Extension of single-tube tunnel with service tube to a two-tube tunnel

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Summary

This paper presents the analysis of different design and construction models for extension of single-tube tunnels for bidirectional traffic with service tube, to a standard two-tube tunnel for one-way traffic in each tunnel tube on state roads or expressways. Namely, in the last years several long single-tube tunnels for bidirectional traffic with service tubes were built in Croatia (Sveta Tri Kralja Tunnel – 1.741 m, Sveti Ilija Tunnel – 4.248 m) and many more are planned or are in the design phase (Omiš Tunnel - 1.471 m, Drvenik Tunnel - 5.650 m, Babja Gora Tunnel - 1.925 m, Oštri Kuk Tunnel - 3.125 m, Debeli Brijeg Tunnel - 2.467 m).

This kind of solution of a long single-tube tunnel for bidirectional traffic with a service tube on state roads and expressways is satisfactory according to the valid regulations (EU Directive 2004/54/EC [1] and national laws and regulations for the respective field [2]) only in cases of low traffic intensity (AADT <10.000 veh/day/per lane, low seasonal daily traffic or low heavy goods vehicle traffic). However the possibility of significant traffic increase has to be considered, as well as possible stricter safety requirements for road tunnels. In this case, a full profile, second tunnel tube has to be constructed in order to achieve the solution with two tunnel tubes and one-way traffic in each one.

Keywords: service tunnel, single-tube tunnel, two-tube tunnel, extension of tunnel tube

1. Introduction

This paper gives an elaboration of variant solutions for extension of the existing long single-tube tunnels with a service tube to a full profile two tube tunnel, with a one-way traffic in each tunnel tube. The aim is to reach an optimum model with regards to costs, construction technology and traffic safety requirements.

This paper is an excerpt from the author’s post-graduate thesis [3] and year-long work experience in the field of road tunnel design development. As such, this paper will have a practical, and what's most important, a timely usage so that all participants in the planning and development process of this type of tunnels can have adequate solutions when needed.

Numerical values and calculation results presented in this paper were taken from above mentioned postgraduate masters theses at the Faculty of Civil engineering at University of Zagreb, Croatia [3].

2. Service tunnel tubes

Service tunnel tube is an auxiliary tunnel tube which can be used for evacuation purposes in case of emergency, i.e. fire or accident in the main tunnel tube, and also for access of the service and emergency vehicles to the main tunnel tube [2]. The service tunnel tube is constructed in long, single tube tunnels which have two-way traffic, in cases when it is not cost efficient or compulsory to construct a second tunnel tube due to relatively low traffic load, but still fulfil the defined safety requirements.

Main characteristics of the service tunnel tube are:
Two to three times less clearance profile area in relation to the main tunnel tube (22 to 38 m² as opposed to the main tunnel tube whose clearance profile area ranges between 55 and 80 m²), which is sufficient for safe passage of emergency vehicles (fire fighters, ambulance car);

- In most cases the service tunnel tube is equally long as the main tunnel tube along which it runs, with a recommended minimum axes distance of 25 m;
- It is connected by emergency cross-passages with the main tunnel tube, with a maximum distance between the cross-passages of 500 m;
- Free vehicle traffic is not permitted through this service tube. It only serves as approach for the emergency services to the main tube and for evacuation of the main tunnel tube users;
- Complete primary support, drainage and partially the pavement structure (mostly only sub-base course, concrete slab or one course of asphalt) are executed in the service tunnel tube but without waterproofing, secondary lining, complete pavement structure courses, sewage system, ventilation or installation of any other tunnel equipment.

![Typical Cross Section of Main Tunnel Tube](image1.png)

**Drawing 1** Typical cross sections of main and service tunnel tubes of the Debeli Brijeg Tunnel [4]

Due to the possibility of significant traffic increase in the future, as well as possible future stricter safety requirements for road tunnels, one has to consider now about the means of extension of single-tube tunnels with service tubes to a two-tube tunnel for unidirectional traffic in each tunnel tube, and offer the road authorities finished optimum technical solutions.

