

# PROPOSAL OF OPERATIONAL CONCEPT FOR BULK SUBSTRATES TRANSPORT BY FREIGHT TRAINS AND ITS APPLICATION WITHIN CASE STUDY OF AGGREGATE TRANSPORT FOR CONSTRUCTION OF VLACHOVICE DAM

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**ABSTRACT.** Railway freight transport represents an advantageous way for regular transport of bulk substrates. As a result of changes within the industry and energy sectors as well as in the field of consumer behaviour, such business cases decline significantly. Nevertheless, transport such of the characteristic have being (and will be) still realized however, in addition, quantities of transported goods will be known in advance – as a part of major construction or environmental remediation projects.

In the period of 2020–2021, the Department of Transporting Systems in the CTU in Prague, Faculty of Transportation Sciences prepared the study “Vlára, Vlachovice Hydraulic Structure, Logistic Study of Material Transport for the Dam Construction” for the state enterprise Povodí Moravy (the Morava River Basin). Among other things, the study dealt with transport of more than 2.5 million tonnes from two quarries to the construction site of the Vlachovice dam by goods trains (the Vlachovice dam will be built in Moravia – the eastern part of the Czech Republic). It was necessary to determine an optimal route of the goods trains, their parameters and general operating concept so that the transport costs would be minimised and, concurrently, the transport performance would be as high as possible.

This paper sets itself a goal to present a general procedure and principles for proposal of freight trains for a business case characterized by long-term and regular transport of large quantities of goods. For the stated case study, transport technology in the railway station Bohuslavice nad Vlárí is discussed in detail.

**KEYWORDS:** Railway freight transport, bulk substrate, operating concept, Innofreight technology, Vlachovice Hydraulic Structure.

## 1. RAILWAY FREIGHT TRANSPORT AND BULK SUBSTRATES TRANSPORT

Railway freight transport represents an advantageous way for regular transport of bulk substrates. As a result of changes within the industry and energy sectors as well as in the field of consumer behaviour, such business cases decline significantly. Nevertheless, transport such of the characteristic have being (and will be) still realized however, in addition, quantities of transported goods will be known in advance – as a part of major construction or environmental remediation projects (construction of dams, power stations, transport infrastructure, pipelines; restoration of areas after mineral extraction, removal of soil contaminated by toxic substances).

Both railway and water transport are together considered as a sustainable way of transportation. Sustainability parameters may be various (for example greenhouse gas emissions, dependence on fossil fuels, impacts of transport accidents) and are of different importance. Some of them may be considered according to extents of so-called external costs; at the same time, it is necessary to perceive positive benefits of

individual kinds of transport (for example economical and social development) [1]. Sustainable development of transportation was solved e.g. within the scope of FreightVision project [2].

In a specific business case, a rail freight carrier’s revenue depends particularly on the type of rail wagons used, quantity (mass) of goods transported in the train, and chargeable distance (which may not coincide with actual distance travelled) plus any possibly added services. From the viewpoint of costs for freight train running, constant items are: a railway traction vehicle(-s) – its/their depreciation and maintenance costs, costs of energy required for its movement, driver’s personal costs, and costs of covering price of the railway allocation body for allocating and using the railway infrastructure to a specific train. That is why, both carrier and carriage orderer strive to make the freight train carries as much goods as possible.

At solving a task of ensuring transport between two points, an optimal train route is sought for. In defiance of the dense railway network in the Czech Republic, usually no more than two actual options are considered so this preparation phase of transport is not

included in detail in this paper. However, determining parameters of train units providing transport and proposing an operating concept for successful management of the given business case represent more demanding task.

## 2. OPERATIONAL CONCEPT OF TRAINS CARRYING KNOWN QUANTITY OF BULK SUBSTRATE

### 2.1. QUANTITATIVE PARAMETERS OF GOODS TRAIN

Before proper proposing an operating concept of goods trains for a specific business case, it is necessary to determine quantitative parameters of the train, in particular, a maximum amount of freight carried in the train and maximum running speed. For most of bulk substrates – in view of their high (powder) volumetric mass – the maximum transported load weight is determinative.

