REVIEW ARTICLE
DOI: https://doi.org/10.30932/1992-3252-2022-20-1-9

World of Transport and Transportation, 2022, Vol. 20, Iss. 1 (98), pp. 208–213

Application of Artificial Intelligence in Transport Construction: Engineering and Educational Aspects

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ABSTRACT

The article generalises the results of the authors' research, both published and prepared for publication, referring to discussion on the current situation in terms of development of artificial intelligence perception and apprehension, and analyses a possibility of application of currently existing AI in design of transport infrastructure facilities and engineering education.

General methodology and algorithm of application of artificial intelligence intended for design of transport infrastructure facilities are described considering synthesis of structures with pre-set behavioural parameters.

Introduction of AI-related competences and skills into educational process intended for training future transport employees is shown in relationship with engineering tasks solved by the users followed by examples of problems solved by the students with the help of artificial intelligence technology.

The possibilities of an interdisciplinary approach to training are shown to demonstrate how the students are taught to apprehend the need for a comprehensive consideration of design problems.

Experimental learning has shown the feasibility and effectiveness of the use of AI by students when solving educational and practical problems.

Keywords: artificial intelligence, engineering education, transport, transport education, interdisciplinary approach, decision support methods.

For citation: Lyovin, B. A., Piskunov, A. A., Poliakov, B. Yu., Savin, A. V. Application of Artificial Intelligence in Transport Construction: Engineering and Educational Aspects. World of Transport and Transportation, 2022, Vol. 20, Iss. 1 (98), pp. 208−213. DOI: https://doi.org/10.30932/1992-3252-2022-20-1-9.

The text of the article originally written in Russian is published in the first part of the issue.
Текст статьи на русском языке публикуется в первой части данного выпуска.

INTRODUCTION

Despite the actual successes achieved and the many practical projects being implemented in the transport industry, the practical application of artificial intelligence (AI) methods in engineering is at the initial stage from a historical point of view, primarily if assessed based on the degree of realisation of its potential.

Currently, AI is being applied in many sectors of economy. Its application is widespread in transport, e.g., to manage road traffic and parking lots of large cities, process data referring to the users of toll roads, to implement integrated logistics processes. Besides, AI is of particular significance in the design of complex technical systems since the success there-of is defined to a large extent by application of decision support methods [1], necessary *inter alios* to analyse Big Data, solve interdisciplinary and other high complexity problems.

Today, it is accepted to differentiate the so-called artificial general intelligence (AGI) and the narrow artificial intelligence (narrow AI) [2]. AGI with human-like thought processes, according to a survey of AI experts [3], is unlikely to emerge in the next 75–100 years, although many doubt its emergence at all. The reason for scepticism lies with the fundamental impossibility of reproducing mental processes (thinking) on computers [4]. Mentality involves operations not with formal symbols devoid of specific content, but with concepts and meanings. Therefore, the lack of consciousness in AI at the present stage makes AGI so far, an unattainable goal.

The narrow AI that exists today [5] can solve rather complex problems in a highly specialised area [6]. Such an AI is not general, it cannot solve, like a human, various tasks that life itself sets, to solve production-related problems, drive a car, make choices in a store, etc.

At the same time, progress towards the adoption of AI technologies in the economy, including in transport, should be ensured by training of specialists with competencies and skills in development, implementation, and application of AI technology. Obviously, the current goal of higher engineering education is to apply the methodology of narrow AI, the task of which is to reproduce purposeful actions carried out by a human with the help of computer systems.

It should be noted that as cognitive tool, AI is widely used in various fields of science: decision theory [2], system optimisation [1], Big Data processing and machine learning [7; 8], fuzzy logic [9], and genetic algorithms [10].

The *objective* of the work is to confirm the hypothesis about the possibility of implementing an interdisciplinary approach to teaching, which allows demonstrating to students the need for a comprehensive consideration of design problems.

RESULTS

The Problem of Application of AI in the Design of Training Content

What should students be taught today within the academic subject related to artificial intelligence? It seems that the goal of learning is to acquire competences and skills allowing to apply AI methodology in tasks whose solution is beyond the capacity of human intellect. At the same time, it is important that the future engineer should apply knowledge and skills already mastered during the learning within his specialty, using a decision support system, which today belongs rather to narrow AI. And the narrow AI, unable to solve a problem from beginning to end, from formulation of a problem to release of project documentation, suits well this objective. The exact sciences have cumulated a huge amount of knowledge in the form of laws, represented by mathematical expressions in a closed form, therefore it is possible to create decision support systems based on the laws of nature.

