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METHODS FOR COMPUTER AIDING THE CONFIGURATION AND ASSESSMENT OF AUXILIARY MINE TRANSPORTATION MEANS

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Abstract:
Mine transportation of materials in underground mine workings is realized by mine underground railways as well as by suspended monorails or floor-mounted railway. Transportation is realized on tracks placed on the floor of working or on rails suspended to roadway support. Each transport operation must be preceded by a transport design project, made in accordance with obligatory legislation. A part of the project are traction calculations. Their implementation in a computer program allows for minimization of the possibility of errors during the configuration of suspended queues and conducting traction calculations, which consequently leads to improve the level of safety. The article discusses the modular Safe Trans Design system, supporting the design of auxiliary mine transportation. The system has been implemented in the mines of JSW S.A. The assumptions and structure of the system as well as algorithms of operation of the 'configurator of transportation sets' and 'assessment and reporting module' are presented. The method of creating an auxiliary mine transportation system project is presented. Safe Trans Design system is used in planning, organizational and training activities implemented as part of transport safety management in mining plants. Developed methods can be easily adapted to other legislations of hard coal producers' countries, where suspended monorails are used in underground auxiliary mining transportation systems.

Key words: *computer aiding system, suspended monorail transportation, traction calculations, underground mining*

INTRODUCTION

Coal is mined by two methods: surface (opencast) or underground (deep) mining. Underground mining can be divided into room-and-pillar and longwall mining. In the longwall mining, mine transportation of people and materials is realized by mine underground railways (on the main transportation routes) as well as by suspended monorails or floor-mounted railway (in a department transportation). Transportation is realized on tracks placed on the floor of working (floor-mounted rail transportation realized by transportation platforms) or on rails suspended to roadway support (suspended rail transportation realized by modular load-carrying units).

A technical restructuring of Polish mines which started in 90s last century led to intensive development of self-powered suspended monorails. Diesel engine or electric motor can be a power source. Main advantages of using self-powered suspended monorail are as follows: the transport capacity is not limited by length and branching of the route; ability to observe the route by the train operator; fast and easy elongation or shortening of the route; ease of loading and unloading; ease of suspending the different carriers; improving effectiveness of transportation (transportation of machines and mining equipment in one piece) due to high pulling force. The overall view of components of the transportation set is presented in Fig. 1.

Locomotive is coupled with other main components by tension rods. For heavy load a modular load-carrying units are used and in the case of people transport, special benches or passenger cabins are used. One of the significant features of suspended monorail is its modular structure which makes possible to adapt its configuration to the current transportation needs. On the one hand, this means a big advantage, because the configurable means of transport is dedicated to current transport needs, but it is necessary to properly select individual components.

A large number of mining transport means require streamlining of operations during variation and assessing their configuration. The proper use of extensive machinery parks in underground transport forces the appropriate, i.e. safe, selection of the components of the transportation set to specific conditions of transport, e.g. mine suspended locomotive, braking trolleys or transportation units.

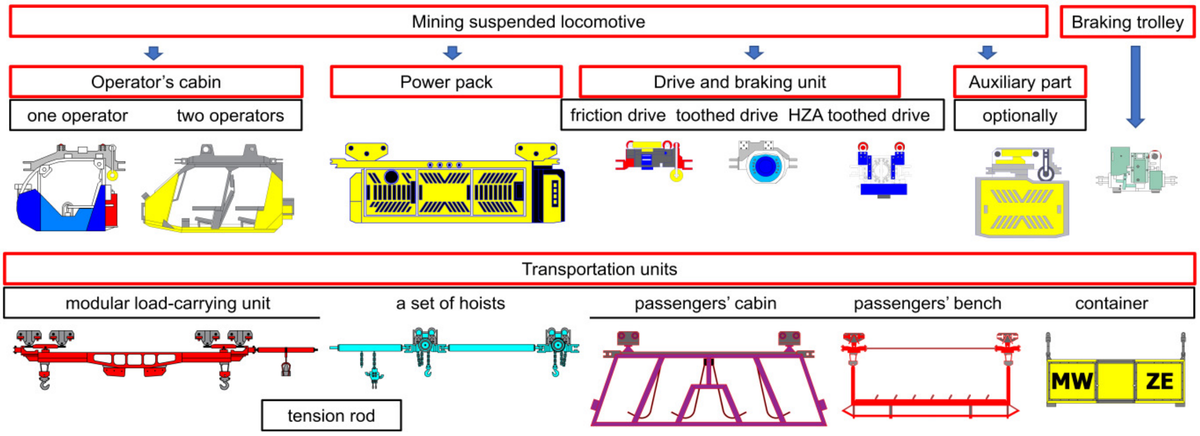


Fig. 1 Components of the transportation set

These conditions in the case of suspended transport are determined by: the inclination of the underground drivage in which the transport is carried out, as well as the parameters of the suspended route: length, profile and type of rails and load capacity of the slings. Whereby is the need for mine employees to carry out many calculations and verification analyzes that are time consuming and can generate errors caused by human factors. Analysing the current situation there is a chance for making mistakes which are associated with the following:

- Human factor issues:
  - Necessity of reviewing many documents (most often in paper version) to collect all required input data.
  - Making calculations is one of many employees' duties; long-time intervals between carry out calculations.
  - A lot of calculations required – a single report requires few tens of calculations.
  - Incorrectly assumed scope of calculations and calculations algorithm.
  - Copying the old report version with calculations and only partial updating of its content for the requirements of a new project.
- Lack of standardization of transportation means' technical-and-operational documentation, especially regarding the mining suspended locomotive's traction characteristics and load-bearing capacity of modular load-carrying unit.
- Manufacturer does not deliver all data required for calculations.
- Use of different terminology and symbols for calculations within one coal company.

LITERATURE REVIEW

There has been rapid development of auxiliary transportation systems in underground mines in Europe. This was related with underground mining restructuring where e.g. in Poland, coal will remain the main component of the energy mix in the coming years [15]. Suspended monorails are one of the main components of this system. Other underground transportation systems, which operate in underground mines, are as follows: mine underground railways, conveyors [10] or self-propelled machines. Auxiliary transportation system supports the main transport and it is used to provide the materials transportation and moving the crew to the most remote places of the hard coal working [18, 24]. Modular systems are well known in the literature, however they are related with the manufacturing industry as RMS (Reconfigurable Manufacturing System) [2, 3, 14, 22] or with the mass customization [6, 23, 25].

In the case of suspended monorail the designing process is continued in the operational phase [12, 23]. Incorrect actions during configuration (design) of transportation set may result in health hazard and can even cause fatal accidents to the people working in mines. Mine transportation belongs to the most dangerous processes. Accidents during underground transportation are the accidents were injuries to workers are most serious, what means a high accident seriousness, measured by a number of sick leave days per accident [11, 12]. Besides, the hazards, which occur during transportation operations, can affect much more people, even those who are not directly involved in transportation, but they work on the transportation routes.

Ensuring safe transportation in the mine undergrounds requires a number of engineering designing work that results in Transport System Documentation developed by mine employees, in particular by Production Preparation Departments and Mining Departments [21].

At the KOMAG Institute of Mining Technology, as a part of the European project MINTOS [8, 16], research work was carried out to develop tools supporting the verification of transport system designed in the light of safety criteria. As a result of the project, a prototype of a modular system supporting the design of auxiliary mining transport systems – Safe Trans Design (STD) was developed. The system was directed to hard coal mines and dedicated to auxiliary transport systems, using suspended and floor mounted self-propelled railways. It enabled the selection of individual components of a suspended monorail and their evaluation. Access to the system is possible via a web browser. This approach has many advantages [17]. The system has a modular structure, which makes it possible to extend it with further modules. The developed system is a form of unification and standardization during planning and creating of mining documentation of underground transport systems. There are other dedicated expert systems available on the market, e.g. used in ventilation systems [5], expert systems for risk assessment in explosive mine atmosphere [4] or dedicated for people evacuation from underground workings [1]. In Polish and world literature there are not computer programs for carrying out traction calculations for suspended monorails used in hard coal mines.

METHODOLOGY OF RESEARCH

During the software development and implementation, the following tasks were carried out:

- Development of the prototype of Safe Trans Design system.
- Two-phase verification of the correctness of the obtained calculation results: the first phase performed by software authors (during the development of the prototype), the second phase performed by specialists from mines (trial software release).
- Selection of mines for in-situ test sites – Polish coal mines from JSW S.A. and PGG S.A. coal companies.
- Appointment of testing teams responsible for carry out the test (second phase) and carry out training workshops.
- Carry out the second phase testing – based on the reference projects, the calculations were carried out parallelly, i.e. traditionally and using the system and obtained results were compared.
- Development questionnaires regarding the functionality of developed STD system prototype.
- Carry out surveys among employees from Production Preparation Departments and Mining Departments.
- Considering the results from the in-situ tests and surveys – introducing improvements to the user interface, adding new functions, correction of existing functions.
- Development of the user manual for Safe Trans Design system.
- Commercial implementation of developed STD system.

