Guidelines for the application of artificial intelligence in the study of the influence of climate change on transport infrastructure

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Abstract: *We are witnessing the massive and impressive penetration of artificial intelligence (AI) into many areas of human activity. This process is expected to intensify in the next few decades. In most technical fields, there will be a preponderance of the so-called narrow artificial intelligence with clearly defined tasks and functions. It is usually a coherent set of neural networks trained to solve specific problems. The advantage of narrow AI is that it is entirely controllable and, at the same time, has excellent capabilities. This publication aims to outline guidelines for applying narrow artificial intelligence in investigating the impact of climate change on transport infrastructure. After a brief introduction to narrow artificial intelligence and climate change, various possible areas suitable for AI modeling are explored. Directions and preparatory tasks for collecting climate-sensitive local data on the condition and changes in the transport infrastructure in Bulgaria necessary for AI training are identified.*

Keywords*: CLIMATE CHANGE, ARTIFICIAL INTELLIGENCE, AI, ARTIFICIAL NEURAL NETWORKS, BIG DATA*

1. Introduction

In recent years, climate change has been felt more and more sensitively. Humanity's efforts are therefore increasingly focused on tracking, understanding, and preventing the impact of climate change on various aspects of life, including transport infrastructure. In this regard, artificial intelligence (AI) can offer new and innovative solutions to this challenge.

Narrow AI [1] is a coherent set of trained neural networks with clearly defined tasks and functions that is controllable and very safe. This article proposes and discusses guidelines for using narrow AI to investigate, prevent, and adapt to climate change impacts on transportation infrastructure. The manuscript suggests relevant modeling areas that can be explored using narrow AI. Also, the article addresses the tasks required to collect climate-sensitive data on transport infrastructure in Bulgaria that can be used to train AI.

In continuation of a previous publication [2], dedicated to the impact of climate changes on transport infrastructure in Bulgaria, the authors launched a project called "Impact of climate changes on transport infrastructure in Bulgaria – a conceptual approach to assess the potential impact on achieving sustainability and safety of elements from the transport sector" to RCDC of UACEG, of which this article is a part.

To ensure the sustainable development of transport infrastructure, AI can help reduce the impact of climate change. This technology is expected to offer new opportunities for analyzing large volumes of data, allowing scientists to understand climate's influence on transport infrastructure better. Ultimately, using technologies like narrow AI can lead to better decisions and more efficient use of resources in the future.

After the first section, an introduction, the article's second section describes the features, advantages, and disadvantages of narrow artificial intelligence. A third section is dedicated to climate change and its impact on transport. The fourth section examines various possibilities for applying narrow artificial intelligence in research on the impact of climate change on transport infrastructure. Several key areas that can be modeled with AI are presented, such as analyzing traffic flows, studying the impact of climate on the road and bridge network, and assessing the condition of transport infrastructure.

In conclusion, the paper highlights the importance of applying narrow artificial intelligence in research on the impact of climate change on transport infrastructure. It suggests directions for future research in this area. The development of new AI technologies and data processing methods will allow scientists to make more accurate and reliable assessments of the impact of climate change on transport infrastructure and take adequate measures to protect it.

2. Narrow Artificial Intelligence

2.1. Definition and characteristics

Narrow artificial intelligence (AI), also known as weak or applied AI [1], is a type of artificial intelligence that is designed to perform very specific tasks within a limited and predefined scope. The system gains knowledge from performing the task, but this knowledge is not applicable to any other tasks.

For the AI to perform well on the given task, it must be trained on a very specific dataset and be designed to perform a narrow set of functions. If the dataset is well chosen and the process of learning is strictly following good practices, the AI system will often perform the given task with better accuracy and efficiency than a human can do it.

Narrow AI systems use machine learning algorithms such as neural networks, decision trees, and support vector machines to analyze the training data and make predictions or decisions based on that data. These systems typically require large amounts of training data so that they learn everything from them. Their performance on the given task solely depends on the data we are using, and that is why we must choose precisely what data we are using for the training process.