The maximum quantity of goods that can be loaded into one rail freight wagon or into one exchangeable transport unit (container, swap body) is based on the comparison of the loading (bulk) apparent density of the goods and the apparent density of the space intended for loading the goods. For solid goods of the bulk material type (unlike liquids), it is important to consider the bulk apparent density that is calculated from the bulk apparent density in the compact state using the swell coefficient. The swell coefficient indicates a multiple of volume increase of bulk material of a given weight that normally takes up in normal bulking without any subsequent compaction compared to the compact state of the material (with minimum air gaps). The larger particle size fraction of the bulk material and the smaller the fraction (min/max grain size), the larger the swell coefficient. If the loading (bulk) apparent density is greater than the apparent density of the space intended for loading the goods, the weight of the goods to be transported is decisive.

Determining a type of wagons to be assembled into a train or selecting specific logistics technology represent another task. For transports where quantities of goods to be transported (it means duration of a contract) are known in advance, it is usually advantageous to use flat wagons with transport units (containers, swap bodies). Advantages of separating the wagon from the transport unit are as follows:

- A wagon must meet very stricter (safety) requirements than a transport unit and, therefore, it is a subject to more frequent and demanding inspections and maintenance.
- In particular, the wheelsets and bogies of the wagon are subject to more wear and tear than a transport unit and are therefore subject to more frequent and, therefore, it is a subject to more frequent and demanding inspections and maintenance.

- From the viewpoint of investment costs (it means depreciation too), a wagon is more expensive than a transport unit.
- Unification of the carrier's rolling stock of trailers – so, need for a smaller absolute number of reserve trailers and their significantly simpler maintenance (hence lower operating costs).
- At the end of a contract or when at parameters changing, transport units can be easily replaced and any wagon can be used after loading with another type of transport unit for another contract, so it still earns money for its owner (a carrier).
- If the wagon must be taken out of service for inspection or maintenance, transport units can be transferred to another wagon and the transport can continue smoothly.

After single preparation phase of the transport, the maximum quantity of goods to be transported in one wagon should be known depending on the railway line category (the load carrying capacity of the line) and max. running speed. Flat wagon of modern design intended exclusively for haulage of transport units (containers, swap bodies) usually are of the maximum permitted speed of  $120 \text{ km h}^{-1}$  when empty and  $100 \text{ km h}^{-1}$  when loaded or  $100 \text{ km h}^{-1}$  at all times. The maximum load weight of the goods depends on the type of used transport units and their arrangement on a vehicle (load transfer to the individual axles). This kind of wagons usually cannot be included in a train without transport units so they have to be loaded with ballast (dead weight) in such the case. This is due to low dead weight of such wagons which could cause the wagon to derail due to the traction and braking forces in the train during its trip.

In the next step of the transport preparation, it is necessary to find out parameters of the railway infrastructure affecting length, speed, and weight of freight trains on their expected route and line capacity. In particular, it includes a number of tracks, line speed, compatibility, maximum permitted train length according to length of station running tracks, decisive longitudinal gradient, and possibility of using dependent electric traction (and the type of railway traction system in a case of its existence). The data must be determined for individual quasi-homogeneous sections of the train route. Then, the output represents train composition within individual sections – it means a number and type of traction vehicles, number of wagons, and maximum train speed. This also results in the maximum mass of freight transported in a single train.

### 2.2. PROPOSAL OF CONCEPTION OF OPERATION

For the proposal of the conception of the operation, a qualified estimation of train running times within individual route sections is essential – for both directions: for loaded rake there and return empty ones. If

freight trains of similar parameters (especially weight, and number and type of traction vehicles) are operated on the line sections in question their journey times can be used with advantage. Otherwise, it is appropriate to simulate the train running based on the motion equation of the train of the assumed parameters. For estimating travel times, the authors of the paper recommend to consider stopping the train at all operating posts suitable for overtaking or crossing the given train even though most of the operating posts will be passing in normal operation. It creates a reserve to cover various operational contingencies and, then, the proposed conception of operation will be stable. For this purpose, it is necessary to determine duration of necessary technological operations during the train route (e.g. traction vehicles changing). Furthermore, it is necessary to analyse in detail the theoretical diagram of train running valid at the time of the business case realizing and propose train routes within the theoretical diagram of train running and optimum number and parameters of the trains – for both directions of train movement. If it is necessary to shorten journey times in some sections to ensure the operation of other trains it is possible partial using of the journey time reserves (see above) realising the increased probability of timetable instability. If the timetable is not yet known at the time of the business case it is possible to estimate the differences from the current situation within the scope of discussions with the carriers of existing passenger and freight trains and, further, in the case of passenger trains, from the transport service plans of individual regions and the whole country (the Czech Republic). The operational concept proposal is completed by a proposal of train circuits resulting not only in a number of trains required but also in daily train movements, daily transport volume (in metric tons), and transport capacity (in tonne-kilometres [tkm]).

