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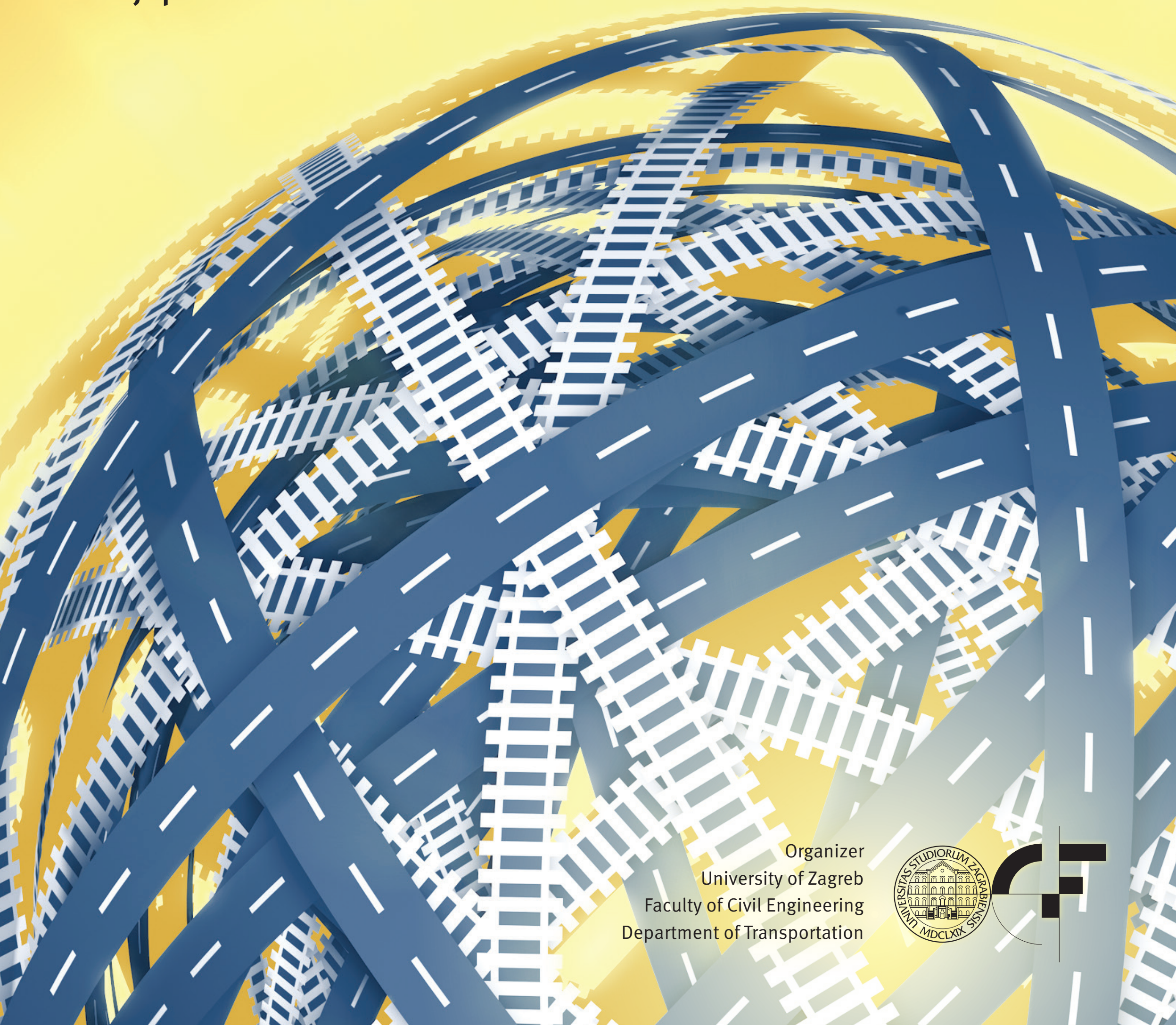
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



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ANALYSIS OF POSSIBILITIES TO INCREASE THE CAPACITY OF M202 ZAGREB-RIJEKA RAILWAY LINE ON SECTION OGULIN-ŠKRLJEVO