ASSUMPTIONS FOR THE STD COMPUTER AIDING SYSTEM

The following assumptions for the prototype system were developed:

- Access via any web browser – no need to install the system on local computers.
- Possibility of operation on various electronic devices: desktops, laptops, tablets, smartphones.
- Integrated data collection describing the components of transportation sets (database structure).
- Possibility to assess many variants of created transportation sets.
- Unification of the form and automatic generation of reports from the calculations carried out.
- Electronic archiving of created projects.
- Modular structure of the system.

The structure of the STD system is presented in Fig. 2.

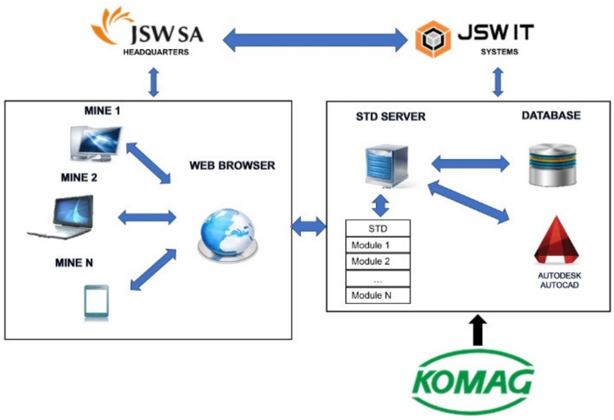


Fig. 2 Structure of the STD system

Access to the STD system is possible through any web browser installed on various electronic devices. Depending on the obtained rights, database resources can be made available selectively, i.e. the user "sees" only those means of transport that are currently in the mine machine park. Internet access to the STD system also allows its remote update, modification and remote adding of new auxiliary transport means to the database. Developed user interface and the database structure of the system provide remote access to resources and enable data flow between each thematic module. The figure shows the system integration with the AutoCAD program. It applies to the collision analysis module, which is not the subject of this article.

SAFE TRANS DESIGN – SYSTEM CHARACTERIZATION

The system allows a comprehensive assessment of the proper selection of a configured, suspended transportation set. It consists of the following modules:

- System administrator module – enables creating the users of the STD system and their authorization.
- Configurator of transportation sets – is used to include all input data to the assessment and reporting module.
- Assessment and reporting module – automatically perform calculations and creates a report based on input data from the transportation sets' configurator. Traction calculations comply with the requirement set out in [19, 21].
- The main advantages of the STD system include:
- Improved safety by minimizing the possibility of making a mistake during engineering work (selection of traction characteristics, braking and load capacity; calculation of the maximum net weight of the load; traction calculations; mutual location of components of the transportation set, etc.).
- Optimization of the selection of created transportation sets through the possibility of assessing many variants.
- Fast and error-free configuration of transportation sets.
- Automation of the traction calculation process – automatic reporting with full documentation of calculations.

Configurator of transportation sets

The purpose of the module is to configure the transportation set consisting of available components that are in the database for the logged user of the system. The following five steps must be fulfilled to configure the transportation set:

– Selection and configuration of mining suspended locomotive (STEP 1).
– Selection and configuration of braking trolleys (STEP 2).
– Selection of transportation units: heavy-duty beams, sets of hoists, cabins and passenger benches, special containers (STEP 3).
– Additional input data – necessary for traction calculations (STEP 4).
– Selection of tension rods and formation of the transportation set – mutual location of the components of the transportation set and the tension rods connecting them (STEP 5).

Fig. 3 presents the main steps of the Configurator of transportation sets.

To start the work with the STD system it is necessary to open a new project or edit the existing one. In this way one can save, modify or delete the results of the completed work. The projects are a kind of electronic archive of attachments of transport system documentation which can be used any time. It is possible to create subsequent projects, with the use of already existing as input.

STEP 1 – selection and configuration of mining suspended locomotive

The individual type of locomotive is selected from the table which contains available mining suspended locomotives. Selected locomotive will be used in current (active) project, Fig. 4.

