ISBN 978-83-975865-0-5

Transport Problems 2025

Conference proceedings

UNDER THE HONORARY PATRONAGE OF

Silesian University of Technology

Krajowa Reprezentacja Doktorantów

XVII INTERNATIONAL SCIENTIFIC CONFERENCE

25-27.06 2025

Katowice - Wisła- Žilina

23-24.06.2025

Katowice-Mysłowice

XIV INTERNATIONAL SYMPOSIUM OF YOUNG RESEARCHERS

Dedicated to the 80th anniversary of the Silesian University of Technology

Silesian University of Technology
Faculty of Transport and Aviation Engineering

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ISBN 978-83-975865-0-5

Media patronage:
Transport Problems International Scientific Journal
ISSN 1896-0596, The Silesian University of Technology,
Faculty of Transport and Aviation Engineering

Transport Problems
International Scientific Journal

Keywords: GIS, mountain roads, remote sensing, interface

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DEVELOPMENT OF AN INTERFACE FOR THE ROAD CONDITION REMOTE FORECASTING SYSTEM

Summary. This study details the development of a dual-interface system designed for the remote forecasting of road infrastructure condition. Leveraging remote sensing data, the system predicts the operational and technical status of diverse road networks, encompassing highways and complex mountainous terrains. A key contribution is the implementation of two distinct interface modalities: a human-machine interface (HMI) for user interaction and visualization of forecasting outputs, and a machine-machine interface (MMI) structured as standardized data tables to facilitate seamless integration with existing road maintenance management systems.

1. INRTODUCTION

The effective management and maintenance of road infrastructure are critical for ensuring transportation safety, economic efficiency, and societal well-being. Timely and accurate information regarding the condition of road networks is paramount for proactive maintenance planning, resource allocation, and ultimately, the longevity of these vital assets. Traditional methods of road condition assessment often rely on manual inspections, which can be time-consuming, labor-intensive, and may not provide a comprehensive and up-to-date overview, particularly across extensive and geographically diverse road networks [1, 2].

To address these limitations, there is a growing emphasis on leveraging advanced technologies for remote monitoring and forecasting of road infrastructure conditions. Remote sensing techniques, coupled with sophisticated data analysis and predictive modeling, offer the potential to provide a more efficient, scalable, and objective approach to assessing the operational and technical status of roads. This capability is particularly valuable for monitoring challenging environments such as complex mountainous terrains, where physical access can be difficult and hazardous.

In previous articles the research team has developed the intelligent geographic information system (IGIS) that forecasts the road condition using open weather and remote sensing data [3, 4], covering the period from January 2016 to March 2023. For special cases we gathered data on the mountain road section located near Almaty city section through visual assessment, measurements of the coefficient of adhesion, and the acquisition of material samples from the structural layers of the roadbed. In the present study the authors focus on the development of an interface for the developed GIS. That is needed to make sure that the system can be integrated.

2. INPUT DATA

To initiate a remote forecast for specific road segments, the client is required to provide certain key input data through the developed Human-Machine Interface (HMI). This information allows the system to focus its analysis on the areas of interest and generate relevant condition predictions. The primary input for the road condition forecasting system consists of geographic coordinates that define the specific road segments under analysis. The client must specify the geographical location(s) of the road segment(s) for which a condition forecast is desired. These coordinates are provided by the client to delineate the sections of the road network for which condition evaluations are required.

Depending on the system's capabilities and the client's needs, there might be other developed option features in future updates to make clients able to specify the types of condition parameters to be forecasted. These parameters may include focus on certain surface defects like cracking, potholes and rutting; or a request for a risk assessment forecast for roadbed slopes if client has the data to analyze. The last parameter may be crucial in mountain regions. Also, while the system can provide the most current forecast based on available remote sensing data, the client may also specify a desired forecast period.