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Abstract

The Port of Rijeka is the main Croatian port within the TEN-T network. This largest Croatian port and third largest city in Croatia, the city of Rijeka, are connected with the rest of Croatia and Europe by main railway line M202 Zagreb-Rijeka (part of the Mediterranean corridor RH2). The line capacity is limited to approximately five million tons per year. This is because of its poor technical and technological features which are mostly a direct consequence of rolling terrain of Rijeka hinterland from Ogulin to Škrljevo. From the Port of Rijeka development plans, whose implementation is under way, the importance of this railway line for freight traffic is expected to increase significantly. A number of solutions to increase the capacity of the railway section Ogulin-Škrljevo have been proposed during the last decades. However, they have not yet developed beyond the level of studies and preliminary designs.
This paper presents an overview and comparison of the technical and technological characteristics of the existing railway section and several proposed solutions to increase its capacity: complete reconstruction of single track line with the introduction of more favourable horizontal and vertical elements, construction of a new double track on the most critical track subsection, and track upgrade by construction of a second track with a partial reconstruction of the existing. The objective of this analysis is to determine the most economic development of analysed railway section, harmonized with the development of the Port of Rijeka and the Rijeka railway junction, as well as other parts of the Rijeka traffic route.

Keywords: Port of Rijeka, railway line Ogulin-Škrljevo, freight capacity, reconstruction, upgrade, variant analysis

1 Introduction

The Port of Rijeka is the main Croatian port within the TEN-T network. This largest Croatian port and third largest city in Croatia, the city of Rijeka, are connected with the rest of Croatia and Europe by main railway line M202 Zagreb-Rijeka (part of the Mediterranean corridor RH2) [1]. The City of Rijeka is currently implementing Rijeka Gateway project or Rijeka traffic route redevelopment project. This is a complex development program which aims at redeveloping port/city interface in order to reconcile the port operation requirements and the city urban and public needs, and improving the port traffic connection with the international road and railway corridors [2].