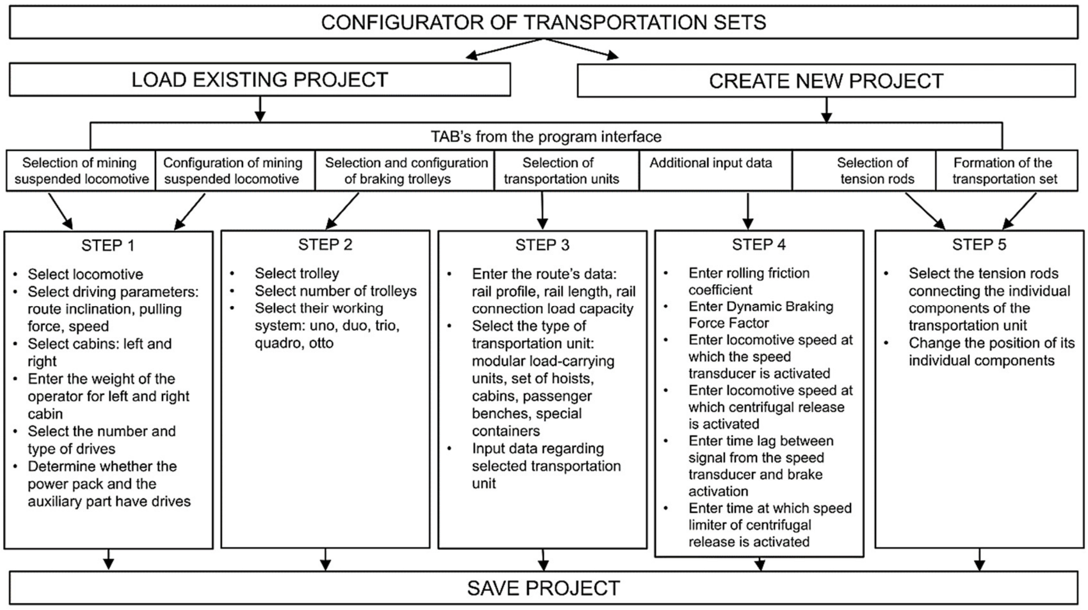


Fig. 3 Main steps of the Configurator of transportation sets

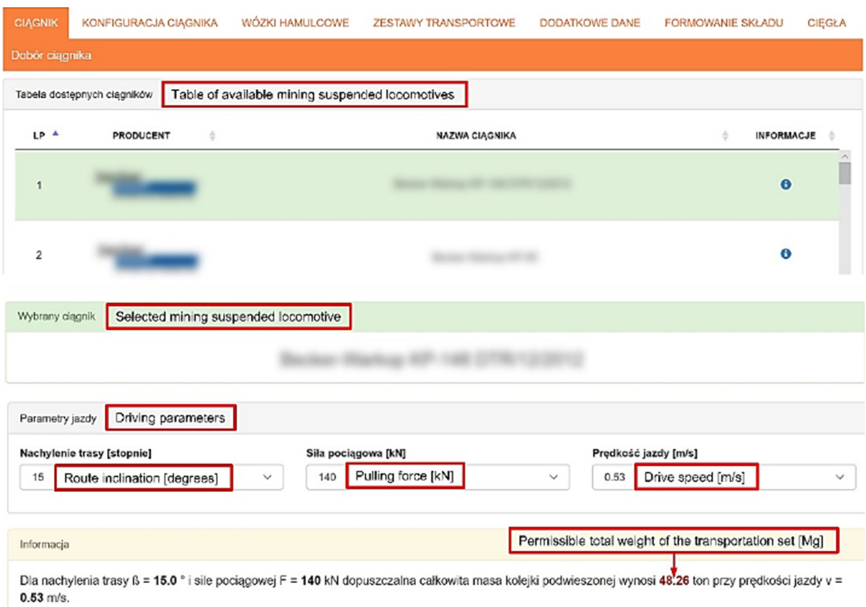


Fig. 4 STD system – selection of the locomotive (top); selection of basic driving parameters (middle); calculated permissible total weight of the transportation set (bottom)

Then one can select the maximum route inclination, maximum pulling force and optionally the speed of transportation. For such selection, based on the locomotive's traction characteristics, the permissible total weight of the transportation set is automatically calculated. Additionally, for the selected locomotive, its traction characteristics is displayed, which can be shown in a graphical form or in a tabular form.
After selecting the mine suspended locomotive, it should be configured in the following way, Fig. 5:
– Selection of cabins (left and right).
– Determining the operator's weight (separately for the left and right cab).
– Selection of the number and type of drives (for variable configurations only).
– Determining whether the power pack and the auxiliary part is equipped with drives or not (for variable configurations only).