### 3. CASE STUDY OF OPERATIONAL CONCEPT OF AGGREGATE TRANSPORT FOR CONSTRUCTION OF VLACHOVICE DAM

#### 3.1. VLACHOVICE HYDRAULIC STRUCTURE AND TRANSPORT OF MATERIALS FOR DAM CONSTRUCTION

The Vlachovice hydraulic structure (dam) is situated in the Zlín Region in the eastern part of the Czech Republic near the Slovakia border and it will be stretched particularly on Vlára watercourse. Water retention and drawing for following treatment into drinking water represent the main purpose of the dam. The dam is designed to retain 29.1 mil. m<sup>3</sup> of water. The structure is designed as a gravity dam with height of up to 40 m. The construction of the dam will require 1 352 mil. m<sup>3</sup> of various materials. In the period of 2020–2021, the Department of Transporting Systems

in the CTU in Prague, Faculty of Transportation Sciences prepared the study “Vlára, Vlachovice Hydraulic Structure, Logistic Study of Material Transport for the Dam Construction” [3] for the state enterprise Povodí Moravy (the Morava River Basin). According to the above-mentioned study, authors succeeded in proposing transport of 1 024 mil. m<sup>3</sup> of aggregate (grain size up to 350 mm) from quarries to the depots situated near the dam by railway transport. So, negative environmental impacts of transport will be significantly less serious than in case of road transport. For this purpose, restored operation on a part of the siding from the Bohuslavice nad Vlárí station to the former Vrbětice warehouse [4] and its extension in several variants were proposed within the scope of the aforementioned logistic study.

In the study, InnoFreight technology [5] was chosen as a wagon type or rather logistics technology. Within this technology two-piece flat wagons InnoWaggon of 80 feet in length with XM containers of 24 m<sup>3</sup> in volume were chosen for this business case. Thus, the InnoFreight technology allows to take advantage of possibility to separate a railway wagon and transport unit.

With regard to requirements for aggregate unloading and loading during day hours, so-called night jump transport was chosen at which two loaded trains one by one leave two quarries after 10 p.m. for the unloading point while four trains work again in the opposite direction for the loading point. Regardless of choice of quarries, it is expected that both loaded and empty trains will run to/from Bohuslavice nad Vlárí station from/to Staré Město u Uherského Hradiště station.

In the viewpoint of train parameters, it can be stated that train length is not a major limiting element. On the contrary, weight standard (maximum load that can be attached behind a traction vehicle) whose lowest value belongs to the Bojkovice – Slavičín section on the line Vlárský průsmyk state border – Staré Město u Uherského Hradiště represents the key parameter. This railway line is also restrictive from the viewpoint of safe passage capability of a rail vehicle since its entire length corresponds to line load class C3 (i.e. a maximum weight of 20 t per axle).

Each train consists of seven loaded wagons, transport weight achieves 1,078 metric tons, i.e. up to 840 metric tons of material transported per train. The proposed operating technology creates the need for eight rakes, i.e. a total of 28 InnoWaggon. The running time of the wagons (rakes) represents 24 hours and the transport volume is 3 360 metric tons per day. The line section Uherské Hradiště – Bojkovice město is heavily loaded with regional passenger rail transport and the insertion of freight train routes at 05 AM–10 PM would be quite problematic. Trains routes were inserted into the diagram of train running so that trains pass each other on double-track lines and do not need to cross on any single-track section. Trains positions in the diagram of train running are

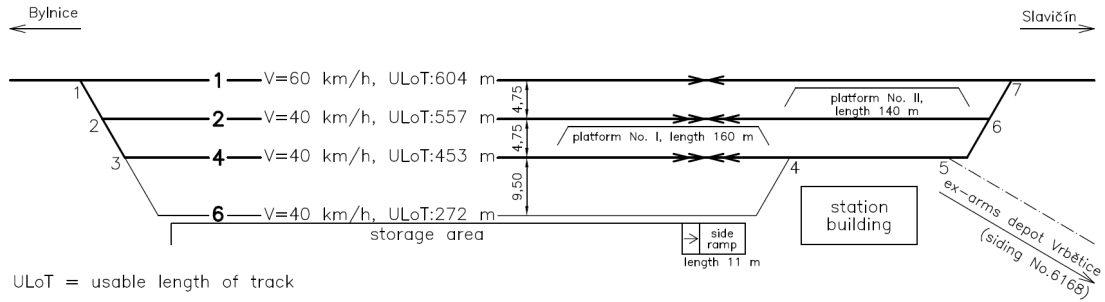


FIGURE 1. Bohuslavice nad Vlárí station track layout (appendix No. 6.3. of [3])