The interface is designed to guide the user through this input process with clear instructions. Validation mechanisms will be implemented to ensure the provided data is in the correct format and within acceptable ranges. Once this client-provided input data is submitted, the system will then leverage its internal processing capabilities and access its repository of remote sensing and ancillary data to generate the requested road condition forecast for the specified locations and timeframes.

An example of the standardized input is provided in Table 1.

Table 1

Input road sections coordinates examples

Section number	Starting X	Starting Y	Ending X	Ending Y
1	43.040848	76.944636	43.042553	76.945698
2	43.042553	76.945698	43.044168	76.947265
3	43.044168	76.947265	43.045352	76.948874
4	43.045352	76.948874	43.045619	76.949636
5	43.045619	76.949636	43.046262	76.949754
6	43.046262	76.949754	43.046089	76.951438
7	43.046089	76.951438	43.046999	76.951309
8	43.046999	76.951309	43.046693	76.953563
9	43.046693	76.953563	43.046003	76.954753
10	43.046003	76.954753	43.046324	76.955150
11	43.046324	76.955150	43.048198	76.953906
12	43.048198	76.953906	43.049076	76.956019
13	43.049076	76.956019	43.049766	76.957865
14	43.049766	76.957865	43.047696	76.958337
15	43.047696	76.958337	43.047336	76.959732
16	43.047336	76.959732	43.046575	76.961073

That shows that every road should be presented as the sequence of lines with ending coordinates of one being the same as the starting coordinates of the next line. This coordinate-based input method allows for precise identification of road segments, enabling the system to accurately focus its analysis and provide targeted forecasting results."

3. OUTPUT DATA

After computing, the system provides a comprehensive set of output data for each road segment, detailing various aspects of its condition. These outputs are crucial for a thorough evaluation and include quantitative measures of distress, categorical assessments, and visualization codes for map representation. That makes these parameters available to use as an input for any client systems, which is needed for the interface accessibility.

An example part for the sections from Table 1 is shown in Tables 2 to 4.

Table 2

Transversal crack evaluation examples

Section number	Transversal cracks, 0-1	Transversal cracks, 1-2	Transversal cracks, 2-3	Transversal cracks, 3-4	Transversal cracks, 4-5
1	27,9606352	18,13166272	8,998526541	7,861586352	1,773811208
2	29,17442057	17,96513841	9,115590376	7,9538535	1,977094558
3	29,1744206	17,96513841	9,115590373	7,953853511	1,977094568
4	27,98517743	17,99981908	8,984255846	7,754000592	1,754121204
5	27,43344623	18,59727973	9,157217075	8,077259434	1,679072951
6	27,98517744	17,99981908	8,984255845	7,754000598	1,754121209
7	27,81960742	18,70122281	9,201346321	8,24701627	1,779534396
8	27,40815327	18,19598637	9,017658592	7,772863196	1,642205615
9	28,41109757	18,30230979	9,199086931	8,030348232	1,828808374
10	28,19547863	18,20529142	9,208163988	7,882971464	1,746110518
11	28,59616143	18,78732879	9,552869003	8,344323917	1,819438055
12	27,78298599	18,30853816	8,901449546	8,027848371	1,822156265
13	28,29996166	18,16333367	9,239341471	7,855042213	1,746153097

Table 3

Longitudinal crack evaluation examples

Section number	Longitudinal cracks left side	Longitudinal cracks axial	Longitudinal cracks right side
1	84,14365235	29,61542598	48,08548681
2	86,45148813	26,25248095	51,76551252
3	86,45148832	26,25248079	51,76551266
4	83,27436293	29,83235365	48,13315488
5	84,04192051	31,48855963	45,6807965
6	83,27436304	29,83235356	48,13315496
7	86,05612707	29,96181435	46,95948267
8	82,1245633	31,77019936	45,99419961
9	85,13317815	28,88066856	48,78832999
10	83,26543014	30,13359515	47,84915792
11	85,88589641	29,42165246	47,9445711
12	86,08943559	28,96190603	48,13689966

The examples are from the table that is about the third year after the prediction. There are also tables for the present time and the second year. As can be seen, the system evaluates the road section’s width, level of cracking observed or predicted, and the risk category. The cracks are categorized by the form, size and location relative to the road center. An example for the present time is shown in Table 5.