The key thesis regarding learning in AI within higher engineering education, namely transport focused education, refers to integration of a human into the control loop of a complex system in which AI will be an effective decision support subsystem, identifying non-obvious dependencies and therefore assisting students to make conceptual decisions in a specific subject area. Thus, the student acquires the skills of interacting with AI. The purpose of the academic subject turns to teach the methodology and application of AI, the task of which is to reproduce, with the help of computer systems, purposeful actions carried out by a person who is aware of the laws of nature.

The methodology developed at Russian University of Transport for designing transport infrastructure facilities using AI allows solving many of the complex engineering problems. Today, the choice of a shape of the structure, of its initial parameters is carried out based on existing experience. Codes of practice almost do not give recommendations on specification of technical parameters, but only contain methods for checking already designed/built structures. That is, these are not design standards, but standards for checking the respect of previously assigned parameters. As soon as a person faces a previously unknown task, lack of experience can lead to serious mistakes.

Lack of experience in construction of high-speed rail (HSR) is a problem in Russia. There is no experience in building a whole class of tunnels in world practice, and trial design will face here great difficulties. Finally, students lack design experience. It is so necessary to adopt the approach based on the synthesis of a structure with pre-set parameters of structural behaviour that meets the standards and prevents, in a certain sense, adverse events [11]. In this case, it is not a verification of the decision made regarding its compliance with regulatory documents, but rather the design (synthesis) of the structure in new conditions, for example, of high-speed traffic.

It is AI that can support a person in assigning design parameters. The participation of AI becomes critical in above specified case of absence of design experience in new conditions.

Finally, the use of AI will be very productive in operation of structures. In this case, constant remote monitoring of the structure will generate a huge amount of information (Big Data). It is quite difficult and often impossible for a person to track and correctly interpret changes in the state of a structure, identify risks at the initial stage and prevent negative consequences.

According to generally accepted algorithm, the design process starts with initial assignment of design parameters, which are changed in space by control functions. Initially, these functions can be set as arbitrary and constant ones. As stated previously, a transition to the state space, occurs with the help of a mathematical model of the system's behaviour over time [12]. There the behaviour of the system is described, and then, using the criteria, the quality of the decision made is assessed in the space of estimates [13]. If there is a possibility to further improve the quality and/or in case of not-respect of predetermined constraints on the behaviour of the system, the control functions are corrected, and the procedure is repeated.

It is worth to note features previously highlighted in [1; 12; 13]. In the algorithm described above, AI manifests itself in several fragments [1]. First, evaluation of the construction quality does not directly follow from the description of the system; a complex mathematical model is involved between these stages. In the described case, this is a system of ordinary differential equations and partial differential equations [12]. In addition, assessment is mediated by quality functionals (criteria) in the form of double integrals [13]. The analysis of trends in the behaviour of the system and sensitivity of this behaviour to changes in control (in design parameters) cannot be comprehended by human intelligence, since it requires orientation in a multidimensional state space, which describes the behaviour of systems under different conditions. The description of the state of the system must be recorded at extremely short time intervals. This process generates an array of Big Data, the identification of patterns in which has turned now to become the traditional prerogative of AI. Since the directions of changes, mediated by fairly complex relationships and operations, are not obvious, the choice of the direction of changing the control (design parameters) in the assessment space to improve the performance of the system and respect the pre-set constraints on interaction is also beyond the control of a person.

It is also obviously that many issues should be solved on the basis of an interdisciplinary approach, in a comprehensive manner, because of the interaction between the components of a complex system considered in the framework of different disciplines.

This determines, among other things, the vector of development of competencies in the field of AI of today's and future employees of the transport sector.

Results of Experimental Learning

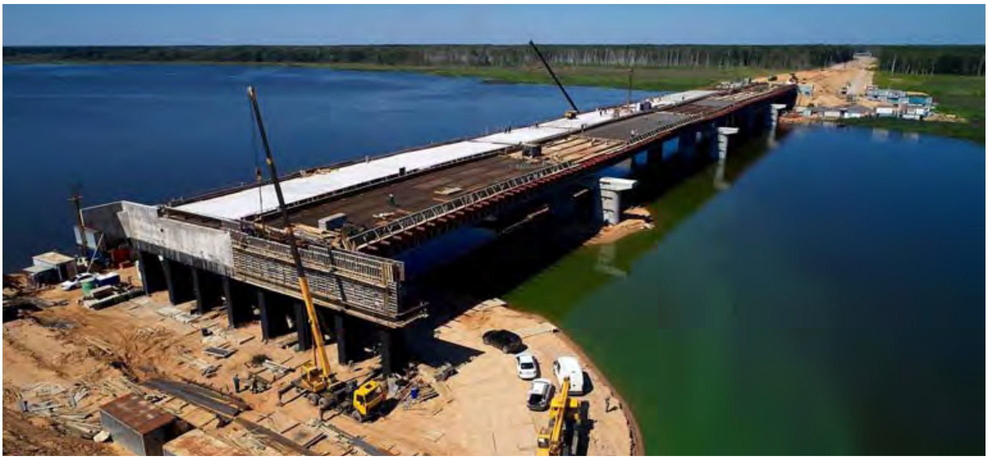
Russian University of Transport has developed a training program in the academic subject of Artificial Intelligence in transport construction for the specialty, code 23.05.06 entitled «Construction of railways, bridges, and transport tunnels». Its adoption had been preceded by experimental test of application of AI in the process of design assignments within the framework of preparing students' term papers and graduation theses.