The large language models chatGPT [3] and Bing [4] summarize, based on their training with numerous publications, ultimately six characteristics of narrow AI:

- Task-specific: These systems are designed to perform a specific task. They are not capable of generalizing to other tasks or adapting to new situations;
- Limited in scope: These AI systems are designed to work within a limited scope, and they are not capable of handling tasks that fall outside their programmed parameters;
- Rule-based: Narrow AI systems rely on pre-programmed rules and algorithms to perform their tasks successfully. They cannot learn or adapt on their own;
- Data-driven: Narrow AI systems require large amounts of data to learn and improve their performance. They rely on machine learning algorithms to analyze and make predictions based on the data;
- Not self-aware: Narrow AI systems are not capable of self-awareness or consciousness. They do not have emotions, feelings, or desires;
- Generally low-risk: Narrow AI systems are designed to perform specific tasks and are not capable of causing harm beyond their intended function.

Narrow AI differs a lot from General AI, and these terms should not be mistaken. General AI aims to replicate human-level intelligence across a range of cognitive tasks and find a solution for every task that is given, even if it is unfamiliar. Many experts are skeptical that General AI will ever be possible [5]. Others question whether it is even desirable. In the context of Industry 4.0, General AI is not really a point of interest. In the study [6], the authors have shown that the gap between the AGI studies and the industrial needs is very high, unlike the gap between the needs and Machine Learning studies, which is almost closed.

It can be expected that applications that combine chatbots and specialized plugins to them that implement narrow solutions through AI will become more and more and will be applied in various areas of the economy.

2.2. Applications

Most forms of modern AI systems can be classified as narrow AI. The main topics from our everyday life in which it is used today are:

1) Images and facial recognition systems, like those used by social media companies like Facebook and Google, automatically identify people in photographs. In the transport sector, this technique is used to detect defects in the infrastructure through images and videos [7];

2) Chatbots and conversational assistants like Google Assistant, Siri, and Alexa, also included are simpler customer-service chatbots, such as a bot that assists customers with online shopping [8];

3) Self-driving vehicles. Autonomous or semiautonomous cars, such as some Tesla models and autonomous trains, drones, boats, and factory robots [9]. These types of narrow AI enhance safety, enable more efficient speed profiles, and improve the energy efficiency of vehicles. The International Association of Public Transport (UITP) has even defined five Grades of Automation (GoA) concerning train operation ranging from GoA0 to GoA4, so such a system can be evaluated [10];

4) Predictive maintenance and failure models. These models rely on data from machines, often collected through sensors, to help predict when a machine part may fail and alert users ahead of time. That is also valid for road maintenance. Thanks to data from such sensors narrow AI system can predict a defect or a failure of the transport infrastructure or predict when an object will need maintenance [11];

5) Recommendation engines. The systems that predict content a user might like or search for next. In the same way, a narrow AI system can recommend which public transport a passenger uses to be as fast as possible or which will be the cheapest;

6) Traffic Planning and Management – this includes traffic state prediction and rescheduling, analysis of passenger and freight transport, estimation of traffic demand and capacity, scheduling of cars and crews [12], etc.

2.3. Pros and cons

The narrow AI has its advantages and its flaws:

The main advantage of narrow AI is its specialization. Because the Narrow AI systems are designed to perform specific tasks, they can be highly optimized for those tasks, leading to high levels of accuracy and efficiency. Also, narrow AI systems are cost-effective. Developing and maintaining narrow AI systems can be fast and cheap because we are focusing our efforts on one specific area. And if this area is of interest, we can use a lot of the knowledge that has already been developed about it, making our work even easier. Narrow AI systems are also very easy to use once programmed. It can be used even by people who don't have a programming background or have any knowledge about artificial intelligence. Another significant advantage of narrow AI systems is their practical applications. Narrow AI is already widely used in various industries [13], such as healthcare, finance, and manufacturing. From a security perspective, the narrow AI is highly controllable because it is targeted to specific tasks and functions. This makes it safer and suitable for applications in critical systems and areas such as healthcare and automotive.