### 3. Extension of single-tube tunnels

There are two main variants of extension of single-tube tunnels with service tubes to a two-tube tunnels; a) by construction of a completely new tunnel tube, or b) by extension of the service tunnel tube to a full profile. Both of these variants have their advantages and disadvantages, each having two main sub-variants. A short outline will be given of the main characteristics of both main variants and their sub-variants with a comparative analysis per key parameters.

The example of the Debeli Brijeg Tunnel shall be used to present the above mentioned comparative analysis. It is the most recently designed single tube tunnel with a service tubel in Croatia. Its Main design was completed in the summer of 2014 [4], and the Building permit is being obtained at present. The Debeli Brijeg Tunnel is situated on the express road connecting the Pelješac Bridge and the State road D8. The main tunnel tube is 2.467,0 m long, and the service tunnel tube is 2.462,30 m long. The tunnel is designed for the speed of \( V_r = 80 \) km/h, and the planned method of construction is the „drill and blast technique“ based on the new Austrian tunnelling method (NATM). Emergency cross-passages are designed to connect the main tunnel tube and the service tunnel in cases of emergency evacuation and accidents. They are designed at a maximum spacing of 250 m between each other, thus fulfilling the above mentioned safety regulations for tunnels [1] [2]. Clearance profile area of the main tunnel tube is 56,17 m², and the clearance profile area of the service tunnel is 24,73 m². The unit excavation area of the main
tunnel tube is 74,64 m², while the unit excavation area of the service tunnel tube is 28,65 m², i.e. 38,40 % of the unit excavation area of the main tunnel tube. The spacing between the main tunnel tube and service tunnel axes is 25,0 m.

3.1 Extension of single-tube tunnels by construction of a completely new tunnel tube

With construction of a completely new tunnel tube, the existing service tunnel largely loses its function as the auxiliary tunnel tube in case of accidents and emergency, which is now taken over by the new main tunnel tube. As a consequence, by constructing a completely new tunnel tube, the construction costs of the service tunnel largely become unnecessary. The construction costs of the new tunnel tube are somewhat larger than the costs of the existing main tunnel tube because of certain parameters, while construction costs of a service tunnel tube can be considered as losses.

Also, with this variant, additional costs appear due to the need for considerable widening of the tunnel approach cutting, as well as costs of reconstruction of the existing road route in the portal approach zone in order to adjust the new traffic conditions for two main tunnel tubes.

Namely in order to construct the new tunnel tube, the existing tunnel approach cuttings need to be widened (entrance and exit) for the width of the new main tunnel tube and for the length of the axial distance up to the first tunnel tube (main or service). When both tunnel tubes are simultaneously constructed the usual axial distance is 25 m, but when a new tunnel tube is constructed along the already existing one, this mutual distance is increased to app. 35 to 40 m in order to decrease the negative effects of blasting on the already constructed tunnel tube. Therefore, if this variant is applied, the existing approach cuts need to be widened to at least 45 m, i.e. more than 100 % of the existing width of the approach cut, creating additional significant costs of approach cut excavation, geotechnical support of new cuts and slopes of approach cutting face and sides as well as costs of new channels and new drainage of approach cuts.

Also the construction of a new tunnel tube and widening of the tunnel approach cuts introduce a new regime of traffic operation, therefore because of a significant separation of tunnel axes the road axes have also to be separated in the portal approach zones (app. 1 km in front and after the tunnel portals) in order to satisfy the layout geometry elements of the road. All this requires significant work on the reconstruction of existing road with complete works on the pavement structure and road drainage.

Additional cost caused by the increase in the distance between tunnel tubes is also the increased length of the new cross-passages between the tunnel tubes, which are at a standard axial spacing 18 m long, but when the axial distances are increased, they are app. 30 m long. Having in mind that, in accordance with the provisions of the valid regulations [1][2], the cross-passages are constructed maximum at every 250 m, and that they are constructed with complete primary and secondary lining, it is obvious that the increase in length of cross-passages significantly increases the overall tunnel construction costs.

The analysis of phased construction of the Mala Kapela Tunnel (length 5.800 m), prepared by the INSTITUT IGH d.d. [5], shows that because of increase in the above explained additional works caused by the increase in axial distance of tunnel tubes and length of cross passages, the overall tunnel construction costs are increased for app. 1,6%, which is not insignificant. With shorter tunnels, this percentage of costs caused by widening of the tunnel approach cut proportionally increases.

