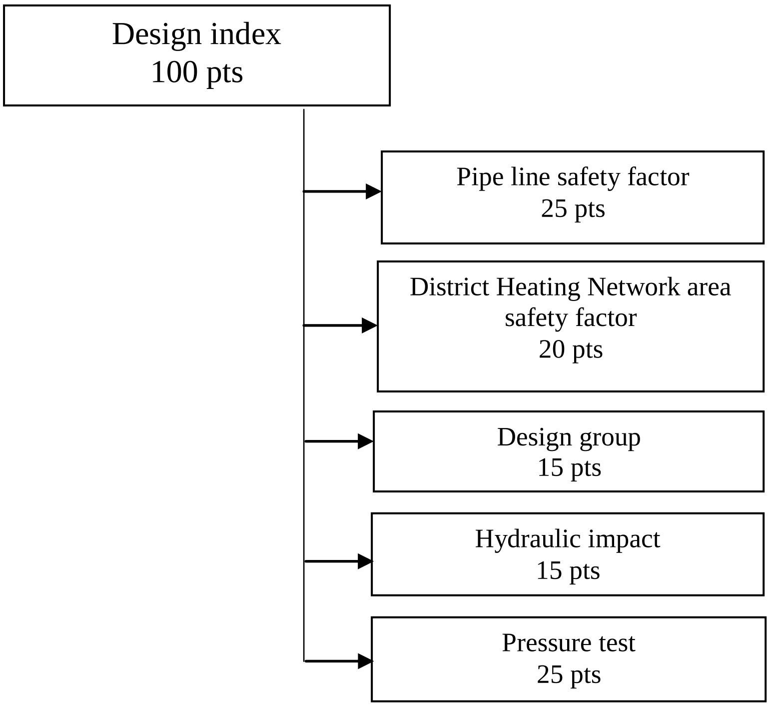

Fig. 4 Flowchart of design index

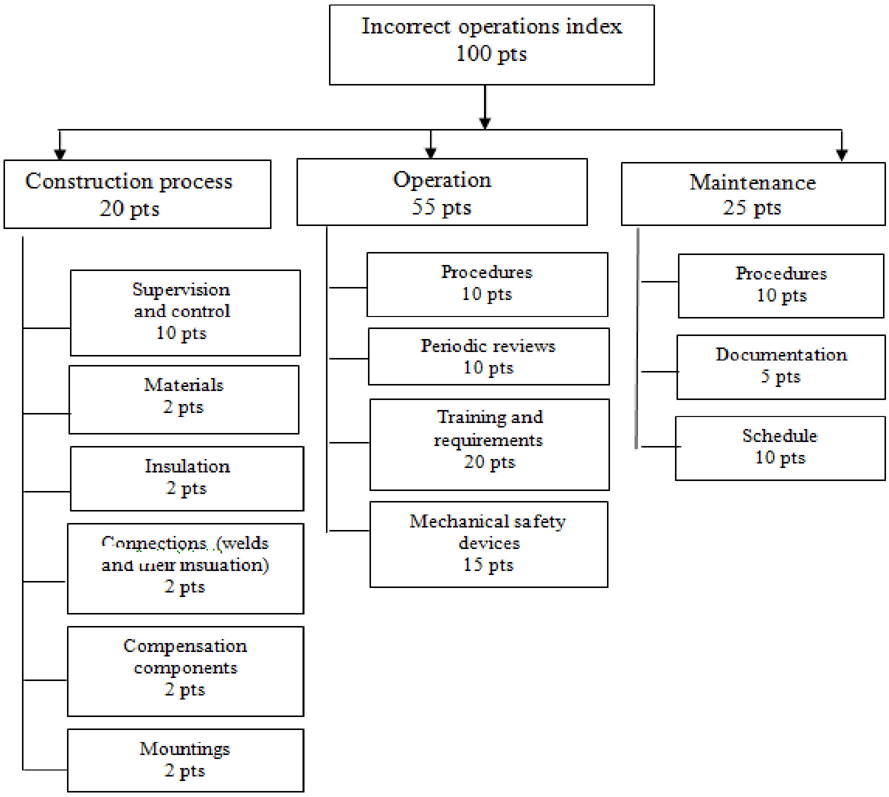

Fig. 5 Flowchart of incorrect operations index

The relative risk score, i.e. the final score, is obtained for the analysed network section after summing up the points in the baseline assessment, taking into account the stress module and the intensity of leaks module, and after dividing the leak impact factor.