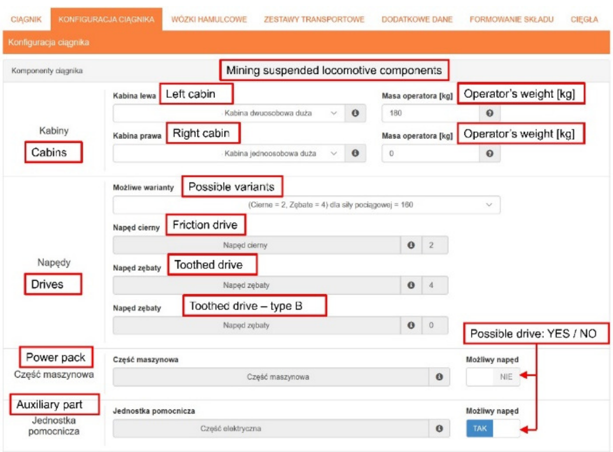


Fig. 5 Configuration of the selected mining suspended locomotive

STEP 2 – selection and configuration of braking trolleys

The input data regarding the braking trolley is entered by choosing the name, number of braking trolleys and their operational system (uno, duo, trio, quadro or otto). Braking trolleys which are in the same operational system means that activation one of them also activates the rest braking trolleys within this system. After entering input data, a dynamic graph is displayed representing the braking characteristics of the trolley or the operational system of the braking trolleys. The graph shows two curves: the upper curve (blue) determines the maximum total weight of the transportation set. The lower curve (green) defines the minimum total weight that a transportation set should have when transporting people due to the maximum permissible deceleration. For such a selection, based on the braking's trolley characteristics, the permissible total weight of the transportation set is automatically calculated, Fig. 6.

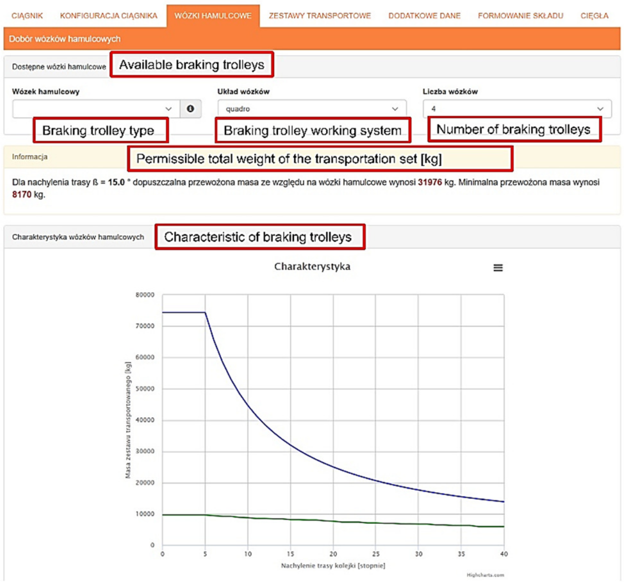


Fig. 6 Selection and configuration of braking trolleys

STEP 3 – selection of transportation units

The input data which are related with a transportation unit (modular load-bearing units, hoist sets, passenger cabs/benches and special containers) is entered through interactive, dynamic tables that are "drop down" depending on the number of transportation units used in a given project. For such a selection, based on the transportation unit's characteristics, the maximum mass of transported load is automatically calculated, Fig. 7.

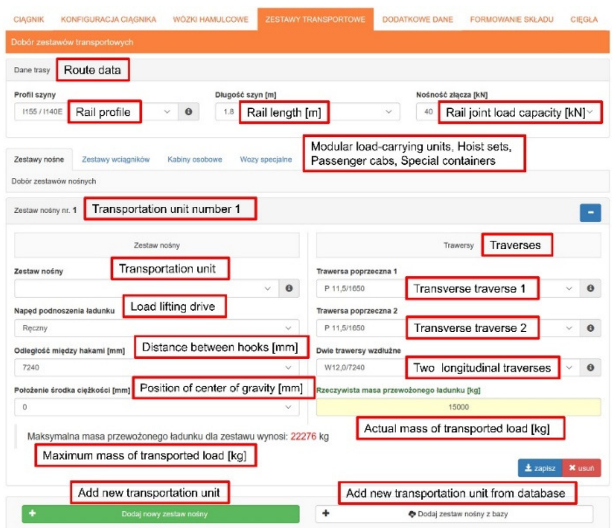


Fig. 7 Selection of transportation units

STEP 4 – additional input data

Within this step, additional data necessary to perform traction calculations are provided. The data are pre-defined for the mine suspended locomotive selected in STEP 1, but it is possible to edit it. In STEP 4, the following data is provided:

- Rolling friction coefficient – is taken into account when calculating longitudinal forces in tension rods.
- Dynamic Braking Force Factor – lowers the static braking force (default value equals 0.7).
- Locomotive speed at which the speed transducer is activated (if applicable) – vA1.
- Locomotive speed at which centrifugal release is activated – vA2.
- Time lag between signal from the speed transducer and brake activation (if applicable) – tA1.
- Time at which speed limiter of centrifugal release is activated – tA2.