Let us consider the process of teaching RUT students to interact with AI. Typically, the student assigns the parameters of a traditional and well-known design based on building experience

Table 1

Main parameters of steel reinforced concrete superstructure [11]

Superstructure parameters	Prototype	AI recommendations
Total weight of the superstructure, t	1985	1729
Steel beam, t	240	195
Reinforced concrete slab, t	812	621
Flexural stiffness, MN•m^2	11,2•10^5	6,45•10^5
Maximum deflection under a high-speed train, mm	5,5	7,1
Maximum dynamic moment, MN•m	20,02	20,12



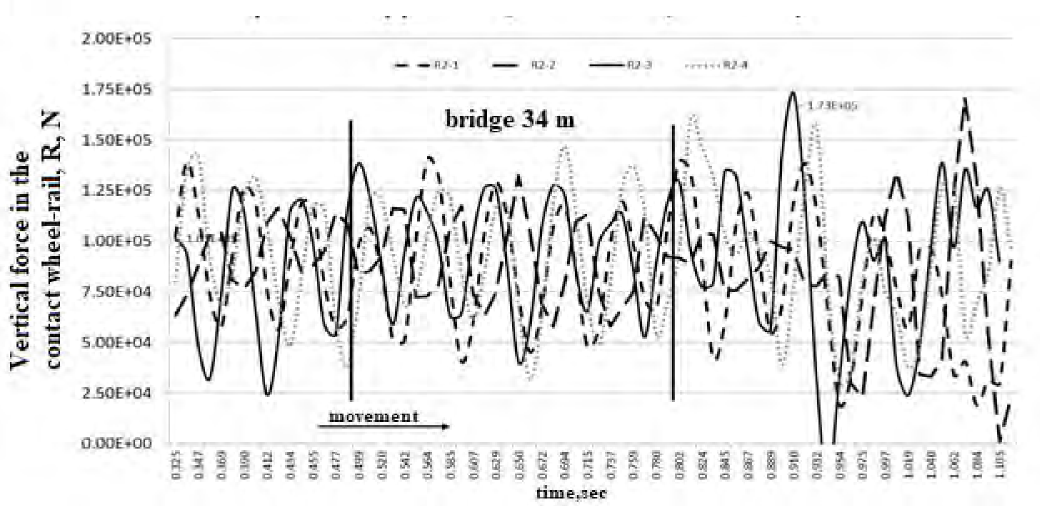
described in textbooks. The resulting design turns to be far from optimal due to numerous checks of design regarding its compliance with the standards and following numerous amendments. In addition, the student, in accordance with the norms, accepts a load model that does not reflect the actual interaction, for example, in such a complex system as «bridge–track–train».

On the contrary, with the help of AI which in that case serves as decision support system, the student can get an idea of the real interaction in a multicomponent system. Thus, the student acquires a new competence which is a systematic vision of engineering activity. That presumes conscious comprehension of its integrity, multidimensionality, phasing, interdisciplinary relationships.