In order to take into account the diversity of areas through which the route of the district heating network has been introduced, the leakage coefficient has been introduced, i.e. the ability to assess the influence of hot water leakage and its impact on the environment. Thus, the risk of leakage can be differentiated, ie, the failure of the district heating network in the vicinity of a dense apartment building against the risk of opening a green strip on the edge of a city square. The impact of the leakage is assessed taking into account the risk of material damage and the risk of environmental damage, such as the threat of vegetation of plant species and habitats of protected animals, the risk of damage to the historical features of the architecture and the deterioration of the landscape. Spot score is the relative rating of risk of sections of a district heating network which is subject to analysis. Spot ratings of two different district heating networks are incomparable.

III. Interpretation and Presentation of the Results of Risk Analysis

For the analysis, a district heating network consisting of the main and distribution networks i.e. the main areas of city supply by selected networks. Line elements that are connected to heat exchanges stations and non-linear elements are omitted: network pumping stations and dispersed heat storages.

Figure 6 shows a graph of the district heating network with a marked heat source - a black square in the lower right corner.

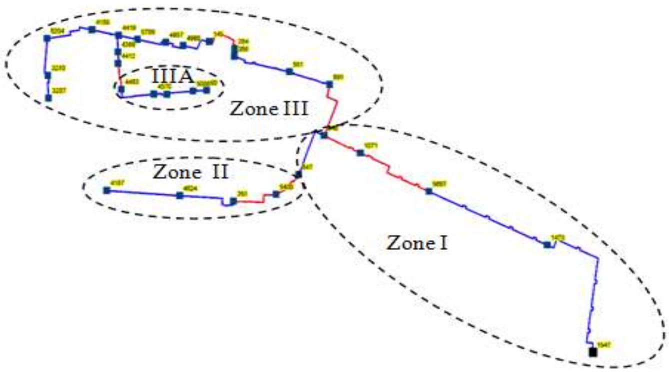

Fig. 6 Graph of the district heating network

Legend:
Zone I - industrial zone of the city, manufacturing plants,
Zone II - the industrial zone of the city, located directly in the vicinity of the railway line, in-creased truck traffic, cargo handling points,
Zone III - residential area of the city, multifamily housing
Zone IIIA - close city centre, monumental buildings

As a result of the adaptive risk analysis method, a number of numerical values have been derived describing the risk level of each section of the analysed network. Table 1 shows numerical results, denoting red - high risk (lowest point), green - lowest (highest score) and yellow mean - average for the median for the results set. The pipeline cord IDs are listed in the table. The return lines are omitted because their numerical rating is the same as that of the mains. A total of 52 network sections were evaluated, 26 are in the table.

Tab. 1 Results of adaptive method of risk assessment of district heating network

ID section	Corrosion index	Third-party damage index	Design index	Incorrect operations index	Leak impact factor	**Relative risk score**
535	78	54	47	73	7,11	35
603	81	49	47	79	9,00	28
607	81	49	47	79	9,00	28
1286	63	54	47	73	7,11	33
1531	81	49	47	79	9,00	28
1536	78	49	37	70	7,11	33
1734	78	49	37	70	7,11	33
2160	78	54	47	73	7,11	35
3336	64	30	9	46	21,33	7
3636	51	49	37	65	9,14	22
3658	51	54	37	65	9,14	23
3662	51	54	37	65	9,14	23
3810	61	35	37	70	21,33	10
4445	64	30	9	48	21,33	7
4589	78	49	37	70	7,11	33
4755	64	30	9	48	21,33	7
4776	66	30	23	65	21,33	9
4806	66	35	37	70	21,33	10
4811	61	35	37	68	21,33	9
4914	81	49	47	79	9,00	28
4928	54	54	37	65	8,00	26
5039	78	54	47	73	7,11	35
5321	61	30	23	67	21,33	8
5687	66	35	37	70	21,33	10
5749	78	49	37	70	7,11	33
5777	78	49	37	70	7,11	33

The obtained rating matrix in each category and the final rating, i.e. the relative risk score, indicate that the three sections of the district heating network that are characterized by the lowest number of points are at danger of failure or are characterized by a high level of risk. The analysis of the individual indexes showed that the sections of the district heating network that were rated at high relative risk, at least in the assessment of the two primary indexes, also ranked at high risk. In total: the Corrosion Index identified three sections at high risk level (11.5% of the number of network sections assessed), Third-Party Damage Index rate (19.2%), Design Index three (11.5%) and in the Incorrect Operations Index rate one (3.8%). For risky sections i.e. high risk levels, the leak impact factor is a major coefficient in assessing relative risk score. For the five sections, it assumes the highest value, which means that in the area of the route of the analysed sections of water from the district heating network it can cause considerable damage and lead to significant losses. Combining an adaptive risk assessment meth-od with a GIS application gives the ability to locate network sections in geographic space. Figure 7 shows graphs of district heating network showing the highest relative risk and high risk area with a number of points below the median for the entire set of point values of the analysed network.