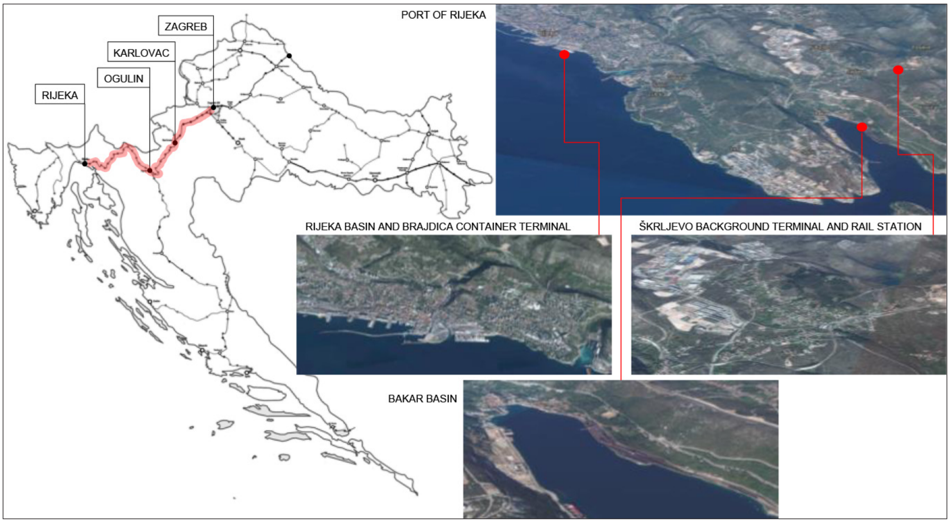

Figure 1 Main rail line M202 and Port of Rijeka Basin

The development and modernization of the Port is not accompanied by concurrent development of both road and railway infrastructure of Rijeka hinterland. This statement is best shown through the following historical data on the amount of freight rail transport. The share of railway cargo transport with the source and destination in the Port of Rijeka in the 1990's amounted to about 90%. However, construction of the new motorway diverted much of the cargo to the road transport. Today, the railway participates in delivery/dispatch of goods with approximately 20-25% (Figure 2, left) [3], and realized freight transport on rail section Ogulin-Rijeka has dropped to a third of the value achieved thirty years ago (Figure 2, middle) [4, 5, 6]. The Port of Rijeka development strategy is to increase the port present capacity of about 10 million tons of dry cargo to around 20 million tons by the year 2017. Together with planned liquid cargo, port capacity should amount to 45 million tons. Planned major investments in the Port development by 2030 should further increase its capacity to over 30 million tons of dry cargo, i.e. to a total of over 55 million tons. For the purpose of this analysis, it can be assumed that the cargo operations in Ports railway stations (Rijeka, Rijeka Brajdica, Bakar, Figure 1), will amount to 12 million tons by the year 2045 (Figure 2, right) [6].

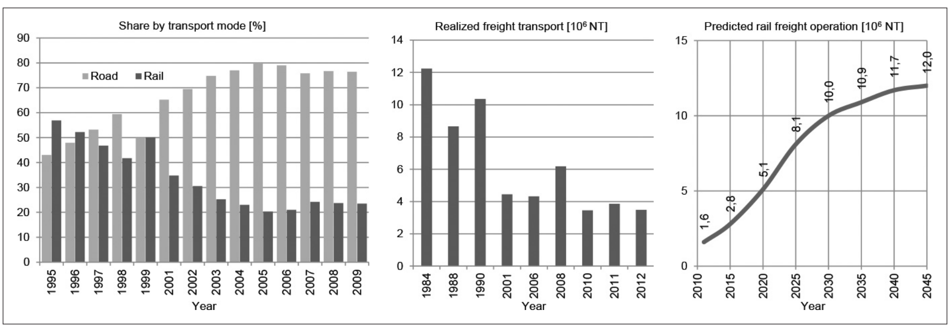

Figure 2 Left: share of land transport in container transhipment of the Port of Rijeka; Middle: realized freight transport on rail section Ogulin-Rijeka; Right: predicted rail freight transport on rail section Ogulin-Rijeka

The existing railway line servicing the Port does not have sufficient capacity to accept the above mentioned planned maximum traffic volume. The line was built in 1873 and its capa-

city is limited to technical and technological features characteristic of the time and rolling terrain of Rijeka hinterland: it is a single track line for mixed traffic with small curve radii and steep gradients, which in some parts are limiting train speed to 40 km/h. Line capacity is approximately five million tons per year, mostly because of the poor operation characteristics of section from stations Ogulin to Škrljevo [1]. Around 50 km long continuous maximum gradient from Rijeka (Škrljevo) toward inland makes this particular rail section one of the most challenging railway lines in operation in Europe [7].
The much needed increase of the capacity on this railway line is discussed basically from the day of its construction, but only in the last few years there is a serious trend of shifting the investment focus from road to railway sector in this area. It has carried out a number of activities including design, construction, reconstruction and modernization of the complete corridor RH2 (Figure 3).