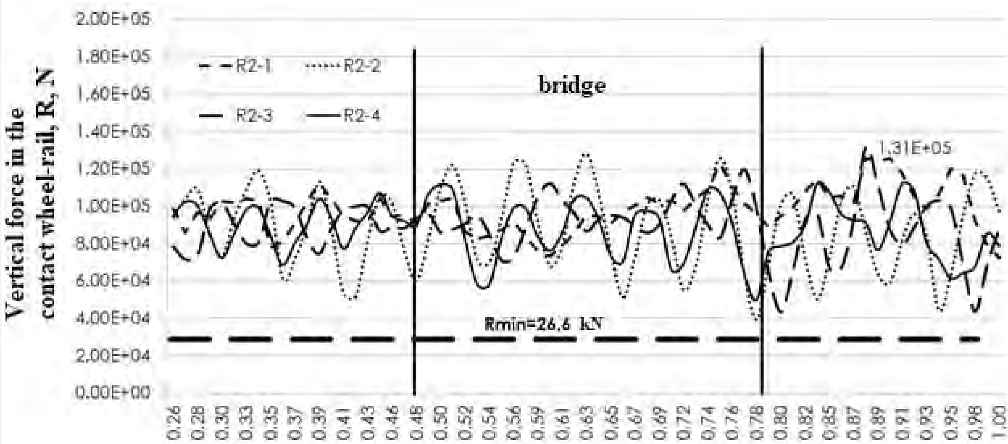
Here-after, are some examples of application of AI in the learning process (examples in more detail are described in several papers, e.g., [14]).

In practice, after a professor, using the AI software package, has issued recommendations on changing the design parameters of the length of the railway bridge beam, a student (in the described case a student obtaining qualification within the specialty «Bridges») starts making design decisions. Since the design can be optimised according to several criteria simultaneously [15], a criterion of minimum beam mass is chosen for simplicity of presentation. Optimisation is accomplished with strict respect of technological constraints regarding design parameters, constraints limiting beam deformations, vertical acceleration in the car, etc. At this stage students acquire also new competences generated through an interdisciplinary aspect and evaluation of design solutions according to several criteria, since the dynamic behaviour of the bridge and car structure is studied not only within different specialties, but also in different areas of training (23.00.00 «Technique and technology of land transport» and 08.00.00 «Technique and technology of construction»).

In the example under consideration, besides the requirement to minimise the mass of the structure, the requirement was put forward to maintain the maximum dynamic bending moment from a high-speed train, which was performed with acceptable accuracy. It was decided to implement into design control functions that give the minimum to the quality functional (total mass of the span) by reducing the thickness of the reinforced concrete slab of the roadway and the overall height of the steel beam. The results of the work are shown in Table 1. At the same time, all



Pic. 1. The force in the contact area of the wheel and the rail for the second car at a speed of 350 km/h. After the passage of the bridge, there is a lift of the wheel.



Pic. 2. The force in the contact area of the wheel and the rail after track design with the AI decision support system does not fall below the minimum allowable value of 26,6 kN.

checks according to the code of rules were completed with success. Despite the increase in deflection to 7,1 mm, it does not exceed the limits established by the standards.

Another student was working on a project of a reinforced concrete superstructure for high-speed railway, pursuing during the optimisation process the goal of reducing material consumption. In this case, the AI recommended a beam with inhomogeneous properties, since during the optimisation process, the beam deflection exceeded the allowable limit. The student made a decision to change the height of the beam and the thickness of the wall to fulfil the recommendations of AI. Reinforced concrete savings in comparison with the prototype (real project) amounted to 58 m^3.

For students with the learning profile dedicated to control of the technical condition of the railway track, a different system of criteria is used, corresponding to the tasks assigned to the bridge deck and the superstructure of the track. An AI-based decision support system proposed the optimal distribution of railway track stiffness, which ensures minimal impact on crushed stone ballast and is as uniform as possible to reduce track deterioration along its length. At the same time, a constraint was formulated to ensure continuous movement of the wheel along the rail to prevent derailment as a safety requirement (e.g., [16]). Pic. 1 shows diagrams of the vertical force in the contact of the wheels and the rail of one of the cars of a high-speed train. After the passage of the bridge, due to vibrations of the beam, rail and cars, the lift of the wheel occurs which is unacceptable. AI offered a control function on which the rigidity of the track depends. Based on this function, it is possible to select the stiffness of the spacers in the intermediate rail fastening in accordance with the AI recommendations using a piecewise linear approximation of the function. As a result, the average sleeper load was reduced by 17 %, local ballast overloads were reduced by almost two times, and most importantly, the safety constraint was met. The force in contact area for the entire time of passage through the bridge not only does not show the lift of the wheel, but also does not fall below the minimum required to ensure traffic safety (Pic. 2).

The given examples clearly show the role of AI in recommending non-obvious patterns due to a complex interaction process and multi-stage computational procedures.

SHORT CONCLUSION

Based on the results provided, it can be stated that AI is a highly demanded tool for designing new structures or known structures under new conditions, as well as for teaching students at technical universities. Experimental learning has shown the feasibility and effectiveness of the application of AI, also by students. A course for teaching students to apply use of AI in practical design activities has been developed.

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Article received 08.12.2021, revised 23.01.2022, approved after reviewing 04.02.2022, accepted 11.02.2022.