The narrow AI systems have their flaws. The main one is its limited functionality. The main issue is that narrow AI systems are very limited in their ability to perform tasks outside of their specific domain. They cannot apply their knowledge to new and unfamiliar situations or tasks. Also, they lack creativity. Narrow AI systems don't possess the creativity and innovation that AGI systems do, making it difficult for them to solve novel problems or generate new ideas. Another issue is the risk of scaling: narrow AI can run into scaling issues, especially if used to solve complex problems where there are many factors to consider. Also, narrow AI systems are highly dependent on data. That is why the training data must be large and diverse enough, so the system can be effective. This dependence on data can also lead to biases in the AI's decision-making. And lastly, the need for specialists - Narrow AI requires programming to accomplish the task it is designed to solve. This means that programming must be done by computer science professionals, which can be expensive and time-consuming.

3. Climate changes

3.1. Definition and consequences

Climate changes are defined as significant, long-term changes in the Earth's climate, particularly those related to global temperature, precipitation patterns, and other atmospheric conditions. It is primarily driven by human activities, such as the burning of fossil fuels, deforestation, and intensive agricultural practices, which release greenhouse gases like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) into the atmosphere [14].

These greenhouse gases trap heat from the sun, causing the Earth's average temperature to rise. This phenomenon is known as global warming. As a result, the climate system becomes more unstable, leading to various impacts on ecosystems, biodiversity, and human societies. Some consequences of climate change include [15]:

- Rising temperatures: Increased global temperatures can exacerbate heatwaves, affect agriculture, and alter ecosystems and their inhabitants.
- Melting ice and rising sea levels: Warmer temperatures cause polar ice caps and glaciers to melt, contributing to rising sea levels, which can lead to coastal erosion, flooding, and the displacement of human populations.
- Changes in precipitation patterns: Climate change can lead to more extreme weather events, such as intense storms, droughts, and floods, which can damage infrastructure, agriculture, and ecosystems.
- Ocean acidification: The absorption of CO_2 by seawater increases its acidity, which can harm marine life, particularly shell-building organisms and coral reefs.
- Biodiversity loss: Changing climate conditions can disrupt ecosystems, leading to the extinction of vulnerable species and the disruption of essential ecosystem services.

Addressing climate change requires global cooperation and implementing mitigation and adaptation strategies. Mitigation involves reducing greenhouse gas emissions by transitioning to renewable energy sources, improving energy efficiency, and protecting and restoring forests. Adaptation involves adjusting to the impacts of climate change by developing climate-resilient infrastructure, protecting ecosystems, and planning for sea-level rise and other climate-related risks.

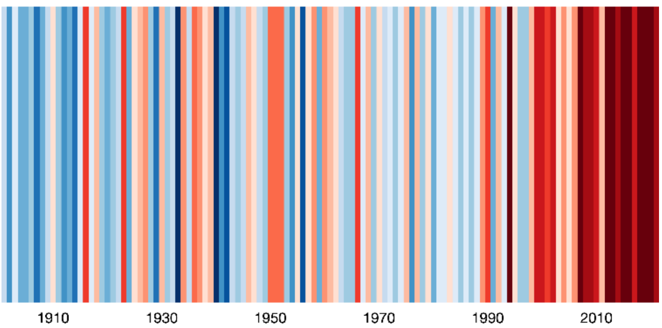

Fig. 1 *Temperature change in Bulgaria since 1901 [16].*

3.2. Consequences of climate change for transport infrastructure

Climate change has significant implications for transport infrastructure, as it can affect various transportation systems' design, construction, maintenance, and operation. The consequences of climate change on transport infrastructure include:

- Flooding and inundation: Rising sea levels and more intense precipitation events can increase the risk of coastal and inland flooding, which may damage roads, bridges, railways, ports, and other transportation infrastructure. This can lead to disruptions in transportation services, increased maintenance costs, and the need to relocate or adapt vulnerable infrastructure.
- Heat stress: Higher temperatures and heat waves can cause thermal expansion of materials, softening of asphalt, and deformation of railway tracks, leading to buckling or other forms of damage. This can result in increased maintenance and repair costs and temporary service disruptions.
- Permafrost thaw: In cold regions, the thawing of permafrost due to rising temperatures can destabilize the ground, leading to the sinking or shifting of roads, railways, bridges, and other infrastructure. This can cause damage and require costly repairs or replacements.
- Geological risks (landslides, collapses, and erosion): Changes in precipitation patterns and more frequent extreme weather events can increase the risk of landslides and erosion, damaging roads, railways, and other infrastructure, particularly in mountainous or coastal areas.
- Storm surges and hurricanes: More intense and frequent storms can lead to storm surges and hurricane-force winds, which can cause significant damage to transportation infrastructure, such as ports, airports, roads, and bridges.
- Combinations of climatic events: The formation of phenomena such as freezing rain, in which all elements of the linear infrastructure are iced, the formation of “black ice” on the roads concerning road safety, reduced visibility in fog and smoke (from fires that occurred as a secondary effect from prolonged droughts in the conditions of high mean day and night temperatures) and others.
- Changes in demand patterns of transport services: Climate change can affect transportation demand by altering seasonal patterns, such as increased demand for cooling or reduced demand for heating in buildings, and shifts in agricultural production, which can affect the transport of goods.

To address the impacts of climate change on transport infrastructure, governments, and policy-makers for the transport sector need to integrate climate change considerations into infrastructure planning, design, and maintenance. This may include updating design standards to account for future climate conditions, investing in more resilient infrastructure, and implementing adaptive management strategies to minimize disruptions and ensure the continuity of transportation services.

Environmental elements such as solar radiation, amount and intensity of precipitation, temperature inversions (extreme high/low temperatures or a wide mean diurnal temperature range), snowfall including in high wind conditions, fog, and combinations thereof, may result in acceleration and/or complicating the processes that negatively affect the operational design indicators of the transport infrastructure. As a result, one can expect unwanted and unforeseen traffic interruptions, increased risk of accidents, the deteriorated performance of the routes and their facilities, the need for more frequent repairs with expanded scope and cost, etc.

3.3. Effects on elements of transport infrastructure in Bulgaria with correlation to climate change

The combination of climatic zones and geographical relief in Bulgaria leads to many problems in the transport infrastructure. These issues concern the interaction of road, rail, airport, and port infrastructure with extreme climate events. Some main problems include damage to asphalt surfaces and pavements, thermal expansion of railway tracks, erosion and geological hazards, fires, and overloading of drainage systems in urban environments. All these factors can lead to disruption of road safety and traffic. Significant rainfall and extreme temperatures lead to numerous problems in transport infrastructure, such as overloading of river capacity, damage to bridges and roads, and freezing of road surfaces [2]. These factors can lead to reduced visibility, icing of equipment, and risk to road safety. The formation of “black ice” and “ice rain” also poses a threat to traffic safety. Snowfall and snowdrifts cause additional difficulties by disrupting traffic flow and limiting visibility.

4. Investigating the impact of climate change on transport infrastructure using narrow artificial intelligence

4.1. Difficulties in assessing the dynamics of the impact of climate change on transport infrastructure

Different climate scenarios describe how the planet's climate could change. The reasons for their existence come from the uncertainty in climate models and the complex interaction of climate factors over the long term.

Meteorology is progressing toward increasingly accurate weather forecasting within a few days to weeks. Weather forecasting in the next few seasons is getting more and more accurate. But there is significant uncertainty over periods longer than a few years, although the changing trend is known to a large extent, as regular changes in climate parameters determine it. In the short term, uncertainty comes from the stochasticity of climate phenomena.

Neural networks, which are a type of AI, can be used to create dynamic models, i.e., to have a predictive character. Thus the result can be extrapolated into the future. This is the subject of AI application in the field of climate models.

Regarding the impact of climate change on transport infrastructure, it is important to define for periods of 5 (or 10) years: 1) the trend of climate change, as well as 2) the maximum deviations from it, and 3) the expected frequency of deviations (increasingly warm winters can be expected, but this does not exclude sometimes very cold winters due to the instability of the Polar Vortex [17] due to climate change).