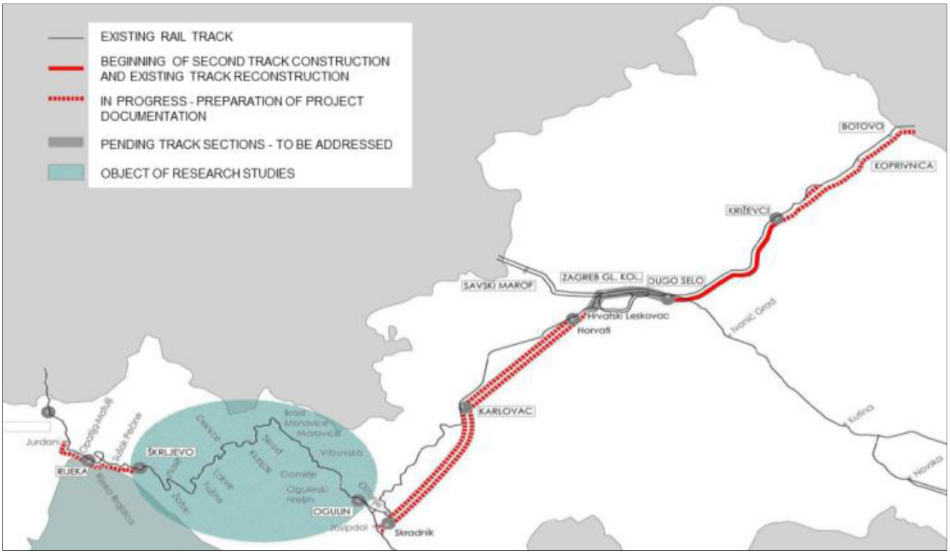

Figure 3 Activities on design of construction, reconstruction and modernization of the corridor RH2, State Border-Botovo-Zagreb-Rijeka [6]

From Figure 3 it can be seen that the modernization of the railway line section Ogulin-Škrljevo is still in the research phase. To date, measures to increase the capacity of the said section are limited to periodic renewal of interstation sections, upgrade of the existing signalling system, and modernization of electric traction system. Possible design and construction solutions to increase the capacity of the railway section, whose first variants are more than 50 years old, can be divided into three basic groups:

- construction of new double track high performance line,
- reconstruction of single track line with the introduction of more favourable horizontal and vertical elements,
- upgrade by construction of a second track on most critical subsections together with a partial reconstruction of the existing track.

2 Characteristics of analysed variant solutions

For the purpose of this study the characteristics of the existing Ogulin-Škrljevo rail section and variants of its design betterment were discussed and mutually compared from the construction, transport and economic point of view. Variants observed were second track construction and reconstruction of existing one, together with construction of new and reconstruction of existing stations in order to extend usable track length. Variant that proposes construction of new double track high performance line (Figure 4) is not considered in this study because its main goal was to determine the possibility of using the existing rail route and infrastructure to increase its capacity.

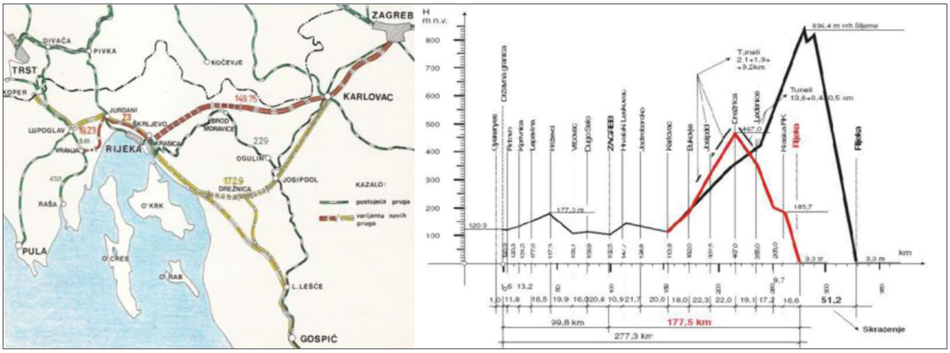

Figure 4 Left: Kupa and Drežnica variants of the new two-track railway Zagreb-Rijeka; Right: Preliminary design for Drežnica variant of railway State Border-Botovo-Zagreb-Rijeka [3]

During the development and analysis of variant solutions, exclusively freight traffic was considered, since it is dominant on the observed railway line section. The reason for this is the highly developed motorway network and the existence of several international airports in this area. In other words, here the railway passenger transport system can hardly compete with other modes of transport. Also, geomorphological characteristics of Rijeka coast technically complicate and therefore make unprofitable the efforts to connect the northern Adriatic and inland by construction of modern high speed railway line for passenger traffic [8].