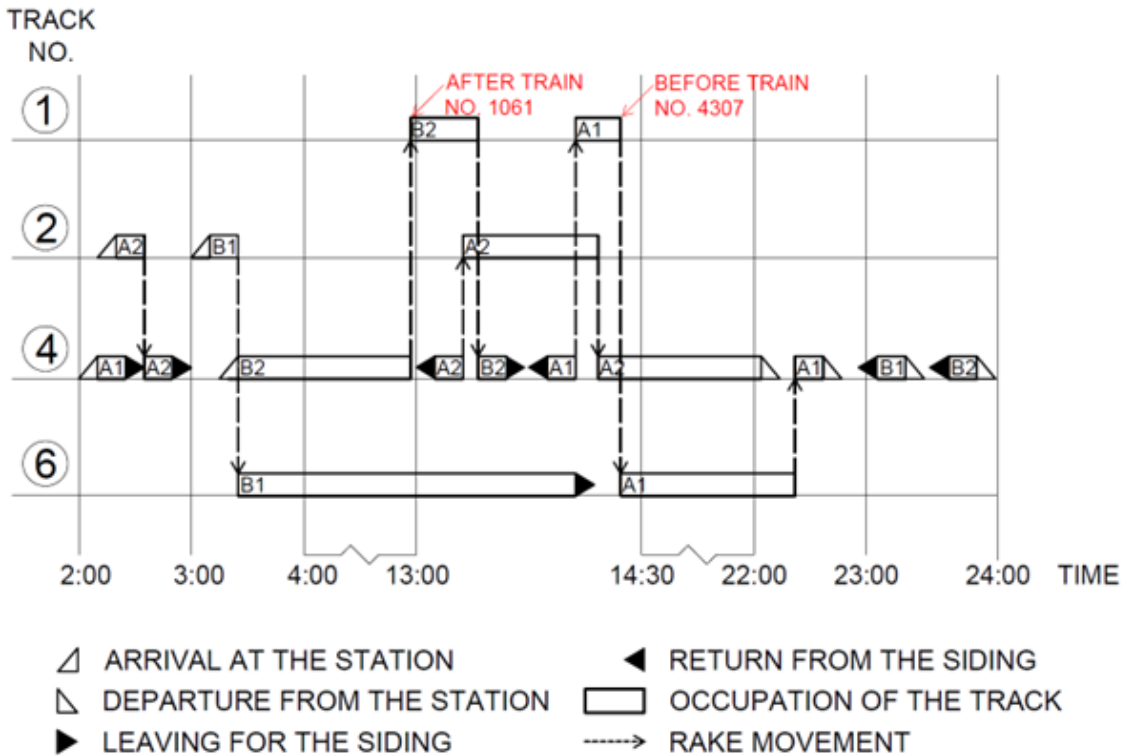


FIGURE 2. Handling of rakes at the Bohuslavice nad Vlárí station.

set so that the pairs trains arrive to the Bohuslavice nad Vlárí station with a mutual time gap of at least 60 min.

### 3.2. TRANSPORT TECHNOLOGY AT BOHUSLAVICE NAD VLÁŘÍ STATION

Aside from determining the train routes and their positions in the diagram of train running, the study [3] included also the transport technology of operation with rakes at the Bohuslavice nad Vlárí station incorporating also the siding for the deposit of material for construction of the Vlachovice dam connecting to the public connected with the railway network. The Bohuslavice nad Vlárí station currently consists of three running tracks and one service track (see diagram in Figure 1). To ensure standard train operation in this station, the running track No. 1 must always remain

free for the passage of trains and, during the time of train crossings, also the running track No. 2. The running track No. 4 will be used exclusively for entry and exit of rakes to the siding – connection of the siding to this track (via switch No. 5) represents a reason for that. The service track No. 6 will be intended for the staging of rakes waiting to enter the siding or for the arrival of empty rakes from the siding. The transport technology will be simplified by allowing departures to the siding directly from the service track No. 6. At the point of material unloading from the rakes at the end of the siding, this study proposes construction of two dead-end tracks so that two rakes could be unloaded at the same time.