Table 4

Summary evaluation examples, year 3

Section number	Crack network	Width	Crack sum	Category
1	7,002330556	7,5	0,30267783	3
2	7,427779215	7,5	0,320900204	3
3	7,427779194	7,5	0,320900203	3
4	7,198947866	7,5	0,311047963	3
5	6,797112065	7,5	0,293930319	3
6	7,198947853	7,5	0,311047963	3
7	6,655799884	7,5	0,287949985	3
8	7,084126208	7,5	0,306123312	3
9	7,264602774	7,5	0,313912126	3
10	7,53622908	7,5	0,325462323	3
11	7,526954299	7,5	0,325157464	3
12	6,36796211	7,5	0,275639914	3
13	7,699648524	7,5	0,332432922	3
14	7,412955368	7,5	0,32026235	3
15	8,244328874	7,5	0,355486043	3
16	8,470434005	7,5	0,365314441	3

Table 5

Summary evaluation examples, year 1

Section number	Crack network	Width	Crack sum	Category
1	2,334110185	7,5	0,100893	2
2	2,475926405	7,5	0,106967	2
3	2,475926398	7,5	0,106967	2
4	2,399649289	7,5	0,103683	2
5	2,265704022	7,5	0,097977	1
6	2,399649284	7,5	0,103683	2
7	2,218599961	7,5	0,095983	1
8	2,361375403	7,5	0,102041	2
9	2,421534258	7,5	0,104637	2
10	2,51207636	7,5	0,108487	2
11	2,508984766	7,5	0,108386	2
12	2,122654037	7,5	0,09188	1
13	2,566549508	7,5	0,110811	2
14	2,470985123	7,5	0,106754	2
15	2,748109625	7,5	0,118495	2
16	2,823478002	7,5	0,121771	2

As can be seen, the prediction made much higher risk evaluation over the years and changed the category on presented sections.

The last is a column made for visualization purpose. It shows the overall observed/predicted condition. That lets the system form a map with lines drawn according to the coordinates in colors according to this parameter values. The Table 6 shows an example set of data for the year 1.

Table 6

Visualization table example, year 1

Section number	Visualization	Section number	Visualization	Section number	Visualization
1	20	9	20	121	13
2	20	10	20	122	13
3	20	11	20	123	14
4	20	12	14	124	13
5	14	13	20	125	13
6	20	14	20	126	12
7	14	15	20	127	14
8	20	16	20	128	14

As can be seen, the full table for the studied road segment consists of 128 sections. The resulting image is depicted as Fig. 1.