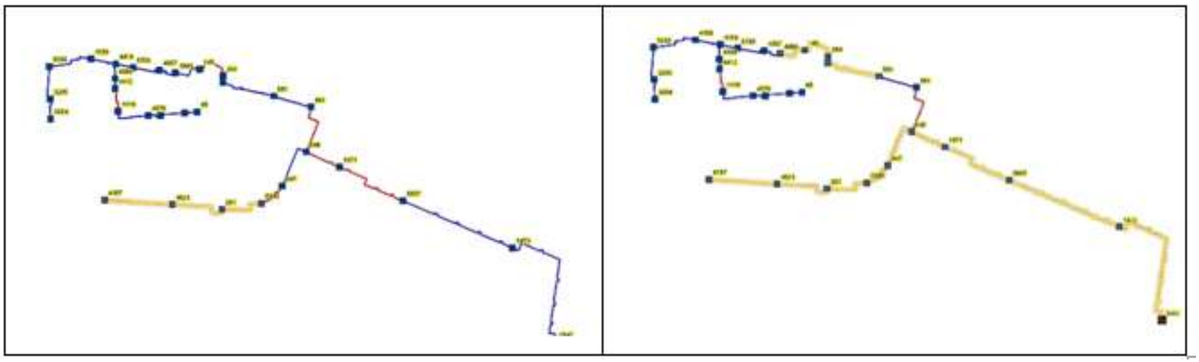

Fig. 7 Segments of district heating network with the highest relative risk (left side) and segments with increased relative risk (right side) - yellow

The segment of the network in danger of failure and the remaining sections of the high risk networks are located in areas I and II, i.e. industrial and multi-family housing. Figure 8 shows a graph of the district heating network showing the branches for which the network failure and heat leakage are particularly dangerous. It is characterized by the highest value of leakage coefficient.

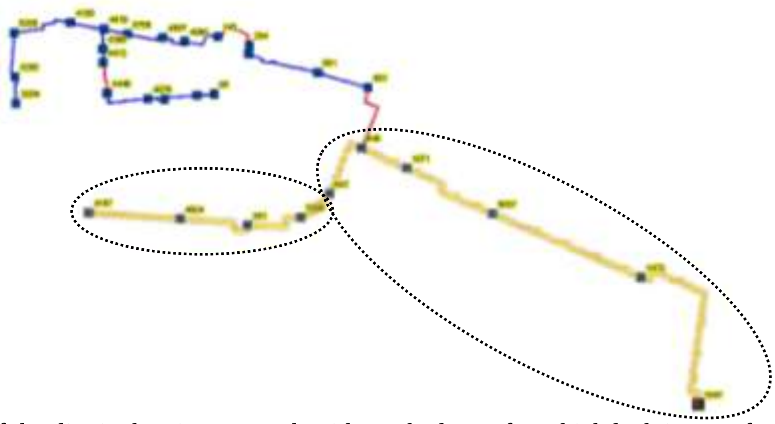

Fig. 8 Graph of the district heating network with marked area for which leak impact factor accepts the minimum value

Figure 9 shows graphs of the district heating network showing the highest level of risk of failure and the higher risk network sections corresponding to the number of points less than the median value broken down by the analysed risk indexes.