2.1 Design characteristics

During the development and analysis of variant solutions the following nomenclature is used:

- VAR.0 represents a single existing rail track whose basic geometry parameters, given the rolling terrain and construction date, correspond to the former steam traction (large number of curves adapting the track route to hillsides and mountains, relatively low travelling speed, and high longitudinal gradients);
- VAR.1 represents a complete reconstruction of the existing single track rail line section Ogulin-Škrljevo in order to improve its geometry and thereby increase travel speed and freight capacity [9, 10];
- VAR.2 represents construction of second track with a complete reconstruction of the existing track section Drivenik-Škrljevo [9];
- VAR.3 represents route relocation and construction of a new single track section Kupjak-Delnice, construction of new double track Delnice-Zlobin, and second track construction with a partial reconstruction of the existing track (retaining the existing vertical alignment) on section Zlobin-Škrljevo [7].

Table 1 shows input parameters used for track variants horizontal and vertical alignment conceptual design (Figure 5 and 6) and their basic characteristics (track section length, number of stations and structure length).

Table 1 Track variants design characteristics.

Variant	VAR.0	VAR.1 [9, 10]	VAR.2 [9]	VAR.3 [7]
Design speed [km/h]	75	100	75	75
Minimal horizontal curve radius [m]	250	500	250	250
Maximal gradient [‰]	27	25	25	27
Single track section length [km]	107.7	102.5	83.3	58.1
Double track section length [km]	0	0	23.5	39.6
Total route length [km]	107.7	102.5	106.8	98.5
Number of stations	21	13	15	15
Tunnels [km’]	3.2	8.9	3.8	14.5
Bridges [km’]	0.1	3.7	3.3	3.6