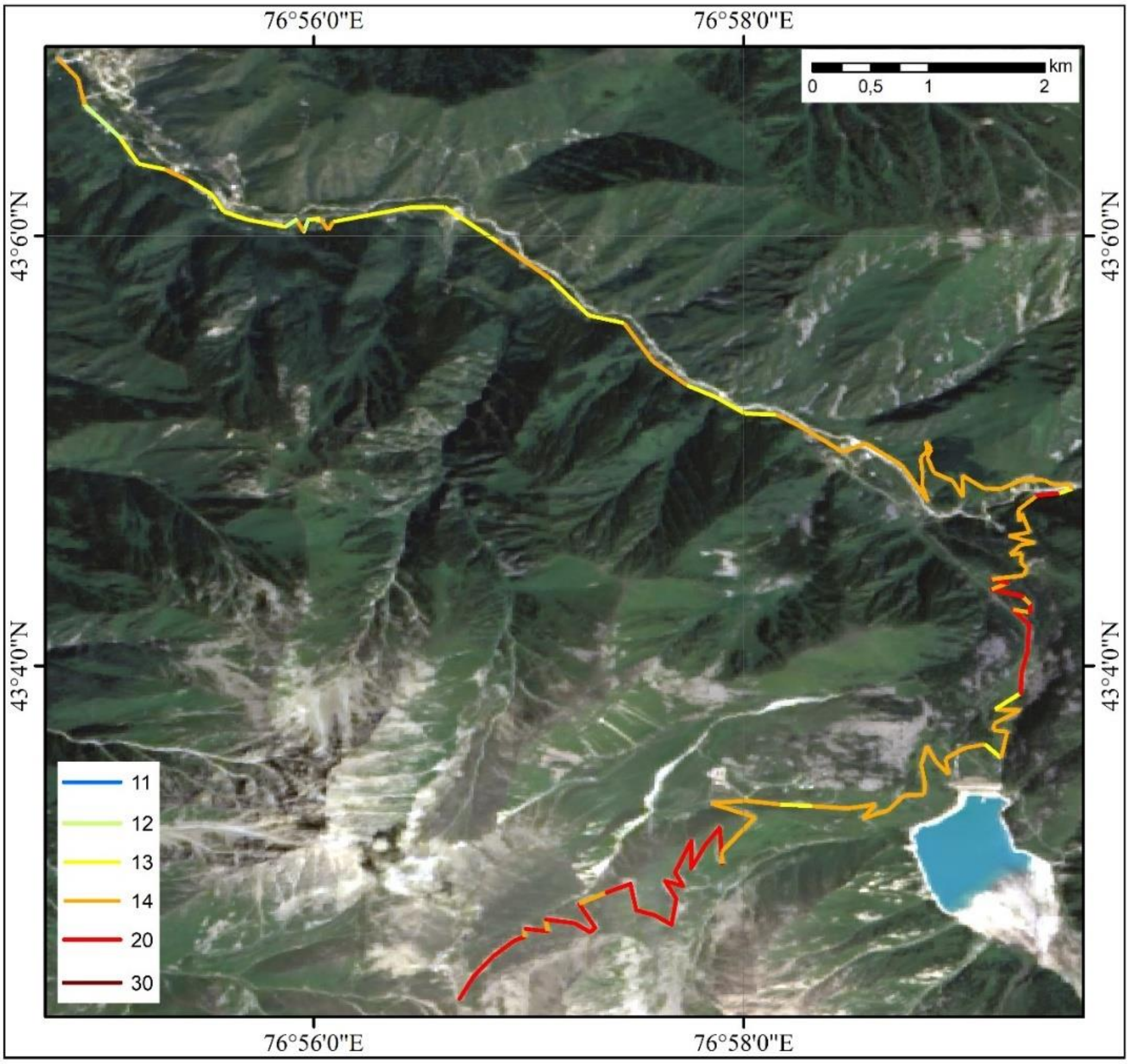

Fig. 1. The present time evaluation visualized

The same goes for the second and third years in the Tables 7, 8 and Figs. 2, 3 respectively.

Table 7

Visualization table example, year 2

Section number	Visualization	Section number	Visualization	Section number	Visualization
1	30	9	30	121	20
2	30	10	30	122	20
3	30	11	30	123	20
4	30	12	20	124	20
5	20	13	30	125	20
6	30	14	30	126	20
7	20	15	30	127	20
8	30	16	30	128	20