A very important question regarding this variant of extension of single-tube tunnels is the function of the service tunnel tube after the construction and commissioning of the newly constructed second tunnel tube. Its function largely depends on its position; is it situated laterally, along only one tunnel tube (Drawing 2 above) or is it situated between the tunnel tubes (Drawing 2 below). This in turn creates two sub-variants of extension of single-tube tunnels by constructing a completely new, second tunnel tube.
3.1.1 Placing the service tunnel tube laterally, along only one of the main tunnel tubes

The main technological characteristics of drilling a tunnel tube along an already existing one are the limitations regarding work progress because of the influence of blasting on the already constructed structure. The limitation refers to the decrease of the maximum tolerated excavation section (max. up to 2.0 m as opposed to the maximum tolerated 6.0 m where there are no limitations and depending on the rock mass). This has a negative influence on the dynamics and costs of construction works of the second tunnel tube.

Apart from the limitations regarding blasting, another negative influence is the fact that traffic is ongoing in the existing tunnel tube during the whole period of ongoing works. This means that the existing tunnel tube cannot be used for the needs of the second tunnel tube construction site. Because of the ongoing of regular traffic through the existing tunnel tube, construction site traffic is not allowed (not even transport of excavated or blasted material or any form of transport of construction site machinery for drilling and loading). This is the reason why in construction of long tunnels there are two almost independent construction sites (one on the entrance portal and the other on the exit portal), with double main technological units (operational face, machinery, stockpiles, logistics, facilities, power generating products...) with very limited intermediate communication of resources. These characteristics also adversely affect the dynamics and costs of works on the construction of the second tunnel tube.

If cross passages were not at least partially build during the construction of the first tunnel tube, even stricter blasting restrictions have to be applied during their construction.

Apart from the unfavourable technological and financial characteristics of this sub-variant, the traffic safety characteristics have to be outlined as well.

It has already been mentioned that during ongoing construction works on the second tunnel tube, unobstructed traffic has to be ongoing in the first constructed tunnel tube, which is not completely achievable. Namely during every blast in the new tunnel tube, restrictions of ongoing traffic have to be undertaken in the already constructed tunnel tube. This actually means short traffic interruptions in both directions, in front and at exit of the first constructed tunnel tube until the blasting is completed. This can result in a temporary traffic jams at tunnel entrance and exit.

On significantly tourist oriented roads, during the summer weekends the daily number of blasts has to be decreased to avoid restrictions in traffic as much as possible and to avoid traffic jams at tunnel entrance and exit. The practice during construction of phase II of the motorway A6 „Bosiljevo-Rijeka“ showed that only one blast was undertaken in the new tunnel tube during the
summer weekends, as opposed to working days when 3 blasts were undertaken per day. An even more adverse situation appears during excavation of the cross passages to the existing tunnel tube which has to be temporarily closed. Under these traffic – safety characteristics, the dynamics of work execution is additionally slowed down and costs of excavation of the new tunnel tube are increased. It is important to say that although it does not have any negative effects on the construction dynamics or costs, contractors often use the existing tunnel tube for transport of their construction material and resources, even though this should not be done. This significantly increases the truck traffic in the existing tunnel tube which in turn results in reduction of speed and traffic safety.

The already mentioned analysis of phased construction of the Tunnel Mala Kapela [5], showed that due to various restrictions during construction of the new tunnel tube along the existing and operational tunnel tube, tunnel excavation costs increase up to 30% in relation to construction without various restrictions and limitations. Since the excavation works are key works in tunnel construction, excavation costs are also the most important ones in the structure of overall tunnel construction costs.

With this sub-variant of the extension of single tube tunnels, the existing service tunnel largely loses in its primary function (its function is roughly decreased by 50%), i.e. it is still used as a service tunnel tube in case of emergencies, but only for one of the main tunnel tubes, while the other, newly constructed tunnel tube is not at all influenced by it or has any use of it.