Handling of rakes at the Bohuslavice nad Vlárí station is indicated on the diagram in Figure 2 and will be realized as follows: two trains from the A quarry

(marked A1 and A2) will arrive in succession (so-called on answer-back signal) at the Bohuslavice nad Vláří station at 02 AM on the tracks No. 2 and No. 4. The rake A1 leaves the track No. 4 as soon as possible for the siding. Then, the rake A2 will be moved to the track No. 4 and also leaves for the siding when the siding section becomes empty. The station tracks No. 2 and No. 4 will be released by 03 AM. Two trains from the B quarry (marked B1 and B2) will arrive at the station in succession in the time period 03 AM–04 AM on answer-back signal (again on the tracks No. 2 and No. 4). Then, the B1 rake will be moved to the service track No. 6 while the B2 rake will remain out of operation on the running track No. 4. Both rakes will await for unloading of the rakes A1 and A2 and their return from the siding to the station.

Simultaneous stay of three rakes in the station around 01 PM represents the most technological demand. The rake B2 will be moved from the track No. 4 to the track No. 1 before entry of the rake A2 from the siding into the station while the rake A2 will be moved to the track No. 2 immediately after its arrival into the station. Afterwards, the rake B2 returns to the track No. 4 from the track No. 1 and departs to the unloading point on the siding. When it will reach the unloading point on the siding, the rake A1 will be dispatched from the unloading point with empty wagons. Immediately after its arrival at the station on the track No. 4, it will be moved to the track No. 1. Subsequently, the rake B1 will depart from the service track No. 6 via the running track No. 4 to the siding. After its departure to the siding, the rake A1 will be moved from the track No. 1 to the track No. 6 and the rake A2 will be moved from the track No. 2 to track No. 4. This manipulation can be carried out during breaks between the passage of other trains through the station.

The rakes A1 and A2 will remain out of operation in the station on the tracks No. 4 and No. 6 until 10 PM. Around this time, these rakes will be dispatched as trains in the direction to Staré Město u Uherského Hradiště. When the station is emptied, the rakes B1 and B2 will be withdrawn from the siding and, after appropriate technological procedures, will be dispatched as trains also in the direction to Staré Město u Uherského Hradiště.

#### 4. CONCLUSION

In the introduction of this paper, rail freight transport was introduced as a suitable mode of transport for solving specific types of business cases that are not often mentioned in the professional literature – for the transport of bulk substrates with known volume of transported goods. Further, input parameters, limiting conditions, and the procedure for planning the conception of the operation of trains that will be applied to such types of presented transport.

The transport of aggregate from two quarries for the construction of the dam of the Vlachovice hydraulic

structure in the East Moravia was presented as a specific case of such the business case. The design of the conception of the operation for this business case was prepared for the state enterprise Povodí Moravy (the Morava River Basin) by the Department of Transporting Systems in the CTU in Prague, Faculty of Transportation Sciences [3]. In the above-mentioned study, it was possible to propose the transport of 1 024 million m<sup>3</sup> of aggregate from the quarries to the depots near the dam construction site by the railway transport. It was proposed to resume operation on the siding coming from the Bohuslavice nad Vláří station. Innofreight technology was chosen as the type of wagons and logistics technology in the study.

Furthermore, the paper describes in detail the optimal transport technology in the Bohuslavice nad Vláří station proposed in this study. It includes movements of the rakes between individual station tracks and their departures to and arrivals from the siding under the constraining conditions resulting from the preservation of standard railway operation in the station and from the configuration of the track facility station.

The transport concept chosen in this study is optimal both in the terms of the required railway vehicles and the transported material. The rakes are interchangeable, the proposed technology does not require any investment in the public railway network and does not restrict the operation of long-distance or regional passenger trains. Successful implementation is conditioned by preliminary negotiation with the infrastructure manager (Správa železnic, state organisation) so that no closure would be planned on the transport route during this time and loading ban would be declared for the Bohuslavice nad Vláří station in the period of material transport; there must also be no reduction of the track at the Bohuslavice nad Vláří station.

This study “Vlára, Vlachovice Hydraulic Structure – Logistic Study of Material Transport” represents also the evidence that railway has an irreplaceable place in the transport of bulk substrates and its use will lead to reduction of negative impacts of transport on the environment.

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