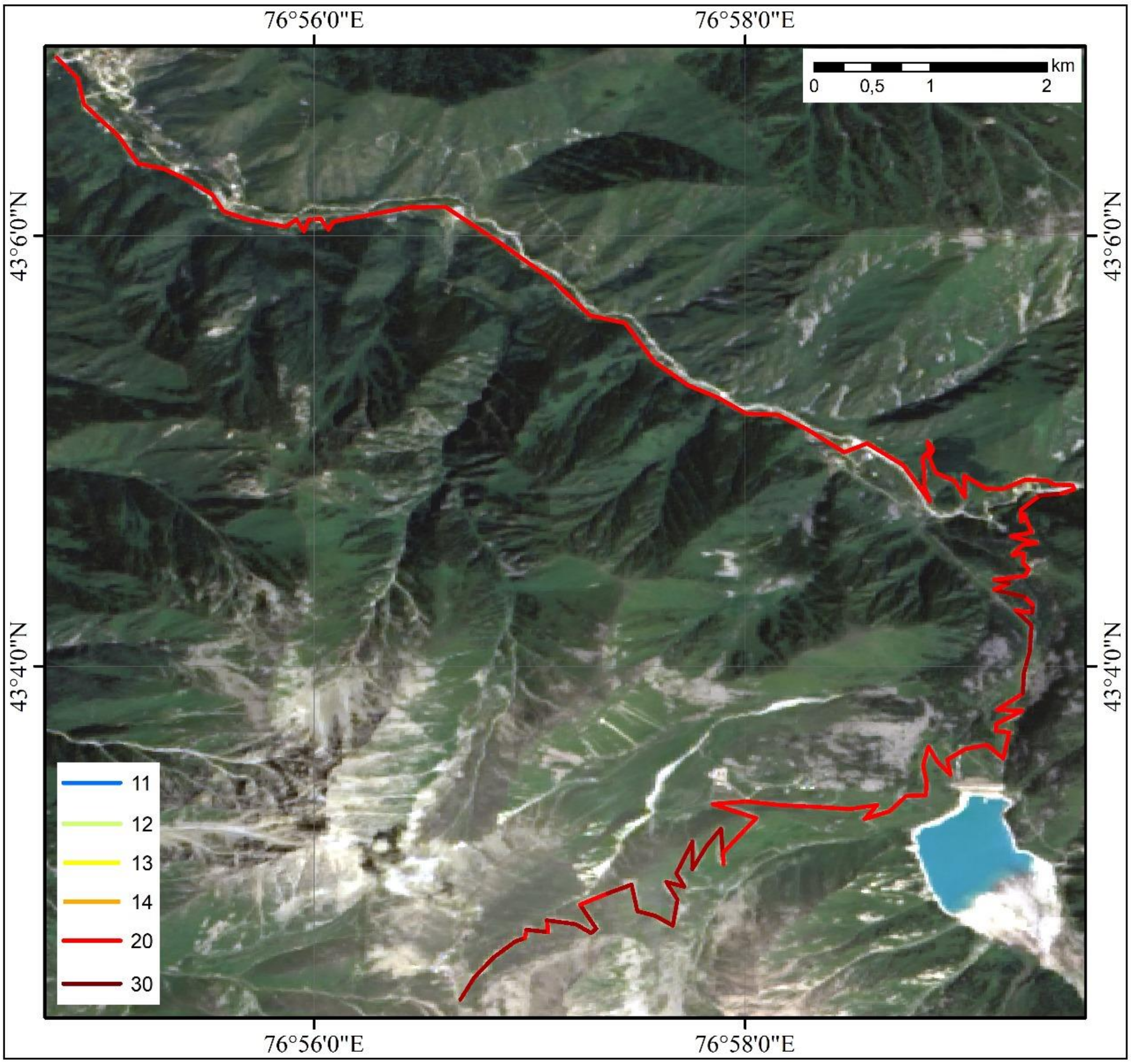

Fig. 2. The year 2 prediction visualized

Table 8

Visualization table example, year 3

Section number	Visualization	Section number	Visualization	Section number	Visualization
1	30	9	30	121	30
2	30	10	30	122	30
3	30	11	30	123	30
4	30	12	30	124	30
5	30	13	30	125	30
6	30	14	30	126	20
7	30	15	30	127	30
8	30	16	30	128	30