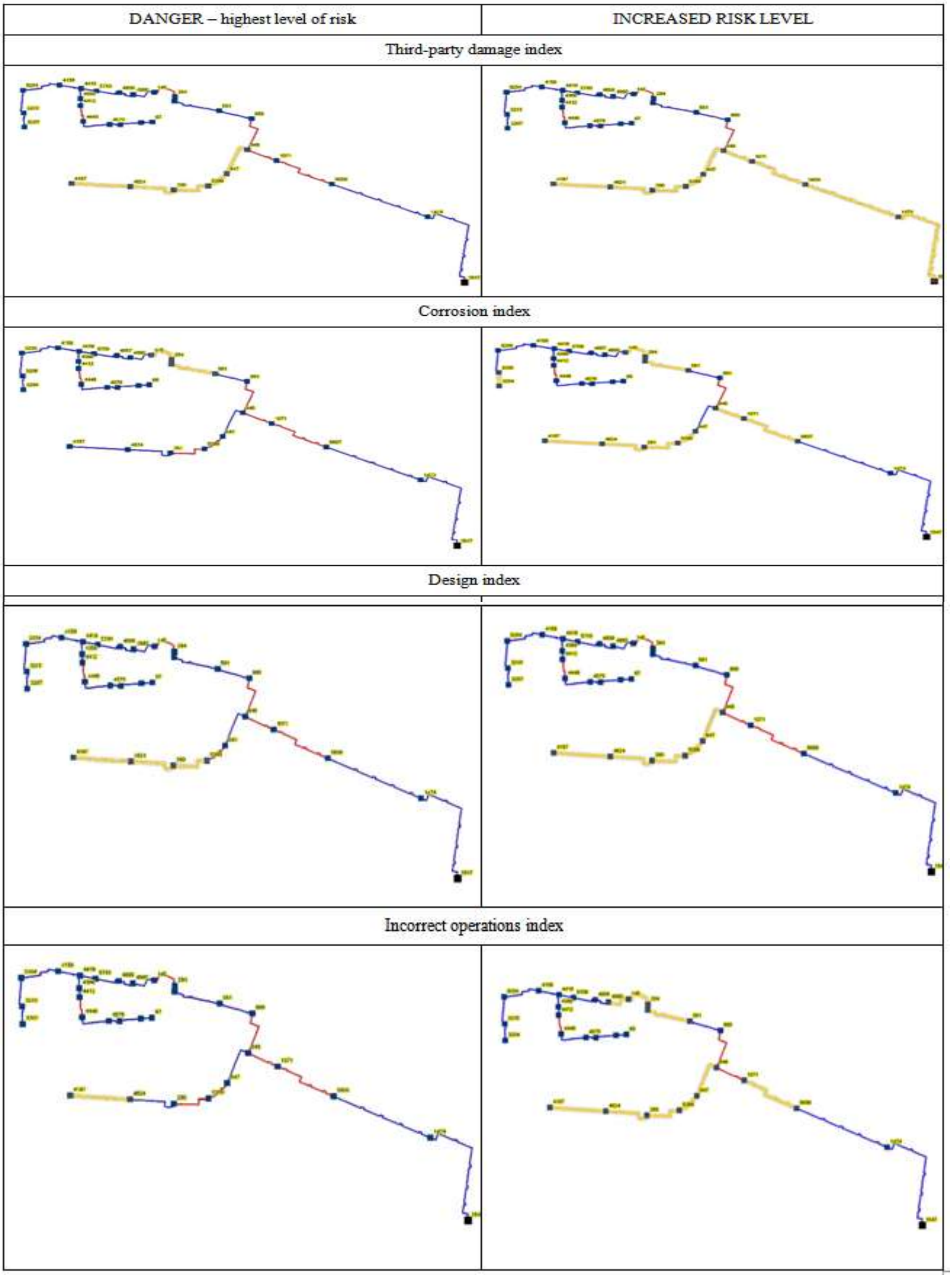

Figure 9 Graphs of the district heating network showing the highest level of risk and increased risk levels by rating indexes

Sections of the district heating network with increased risk of failure leading to of the pipeline are located in the industrial area with increased vehicular traffic and in the immediate vicinity of the railway. The heat distribution pipes in the marked areas are subject to much higher compressive forces transmitted through the ground, channels or shroud are exposed to brine falling off the roads during winter during snow clearance and are in the zone of stray currents. A part of the network is over ground, which means that it is more exposed to third-party activities and corrosive environment than the preinsulated underground network.

IV. Conclusion

Analysis of the risk level assessment divides the sections of the heating network that are exposed to failure or increased risk of failure. The concept of failure is identical to the occurrence of leakage or breakage in the continuity of the pipe wall. The consequences of the disaster for the residents are serious. Evaporation with warm water under ambient conditions, ie in the outside air, evaporates rapidly, leading to the formation of a vapor cloud. Completely detachment from the pipeline results in the leakage of hot water in the quantities that cause cellar flooding, streets and, in extreme cases, lead to landslides, roads, greens, and so on. Diagnosis and allocation of parts of the network that are at risk of failure is an essential tool for the district heating network operator. The effects of a breakdown in addition to the severe impact on the environment, third parties and their property cause a break in the supply of heat to customers - network users. The occurrence of a breakdown certainly deprives the heat of the supply of heat from the local district heating network. In addition, in a construction disaster, the district heating network operator must immediately take up the leakage-stopper and commence repair work as a matter of urgency.

Knowledge of the level of risk for individual sections of the district heating network allows for planning and carrying out maintenance work during the heating season [6,7]. It allows to take action that minimizes and in some cases eliminates interruptions in the supply of heat to network customers. They allow you to plan work using a meshed structure so as not to deprive customers of the heat supply during the work. This means that the analysis and assessment of the district heating network risk is an indispensable element in the efficient (reliable and inexpensive) management of the district heating network. It enables optimal management of network assets by planning district heating repairs and minimizes time and costs and meanwhile ensures continuity of heat supply, resulting in constant revenue for heat supplied and no penalty for failure to comply with customer contracts.

Acknowledgement

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