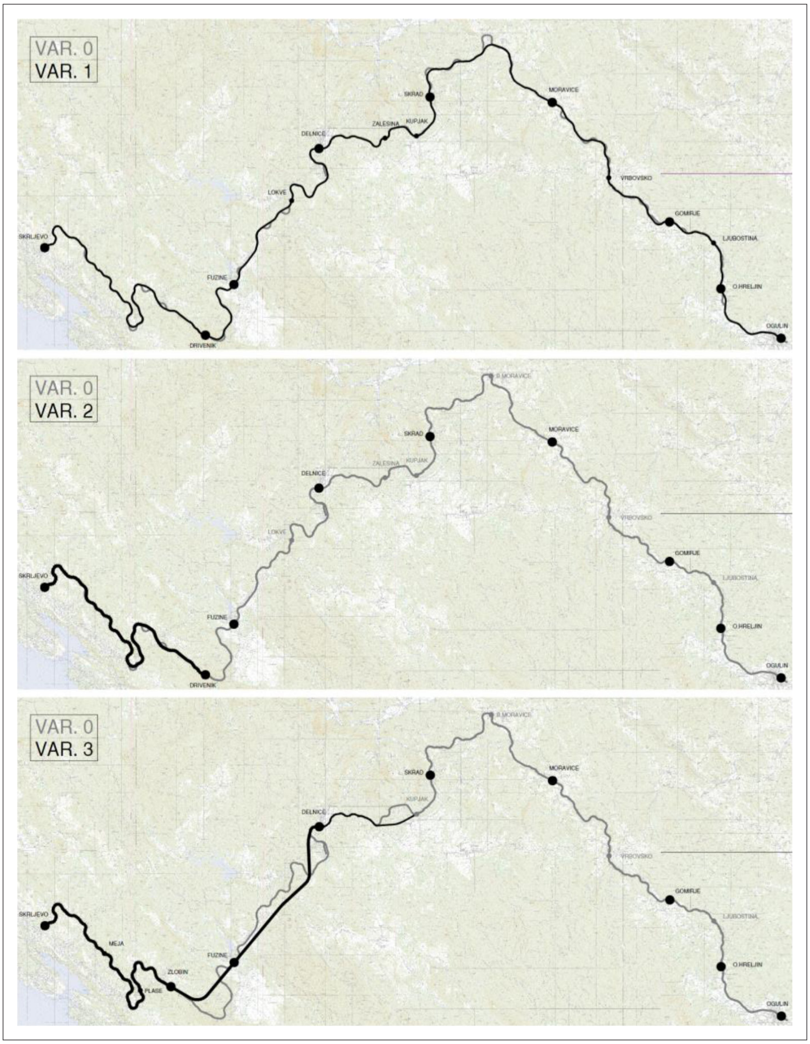

Figure 5 Variants VAR.0-3 horizontal alignments

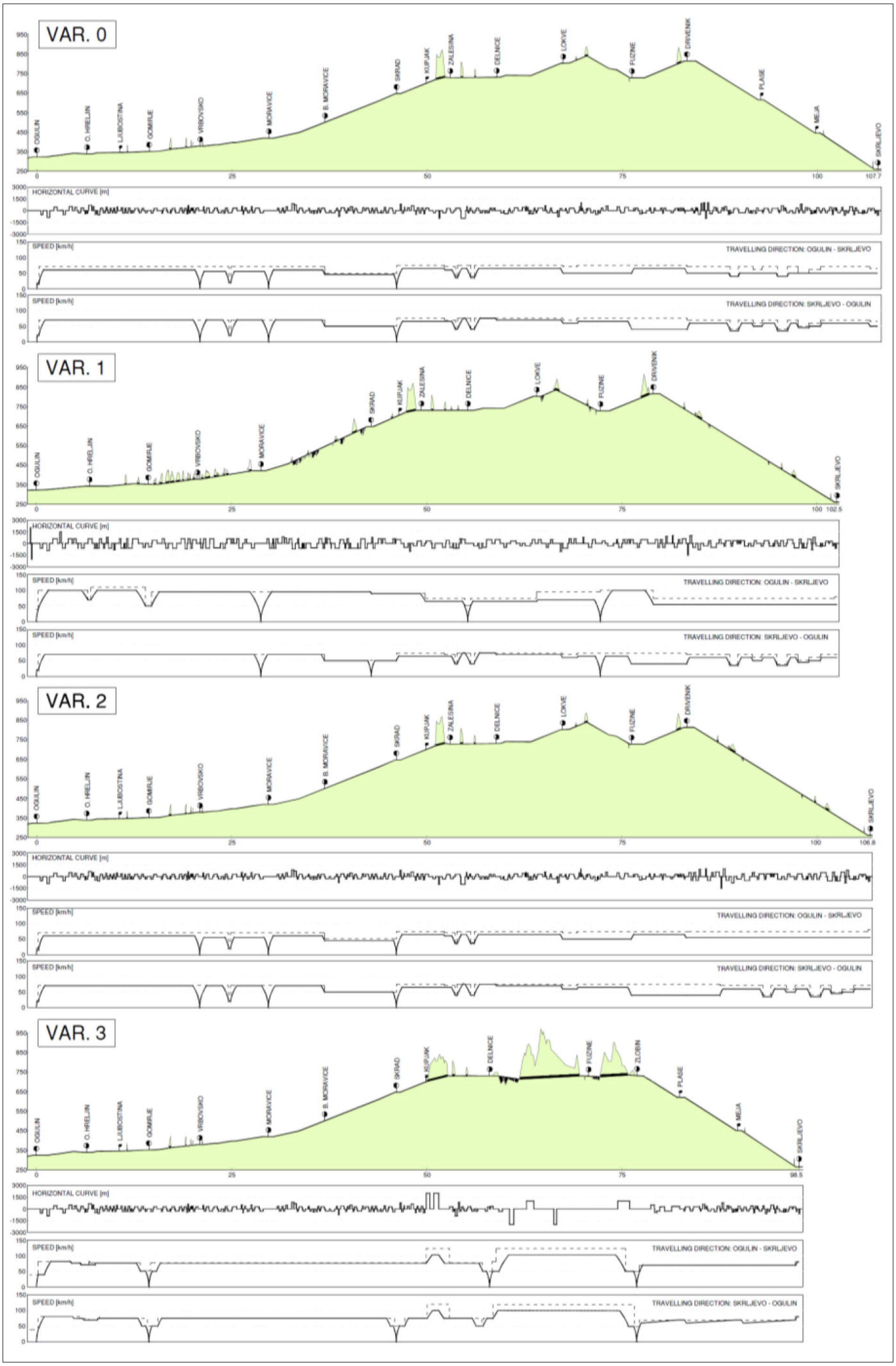

Figure 6 Variants VAR.0-3 vertical alignments and operating speed profiles

2.2 Traffic characteristics

Based on the geometry and traffic characteristics of the existing railway line (VAR.0) and variant solutions (VAR.1, 2 and 3) [7, 9, 10, 11], the following track technical and operational parameters necessary for freight capacity calculations were defined: interstation ruling gradient, type of haul (locomotive class), minimal gross weight of freight train, and operating speed.
In VAR.1 and 2, the reduction of the longitudinal gradient, which demanded the abolition of stations Plase and Meja, reduced the highest ruling gradient from 26‰ to 24‰.
On the existing railway line, haul is performed by means of one or, at critical interstation sections, two electric class 1141 locomotives. It is assumed that the same class of locomotive will be used upon completion of the betterment. Based on the known haul and alignment characteristics, it was established that minimal gross weight of freight train (q) of 900 tonnes is achievable for each track variant, with two locomotives double-heading the service.
Calculated freight train operating speed that can be achieved for such route and towing characteristics is shown on Figure 5 for each travelling direction.

2.3 Interstation travelling time and carrying capacity

Freight train travelling time in both directions was calculated for each track variant on the basis of previously defined track technical and operational characteristics on interstation sections (Table 2). The longest interstation travelling time for each variant is calculated on track most challenging section from station Drvenik (i.e. Zlobin) to Škrljevo. The shortest total travelling time in both directions is achieved for VAR.1 (complete single track reconstruction). This is understandable, bearing in mind that this variant includes most significant improvements of track technical (horizontal and vertical design) elements.

Table 2 Interstation travelling time.

Travelling direction	**Ogulin-Škrljevo**				**Škrljevo-Ogulin**			