STEP 5 – selection of tension rods and formation of the transportation set

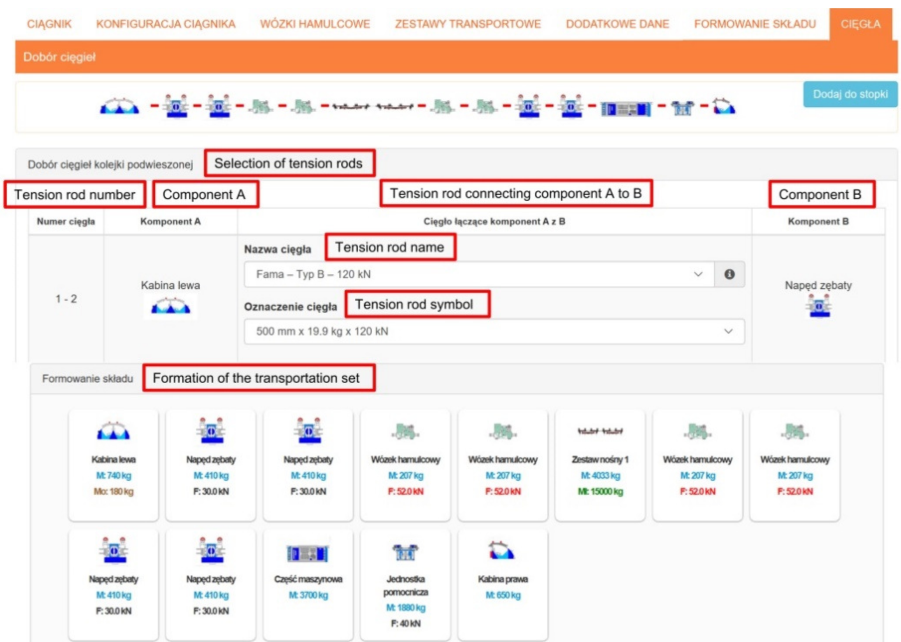
The last step is the selection of the tension rods connecting each component of the transportation units. Designer can view a sketch of the transportation set at any time during the configuration designing process. Individual components of the transportation set are represented by icons (active graphical objects). An example of transportation set's configuration formation is presented in Fig. 8. After completing the configuration, having the entire transportation set, the designer can change the position of each component, interactively dragging the selected icon (transportation's set component) to a new location. There are formal requirements and those related to the work organization in a given mine, which impose the mutual location of the components in the transportation set. For example, the braking trolleys have to be located in front of and behind the passenger cabin's set. Apart of the formal requirements, the transportation set should be configured in the way that internal forces in tension rods should be as equal as possible.

ASSESSMENT AND REPORTING MODULE

The assessment and reporting module uses input data prepared in the module of the STD system, called "Configurator of transportation sets". For the given input data (inclination of the route, length of the suspended route rails and load capacity of the suspended rail's connectors) and the configuration of mining suspended locomotive (selection of the locomotive, transportation sets and braking trolleys), the module automatically calculates the following parameters:

- Total weight of the transportation set (without transported load).
- Maximum net weight of the load transported by the transportation set – selected from minimum of the following values:
  - Maximum net weight of the load that can be transported by the mine suspended locomotive.
  - Maximum net weight of the load protected by the braking trolley/braking trolleys operational system.
  - Maximum net weight of the load that can be transported by the following transportation units: modular load-carrying units, hoist sets, passenger cabins/benches.
- Traction parameters during braking when using the following:
  - Mining suspended locomotive brakes.
  - Braking trolleys/braking trolleys operational system – including the weight of the mine suspended locomotive.
  - Braking trolleys/braking trolleys working system – without the weight of the mining suspended locomotive.

The simplified algorithm of the "Assessment and reporting module" operation is presented in Fig. 9.



Legend:
M – mass of a single suspended monorail component [kg]; Mo – mass of operator (one or two) of the suspended monorail [kg]; Mł – mass of transported load [kg]; F – pulling force (black) or braking force (red) assigned to one component [kN].
Fig. 8 Example of selection of tension rods and formation of the transportation set