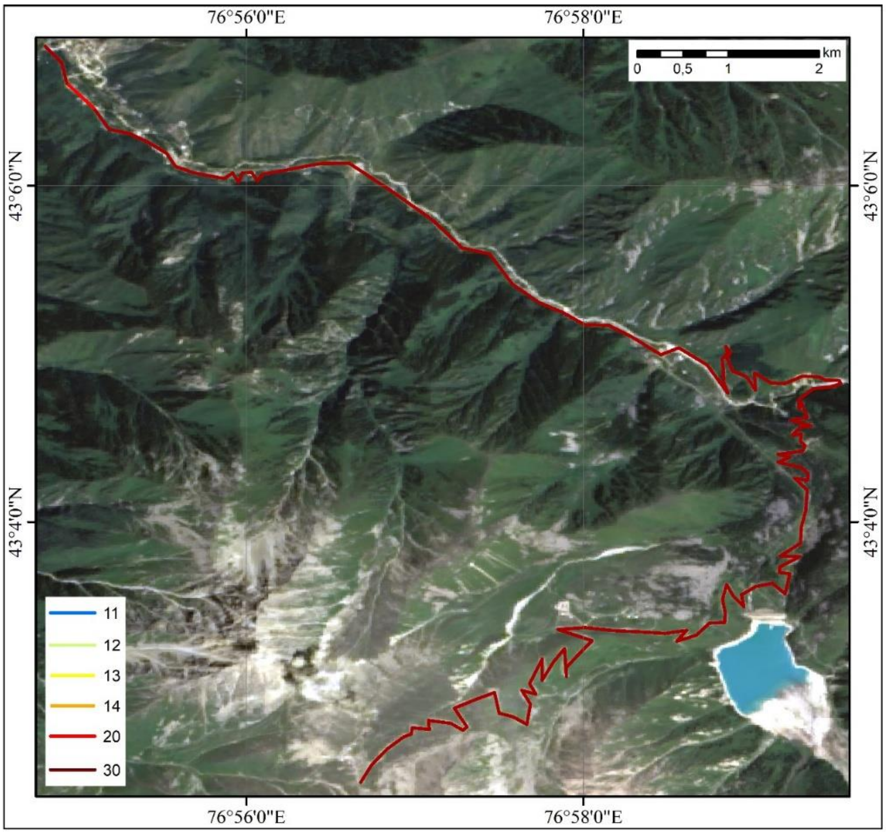

Fig. 3. The year 3 prediction visualized

The resulting visualization shows that the road condition already has great issues and would be in critical condition without maintenance in 2 years, and during the third year this road will become unavailable. News from 2023 regarding the road confirms its condition [5]. Nowadays the road is closed because of state being not operational.

4. RESULTS

The developed dual-interface system for remote road condition forecasting aims to provide actionable insights into the operational and technical status of road infrastructure through its two distinct interfaces: the Human-Machine Interface (HMI) for user interaction and visualization, and the Machine-Machine Interface (MMI) for seamless data integration with existing management systems. The results generated by this system encompass both the visual outputs presented to the user and the structured data provided for automated processing.

Graphic user interface (GUI) was also developed and is presented in Fig. 4.