For a future assessment of the short-term climatic conditions in Bulgaria, there is some accumulated data (on temperature, solar radiation, humidity, precipitation, wind strength, and direction, etc.), mainly in international databases with free or paid access [18, 19]. Most often, they are based on satellite observations, which give a uniform and dense coverage of the entire territory, but at the same time, there is a deviation within a few percent of the actual values measured in meteorological stations. Terrestrial meteorological data measured in Bulgaria and stored for decades in the National Institute of Meteorology and Hydrology of Bulgaria [20] have not yet been digitized and are not available online, which as a result, holds back the development of the assessment of the impact of climate change in various areas, for example, the construction of buildings and transport facilities.

There are also problems regarding the accumulated data on the transport infrastructure problems in Bulgaria. This data should be collected and structured in one database, summarized, and prepared for future use. The interaction between climatic parameters and transport infrastructure highly depends on the location, the local climate, and the construction technologies used. For this reason, there is no significant probability that AI trained with data from other countries with different climates and other construction technologies will also give adequate results for Bulgaria. This requires launching a campaign to accumulate local data on Bulgaria's infrastructure if we want to benefit from this cutting-edge technology in Bulgaria in 5 or 10 years. The reliability of its results is directly related to the correctness of the data with which the AI is trained.

Difficulties in adapting transport infrastructure to improve its resilience against climate risks are related to the possibility of parameterizing the degree of uncertainty. Currently, this leads to a refusal to formulate prerequisites for the scope of the investment area when making decisions in the stages of design and operation of the transport infrastructure, which take into account the influence of climatic phenomena.

Despite the difficulties mentioned, the procedures for adapting to climate change in the transport sector should contain an analysis of climate impacts on the life cycle of transport infrastructure by region in the country.

For this purpose, a research resource and a relatively long period must be allocated for collecting and accumulating climatic data for the country's various regions. Our preliminary studies in [21] combined with the rapid development of AI give reason to believe that AI will significantly speed up and improve the determination of climate priority impact zones while making an algorithm to verify the expected effect on all participants in the implementation of transport services.

4.2. Collection of data to track the impact of climate change on transport services and transport infrastructure

In view of what is stated in section 3.3, it is of great importance to collect the following data to assess the impact of climate change on transport infrastructure:

- Extreme temperature values (maximums/minimums);
- Periods of droughts - with prolonged high/low temperatures without being in constant extremes;
- Amounts of precipitation exceeding the average value of liters per square meter;
- Snowfall;
- Mists;
- Extreme range wind gusts;
- Climatic combinations – fogs with low temperatures, snowfall with wind, and storms, including (wind-rain, hail-wind, excitement, and others).

Climate change tracking data on transport services and transport infrastructure can be collected through the following methods and technologies:

- Geographic Information Systems (GIS) – these can be used to collect data on transport infrastructure such as roads, bridges, railways, airports, and ports. GIS systems can provide information on the geographic location of infrastructure and its condition and use;
- GPS systems – these can be used to collect data on road traffic and the movement of large vehicles such as trucks and ships. This data can be analyzed to determine the impact of transport on the environment and climate;
- Sensors and IoT (Internet of Things) devices installed on various vehicles, such as cars, trains, planes, etc., can help collect data on their movement. These devices can connect to IoT networks, enabling automated data processing and collection;
- Sensors and IoT (Internet of Things) devices installed on transport infrastructure, such as bridges, roads, and railways, to measure temperature, humidity, wind speed, and other meteorological parameters. This will help monitor climate impacts on transport infrastructure in real-time.

The data collected through the technologies mentioned above can be analyzed using various analytical tools, software platforms, and AI. These analyses can help identify trends and changes in traffic, greenhouse gas emissions, and other environmental impacts of transportation.

5. Conclusions

This publication aims to explore guidelines for the application of AI in researching the impact of climate change on transport infrastructure. This would enable real action on climate change adaptation in the transport sector. The implementation of neural networks and artificial intelligence is a long-term task and requires long-term planning and foresight to ensure the timely collection of reliable and accurate data. The application of AI requires significant progress in the accumulation of climate data and data on changes in the state of the transport sector. In the future, this could lead to the creation of working models for climate change simulations on a territorial basis. This will make it possible to assess the severity of the impact they cause on the elements of the transport infrastructure; accordingly, it will be possible to set an increased capacity of the transport routes already within the norms for design, project preparation, operation, and maintenance, response to emergencies, building institutional capacity, adapting to changing demand and others.

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