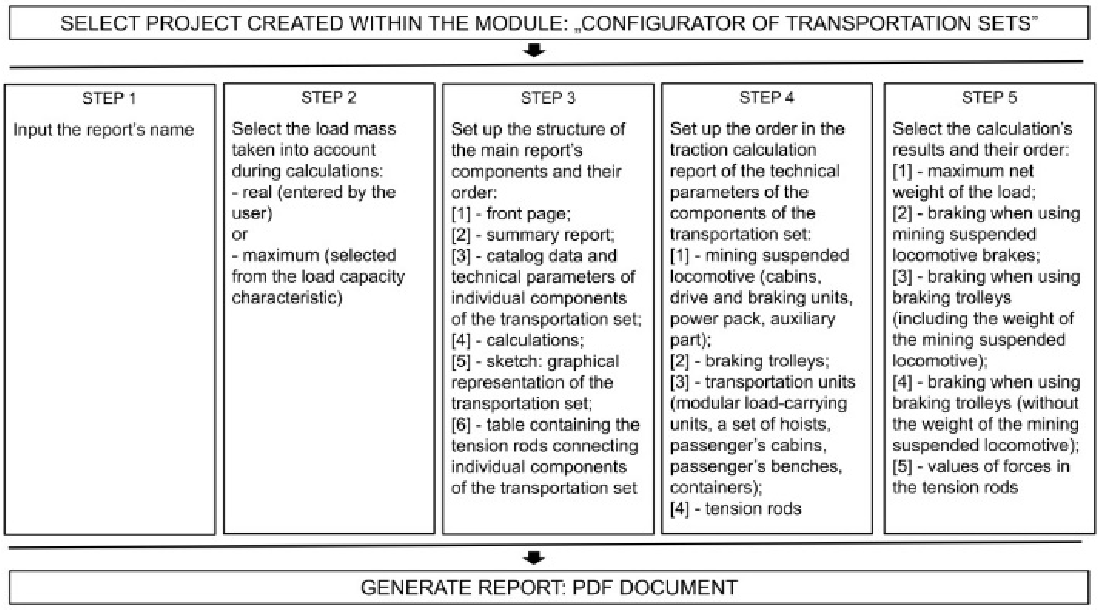


Fig. 9 Simplified algorithm of "Assessment and reporting module" operation

The following results of traction calculations are available: speed of the transportation set at which the brakes must be activated; braking energy; effective braking force; braking distance and braking deceleration. The structure of the traction calculation report allows to choose data that will appear in the report and their order. In addition, the user decides whether the calculations will be carried out for the actual load mass or for the maximum load mass (selected from the load capacity characteristics).

CONCLUSIONS

The use of the STD system supports mine services in labor-intensive calculations, which results in the orientation of engineering work carried out in the mines towards a conceptual work. The configurations of transportation sets created with the support of the STD system are optimal in terms of existing conditions and transported load masses. The innovativeness of the developed STD system is primarily concerned with understanding the essence of the problem and proposing a unique system for conducting complex work related to safe and optimal transport in underground mines. As a consequence, there is a minimization of the possibility of errors (in particular caused by a human factor) during the configuration of suspended queues and conducting traction calculations, which leads to improve the level of safety.

The access to the developed STD system via Internet platform results the improvement of the design process of transportation routes. Improvement of the system's innovation and functionality is also associated with regular training for system users, where the synergy effect is new proposals and improvements or concepts of new modules, which are then introduced to next versions of the STD system.

In the future, it is envisaged to use artificial neural networks to automate the process of configuring the transportation sets. This method is used successfully in many branches of science and industry for imaging the processes and for their control [7, 8, 13, 20, 22].

Described STD system is used on the basis of Polish legislation, however it can be adapted to the legal requirements in other countries in which the presented types of auxiliary mining transportation systems are operating.

REFERENCES

[1] V. Adjiski, D. Mirakovski, Z. Despodov, S. Mijalkovski. "Simulation and optimization of evacuation routes in case of fire in underground mines", *Journal of Sustainable Mining*, vol. 14, issue 3, pp. 133-143, 2015.

[2] T. Alix, Y. Benama, N. Perry. "A framework for the design of a Reconfigurable and Mobile Manufacturing System", *Procedia Manufacturing*, vol. 35, pp. 304-309, 2019.

[3] N. Brahimi, A. Dolgui, E. Gurevsky, A. R. Yelles-Chaouche. "A literature review of optimization problems for reconfigurable manufacturing systems", *IFAC-PapersOnLine*, vol. 52, issue 13, pp. 433-438, 2019.

[4] J. Cheng, J. Mei, S. Peng, C. Qi, Y. Shi. "Comprehensive consultation model for explosion risk in mine atmosphere-CCMER", *Safety Science*, vol. 120, pp. 798-812, 2019.

[5] J. Cheng, Y. Wu, H. Xu, J. Liu, Y. Yang, H. Deng, Y. Wang. "Comprehensive and Integrated Mine Ventilation Consultation Model – CIMVCM", *Tunnelling and Underground Space Technology*, vol. 45, pp. 166-180, 2015.

[6] O. Ezzat, K. Medini, X. Boucher, X. Delorme. "Product and service modularization for variety management", *Procedia Manufacturing*, vol. 28, pp. 148-153, 2019.