Interstation section	**VAR.0**	**VAR.1**	**VAR.2**	**VAR.3**	**VAR.0**	**VAR.1**	**VAR.2**	**VAR.3**
Ogulin – O. Hreljin	8	4	8	7	7	4	7	7
O.Hreljin – Gomirje	8	5	8	8	7	4	7	8
Gomirje – Vrbovsko	7	4	7	6	6	6	6	8
Vrbovsko – Moravice	11	5	11	8	10	8	10	7
Moravice – Skrad	21	9	21	14	18	12	18	16
Skrad – Delnice	15	10	15	9	15	10	15	11
Delnice – Fužine	20	16	20	9	17	12	17	10
Fužine – Drivenik/Zlobin	7	4	7	6	11	5	11	5
Drivenik/Zlobin – Škrljevo	36	26	26	20	35	19	19	22
Travelling time t [min]	**133**	**83**	**123**	**87**	**126**	**80**	**110**	**94**

VAR.0 – Existing rail track (Ogulin-Škrljevo)
VAR.1 – Track reconstruction (Ogulin-Škrljevo)
VAR.2 – New double track (Drivenik-Škrljevo)
VAR.3 – Track reconstruction (Kupjak-Škrljevo) and second track construction (Delnice-Škrljevo) [6]

In order to define the capacity of the analysed variants, the maximum possible daily number of freight trains (n) on each track interstation section was defined according to:

$$n = 2 \cdot \frac{1440}{t_{Ogulin\text{-}Skrljevo} + t_{Skrljevo\text{-}Ogulin}\ [min]} \quad (1)$$

Based on the calculated maximum possible daily number of freight trains (n) and gross weight of freight train (q) on each interstation section, annual gross capacity (Q) was defined according to:

$$Q = n \cdot q \cdot D \cdot \psi \tag{2}$$

The calculations were conducted by adopting following presumptions: freight trains are in operation during D=300 working days per year with coefficient of train mass utilization of ψ=0.80 [6]. Results of these calculations are shown in Table 3.
Interstation section relevant for the calculation of the capacity of the entire track is the one with the smallest calculated number of trains per day i.e. interstation section Drivenik (Zlobin)-Škrljevo. Given the forecasted net freight traffic needs of 12 million of net tonnes by the year 2045, and the presumed gross to net capacity ratio of 2, it is estimated that existing rail section (VAR.0) will reach its maximum capacity by the year 2020. Single line track reconstruction variant (VAR.1) does not meet the forecasted transportation needs. They can be achieved only in the case of second track construction: estimated freight capacity of VAR.2 and 3 is by 13 and 19% higher than forecasted net freight traffic needs.