### 3.1.2 Positioning of the service tunnel tube in between two main tunnel tubes

Positioning of the service tunnel tube between the main tunnel tubes, i.e. construction of a new tunnel tube next to the service tunnel has its technical, financial as well as traffic safety advantages as compared to previously explained sub-variant.

Technological – financial advantages of positioning the service tunnel between the two main tunnel tubes one of which is in operation and the other under construction are in the fact that because of the two times larger axial distance between the two main tunnel tubes, the impact of blasting in the tunnel tube under construction on the one in operation is less, thus causing less restrictions in the already constructed tunnel tube because of the service tunnel in between. On the other hand, blasting of the second tunnel tube has a greater impact on the service tunnel tube since it does not have the secondary tunnel lining, only primary lining which is flexible and can be always additionally supported in case of damage caused by blasting.

Also, since the service tunnel tube is not used for ongoing of traffic but only for emergency purposes and evacuation, it can also be used during excavation of the new tunnel tube for ongoing of construction site traffic, thus making the construction site of the new tunnel tube a comprehensive unit, without the need to duplicate most of the main technological units. Likewise, construction of the cross-passages between the new tunnel tube and the service tunnel allows a better work progress because the contractor is given the opportunity to have several cutting faces in operation using the newly constructed cross-passages for transport purposes.

The blasting restrictions are much less when constructing the cross-passages between new tunnel tube and service tunnel since the service tunnel is not used for traffic ongoing and is constructed only with primary support.

The traffic safety advantages of this sub-variant are in the fact that the new and already existing main tunnel tubes are not in direct contact, because of the service tunnel between them, which allows free ongoing of traffic during construction works. Traffic restrictions in the main tunnel tube caused by blasting are minimal, thus the number of daily blasts in the new tunnel tube do not have to be decreased. In this sub-variant the main tunnel tube shall not be closed during excavation of the cross-passages. Since the service tunnel can be used for the needs of construction site traffic, the truck traffic in the existing main tunnel tube is not increased, thus the traffic flow level and safety level stay unchanged.

The positioning of the service tunnel tube between the two main tunnel tubes significantly decreases the limitations regarding excavation works on the second tunnel tube caused by blasting and traffic restrictions and allows better work progress using the service tunnel and cross-passages. All this positively influences the overall work progress as well as construction costs of the new tunnel tube.
Therefore, it can be concluded that due to minimum restrictions, application of this sub-variant shall not cause a 30% increase in constructions costs of the new tunnel tube, as in the previous sub-variant.

In this case, when the service tunnel is positioned between the two main tunnel tubes, we actually have 3 tunnel tubes, the two outer, lateral, are used for one-way traffic each, and the middle tunnel still keeps its function as service tunnel for both main tunnel tubes. This is an excellent solution traffic-wise, because in emergency situations in one of the main tunnel tubes all evacuation and emergency interventions and actions are done through the service tunnel without interruption of traffic in the other main tunnel tube. This also is another advantage as compared to the previous sub-variant. The same applies in case of any subsequent additional works and inspections in the main tunnel tubes when in operation, where the service tunnel can be used for approach to the main tunnel tubes by way of cross-passages, to minimise obstruction of traffic regime in them.

### 3.2 Extension of single-tube tunnels by widening the service tunnel tube to full profile

Extension of the service tunnel to full profile results in the loss of the service tunnel as such. Its function is taken over by both main tunnel tubes. Since this variant is based on the extension of already excavated service tunnel, whose unit excavation area is app. 38,40 % of the unit excavation area of the main tunnel tube, the excavation costs spent on the service tube were not in vain, but decrease the required excavation quantity for that particular percentage.

It must be stressed that the primary support in the service tunnel which is being widened can present an obstacle during blasting and drilling, requiring certain modifications in the excavation technology as compared to the classical tunnel excavation of rock mass only, but this is not a significant factor influencing the increase in excavation costs.

This variant of extension of single tube tunnels does not require the widening of tunnel approach cuts, i.e. additional approach cut excavation works, geotechnical works on the face slope and approach cut sides and it also does not require additional channels and new approach cut drainage. Also, reconstruction of the existing road route in the portal approach zones to the new situation with two main tunnel tubes is less demanding since the layout geometry elements do not significantly change.