[7] D. Jasiulek, K. Stankiewicz, M. Woszczyński. "Intelligent self-powered sensors in the State-of-the-Art control systems of mining machines", *Arch. Min. Sci.*, vol. 61 (4), pp. 907-915, 2016.

[8] Jasiulek, Dariusz; Bartoszek, Slawomir; Perutka, Karel; et al.. *Acta Montanistica Slovaca,* Volume24 , Issue: 4 , Pages: 2019, 391-401

[9] J. Karliński, M. Ptak, P. Działak, E. Rusiński. "The approach to mining safety improvement: Accident analysis of an underground machine operator", *Archives of Civil and Mechanical Engineering*, vol. 16, issue 3, pp. 503-512, 2016.

[10] B. Karwat, R. Machnik, J. Niedźwiedzki, M. Nogaj, P. Rubacha, E. Stańczyk. "Calibration of bulk material model in Discrete Element Method on example of perlite D18-DN", *Maintenance and Reliability*, vol. 21 (2), pp. 351-357, 2019.

[11] Kovanič, Ľ.: Possibilities of terrestrial laser scanning method in monitoring of shape deformation in mining plants. *Inżynieria Mineralna*. 31, 2013, 1, 29-41, ISSN 1640-4920.

[12] Kovanič, L., Blišťan, P., Zelizňakova, V., Palkova, J., Baulovič, J. : Deformation investigation of the shell of rotary kiln using terrestrial laser scanning (TLS) measurement, *Metalurgija*, vol.58, nr. 3-4, str. 311-314, 2019. https://hrcak.srce.hr/218411

[13] M. Latos, K. Stankiewicz. "Studies on the effectiveness of noise protection for an enclosed industrial area using global active noise reduction systems", *Journal of Low Frequency Noise Vibration and Active Control*, vol. 34 (1), pp. 9-20, 2015.

[14] I. Maganha, C. Silva, L. M. D. F. Ferreira. "Understanding reconfigurability of manufacturing systems: An empirical analysis", *Journal of Manufacturing Systems*, vol. 48, part A, pp. 120-130, 2018.

[15] A. Manowska, K. Tobór Osadnik, M. Wyganowska. "Economic and social aspects of restructuring Polish coal mining: Focusing on Poland and the EU", *Resources Policy*, vol. 52, pp. 192-200, 2017.

[16] MINTOS European Project: Improving Mining Transport Reliability. *RFCS Coal RTD* Programme, contract No. RCR-CT-2007-00003, 2007÷2010.

[17] C. Newman, Z. Agioutantis, N. Schaefer. "Development of a web-platform for mining applications", *International Journal of Mining Science and Technology*, vol. 28, issue 1, pp. 95-99, 2018.

[18] B. Polnik. "Tests of the HK-1 Module of the Mobile Mining Machine", *ECS Transactions*, vol. 95, No 1, pp. 389-396, 2019.

[19] P. Bozek. Robot path optimization for spot welding applications in automotive industry. *Tehnički Vjesnik - Technical Gazette*. Vol. 20, No. 5, pp.913-917, 2013.

[20] D. Prostański, M. Vargová. "Installation optimization of air-and-water sprinklers at belt conveyor transfer points in the aspect of ventilation air dust reduction efficiency", *Acta Montanistica Slovaca*, vol. 23, issue 4, pp. 422-432, 2018.

[21] Regulation of the Minister of Energy. "On detailed requirements for conducting underground mining plant operations", Journal of Laws of 2017, item 1118, 2016.

[22] K. Stankiewicz, D. Jasiulek, J. Rogala-Rojek, S. Bartoszek. "Selected, state-of-the art mechatronic systems in polish underground mining industry", ISARC 2013-30th International Symposium on Automation and Robotics in Construction and Mining. Held in Conjunction with the 23rd World Mining Congress, 2013.

[23] J. Tokarczyk. "Method for virtual prototyping of cabins of mining machines operators", *Arch. Min. Sci*., vol. 60, No 1, pp. 329-340, 2015.

[24] Baranov M., Bozek P., Prajova V., Ivanova T., Novokshonov D., Korshunov A. Constructing and calculating of multistage sucker rod string according to reduced stress. *Acta Montanistica Slovaca*. Vol. 22, no. 2,pp. 107-115, 2017.

[25] M. Windheim, N. Gebhardt, D. Krause. "Towards a Decision-Making Framework for Multi-Criteria Product Modularization in Cooperative Environments", *Procedia CIRP*, vol. 70, pp. 380-385, 2018.

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