Table 3 Variant capacity.

Capacity Parameter	Daily number of trains n				Annual capacity Q [MGT]			
Interstation section	**VAR.0**	**VAR.1**	**VAR.2**	**VAR.3**	**VAR.0**	**VAR.1**	**VAR.2**	**VAR.3**
Ogulin – O. Hreljin	192	360	192	206	69.0	155.5	69.0	88.9
O.Hreljin – Gomirje	192	320	192	180	69.0	138.2	69.0	77.8
Gomirje – Vrbovsko	222	288	222	206	79.6	124.4	79.6	88.9
Vrbovsko – Moravice	137	222	137	192	49.3	95.7	49.3	82.9
Moravice – Skrad	120	137	120	169	43.1	29.6	43.1	73.2
Skrad – Delnice	180	288	180	144	64.7	62.2	64.7	62.2
Delnice – Fužine	137	180	137	303	35.8	38.9	35.8	131.0
Fužine – Drivenik/Zlobin	160	320	160	524	41.8	69.1	41.8	226.2
Drivenik/Zlobin – Škrljevo	41	64	128	137	10.6	13.8	27.6	29.6
Ogulin – Škrljevo	**41**	**64**	**128**	**137**	**10.6**	**13.8**	**27.6**	**29.6**

VAR.0 – Existing rail track (Ogulin-Škrljevo)
VAR.1 – Track reconstruction (Ogulin-Škrljevo)
VAR.2 – New double track (Drivenik-Škrljevo)
VAR.3 – Track reconstruction (Kupjak-Škrljevo) and second track construction (Delnice-Škrljevo)

2.4 Estimated investment costs

Table 4 shows an estimation of investment costs calculated for track variants VAR.2 and 3. Since it can't meet the predicted traffic needs, VAR.1 was eliminated from cost analysis. By comparing the estimated investment costs the following conclusions were made. The manner of which VAR.3 route was designed results in the need to build a large number of expensive new tunnels and bridges. In contrast, VAR.2 does not predict complete redirection of the existing line route but only the correction of vertical alignment and critical sections of track with extremely small horizontal curves radii. Because of that, most of the VAR.2 investment costs refer to the track substructure construction. Also, the length of the predicted double track is two times shorter in VAR.2 than the VAR.3. All this makes the VAR.2 30% less expensive investment than the VAR.3.

Table 4 Estimated investment costs.

Variant	VAR.2	VAR.3
Track substructure (earthworks and drainage)	296.1	87.4
Track superstructure	51.1	83.4
Bridges and tunnels	29.6	321.7
Crossings	6.0	8.1
Noise protection	4.0	11.7
Signaling	3.8	56.7
Central traffic control	0.3	2.1
Telecommunication	1.2	3.7
Electrification	5.6	23.7
Stations (accesses, platforms and buildings)	9.1	12.4
Total investment costs [mil EUR]	**406.7**	**610.8**

VAR.2 – New double track (Drivenik-Škrljevo)
VAR.3 – Track reconstruction (Kupjak-Škrljevo) and second track construction (Delnice-Škrljevo)

3 Conclusion

The necessary modernization of the M202 railway line section Ogulin-Škrljevo is still in the research phase. Variant analysis presented in this paper showed that a favourable solution to increase the track section capacity is to build a second track on the most critical Drivenik-Škrljevo subsection, about 23.5 km long. With regard to the forecasted Port of Rijeka net rail freight traffic needs, existing single track rail section will reach its maximum capacity by the year 2020. This means that there are only few more years available to design, construct and put in operation the second rail track. Otherwise, the existing line and station capacity will not be sufficient for the intended volume of rail freight transport, which would eventually lead to further, and this time perhaps irreversible, decline of railway system of this area.

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