Another important aspect of this variant is that additional cross-passages between the tunnel tubes do not have to be constructed, but the already existing are used. This fact significantly decreases overall costs.

Based on all above given, this variant of extension of single tube tunnels is in its beginning more favourable than the previous variant for the following:

- Value of additional works due to widening of the approach cut (app. 1,6% of overall construction costs of long tunnels and with shorter tunnels this part is proportionally greater),
- Value of construction cost of cross-passages (if we assume that cross-passages are situated at every 250 m maximum, that they are app. 16 m long and app. 1/3 clearance profile area of the cross section of the main tunnel tube it can roughly be estimated that construction of one cross-passage increases the overall construction costs for app. 2%),
- Approximately 1/3 less costs of excavation of the service tunnel tube to full profile (since the tunnel excavation costs are approximately 34% of the overall tunnel construction costs [3] it can be calculated that the application of this variant of extension would save approximately 13% of the overall tunnel construction costs to full profile).

With this variant of extension of single tube tunnels, the distance between the main and service tunnel tube is not increased (i.e. now the new main tunnel tube), which has favourable effects on the approach cut (already explained) but has adverse effects on the progress of work on the excavation of the second tunnel tube because of the already mentioned restrictions regarding blasting, as in the first sub-variant of single tunnel tube extension.

Namely, in the first case, progress of excavation works is limited due to the influence of blasting on the already constructed facility, in the form of decrease of the largest tolerated excavation step.
In this case this is these limitations are even stricter than in the first sub-variant since the standard spacing of 25 m is probably applied here as opposed to the first sub-variant where the spacing is increased to 35-40 m. Also, in this case traffic is ongoing in the existing tunnel tube during the whole period of works and this means that the existing tunnel tube cannot be used for any kind of construction site traffic. Here also we have two almost separate construction sites (one at the entrance and the other at the exit portal), with double technological units and very scarce mutual communication regarding resources.

The traffic safety aspects of this variant are also very similar to the ones in the first sub-variant, because of the same reasons for securing safe ongoing of traffic in the first constructed tunnel tube during construction works on the service tunnel extension. This also cannot be completely realised. In the first case, short traffic interruptions are required in both traffic directions, in front and behind the existing tunnel tube until the blasting works on the service tunnel are completed. The daily number of blasts has to be decreased as well during the summer weekends on roads which are predominantly tourist destinations. It is expected in this variant as well that the truck traffic through the existing tunnel tube will be increased during construction works, although it is an unacceptable practice.

Favourable aspect of this variant is that cross passages need not be constructed thus avoiding the blasting and traffic restrictions. On the other hand the blasting restrictions on extension of the service tunnel are stricter having in mind a smaller spacing. Thus, even if this variant is applied, approximate conclusion is that the tunnel excavation costs are increased by 30% in relation to the case without restrictions.

It has to be stressed that the application of this variant decreases the quantity of excavated material by app. 1/3 (depending on the selected cross sections of the main and service tunnel tubes), thus, for the same tunnel length and under nearly equal restrictions, this variant is more favourable as compared to the previous by app. 1/3 value of the excavation costs or by app. 13% of overall costs of construction of a full profile tunnel tube.

The key adverse characteristic of this variant regarding traffic – safety is that the service tunnel tube during construction works on its extension is completely out of use, i.e. in case of emergency in the main tunnel tube during construction works on the service tunnel tube, there is almost no possibility of intervention or evacuation. This is why the selection of this variant is very questionable, although cost-wise it is very justified, especially with long tunnels on roads having heavy traffic loads. With medium length tunnels on tourist destination roads having greater seasonal traffic loads, this variant is acceptable but with suspension of construction works and assurance that the service tunnel tube shall be passable in certain periods, which again has adverse effects on the work progress and construction costs.

Considering the origin and direction of extension of the service tunnel tube, two sub-variants are possible; radial extension with origin at the level line, in the service tunnel tube axis (Drawing 3 left) or extension with origin in the lateral toe, nearer to the existing tunnel tube, in the outer direction (Drawing 3 right).