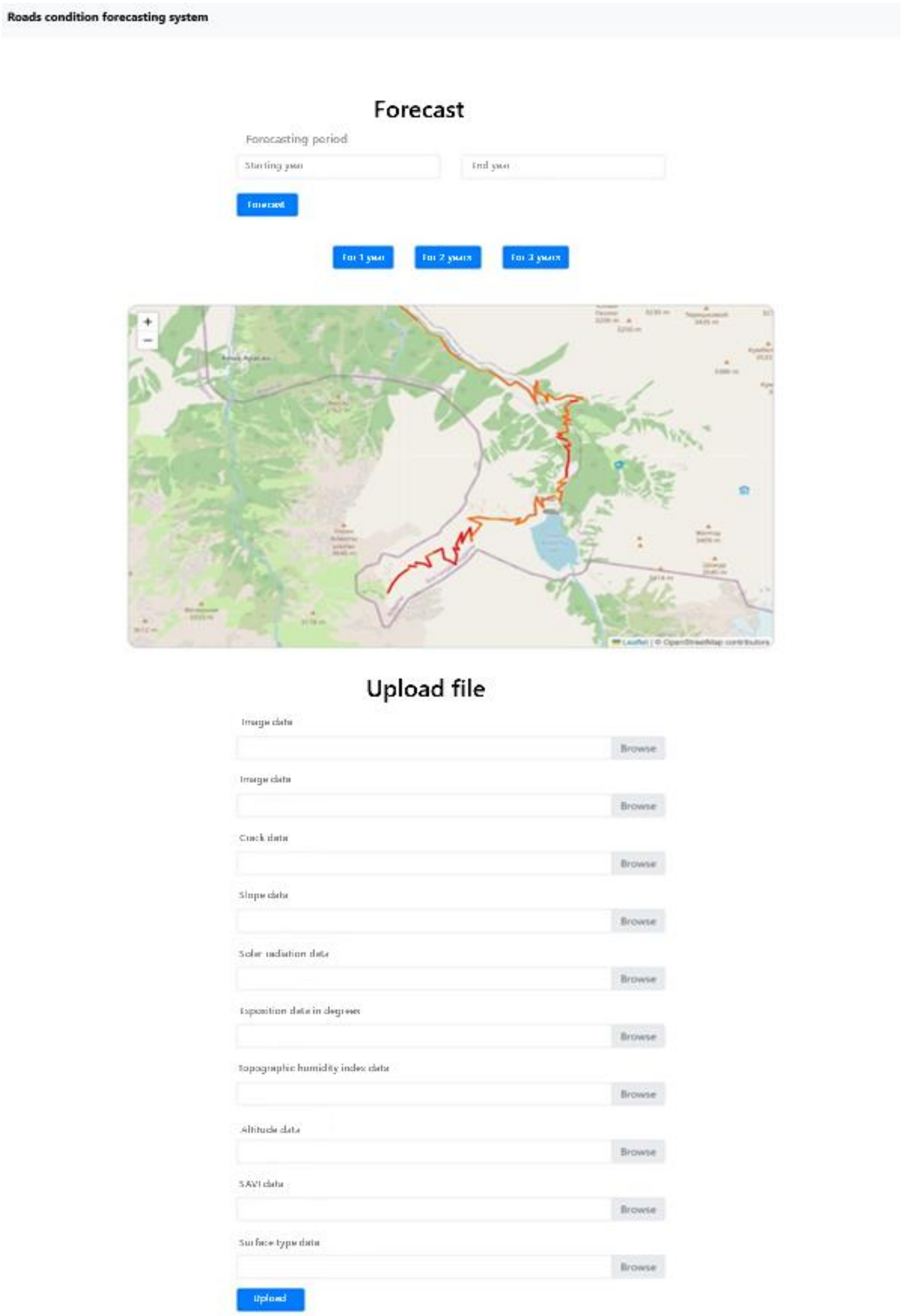

Fig. 4. User interface screenshot

The GUI features distinct sections for setting the forecast period and uploading relevant data files. The “Forecast” section allows users to specify the start and end years for the forecast. Below this comes the visualization described in previous part of the article. The "File Upload” section provides multiple options for uploading various data types, indicated by labels such as “Image Data”, "Crack Data”, and others. Buttons labeled "Browse" next to each data type facilitate file selection.

The system's output is designed to be highly visual, allowing for a quick and intuitive understanding of road conditions. The 'Visualization' codes, as described earlier, are used to color-code road segments on a map, providing a clear representation of risk evaluations. Also, during the development of an interface, the prediction accuracy of the system has been confirmed.

In summary, the results generated by the dual-interface system provide a comprehensive view of predicted road conditions, catering to both human users through intuitive visualizations and automated systems through standardized data exchange. This enables more informed decision-making, proactive maintenance planning, and efficient management of road infrastructure assets.

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