### 3.2.1 Radial service tunnel tube extension with origin in the level line which is in the service tunnel tube axis

As can be seen from the given drawing, the service tunnel tube is radially extended in all directions, for app. 3-4 m, depending on the selected main and service tunnel tube cross sections. Axial spacing up to the main tunnel tube does not change, but due to the extension works the new tunnel tube is coming near to the already existing one by app. 3-4 m, thus imposing stricter restrictions regarding blasting. Movement towards the main tunnel tube imposes the shortening of the cross-passages for approximately same value of extension and this requires works to 3-4 m in the cross-passages and additional construction works on the forming and modelling of their new entrances.

In this variant the complete primary support and the service tunnel tube drainage system is being demolished.
3.2.2 Extension of service tunnel tube with origin in the toe of the wing nearer to the existing tunnel tube, in the outer direction

As can be seen in the attached drawing, origin of the extension is in the toe of the service tunnel side nearer to the already existing tunnel tube, thus the extension is being done in the direction away from the main tunnel tube. This increases the axial distance by several meters and the extension works move in the direction away from the main tunnel tube, thus decreasing the blasting and traffic restriction in relation to the previous sub-variant.

Since the service tunnel tube is not extended in the direction of the main tunnel tube, the existing cross-passages are not being touched and their length is not being changed. Several meters at the entrances need not be buried and no construction works are required.

Since the origin, lateral wing of the newly extended tunnel tube mostly corresponds to the lateral wing of the existing tunnel tube (up to app. 3m height), there is a possibility that a part of the primary support can be preserved in this part of the wing, depending on the used type of support and this in turn depends on rock mass category.

Also if excavation works are carefully done existing drainage can also be preserved on the lateral, origin side, but in practice this is difficult to achieve.

Funds saved this way are not significant and depend on several factors, but they have to be mentioned as a possibility.

From all above given it can be concluded that this sub-variant is more favourable than the previous according to all criteria (less restrictions regarding blasting and traffic, no works on cross-passages, possibility of preservation of a smaller part of primary support), but since an extension of the service tunnel tube has not been done jet (according to the author’s knowledge) a percentage is difficult to estimate.

4. Comparative cost analysis of extension of single tube tunnels with service tunnel tube per given sub-variants

In order to reach a quality conclusion regarding the choice of the best possible variant for extension of single tube tunnels with service tunnel, we have to prepare a comparative table of main construction costs for each of the analysed sub-variants.

For this purpose the values of the main groups of construction works on tunnels were collected from already constructed tunnels on roads and motorways in Croatia in the period 2008 - 2013. Data from contracted Bills of Quantities of 6 constructed two-tube tunnels were analysed each having the same tunnel tube cross section (Zmijarevići, Umac, Šibir, Kobiljača, Puljani, Mali Prolog) [6].
Since percentages of certain groups of work vary, depending on the tunnel, its unique design, shape, position and length, rock mass geology, the mean values of construction works groups were taken for further analyses of the participation of certain groups of works in overall costs (percentage) of the six tunnels and this is presented in the last column of the above table.

For the purpose of comparison of the costs of extension of a single tube tunnel per different sub-variant, an imaginary single tube tunnel of average length was taken as a reference model, with equal cross section and constructed cross-passages, which is not constructed near the already existing structure. Index 100 was taken as the value of the overall construction costs of this tunnel and costs of all other sub-variants will be compared with the costs of equal groups of work of the reference model.

Table 2. Comparison of main construction costs

<table>
<thead>
<tr>
<th>GROUP OF WORKS</th>
<th>IMAGINARY MODEL</th>
<th>SUB-VARIANT 3.1.1.</th>
<th>SUB-VARIANT 3.1.2.</th>
<th>SUB-VARIANT 3.2.1.</th>
<th>SUB-VARIANT 3.2.2.</th>
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<tr>
<td>PRELIMINARY WORKS</td>
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<td>7,90</td>
<td>7,90</td>
<td>7,90</td>
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<tr>
<td>TUNNEL EXCAVATION</td>
<td>33,95</td>
<td>45,26</td>
<td>33,95</td>
<td>30,93</td>
<td>28,06</td>
</tr>
<tr>
<td>PRIMARY SUPPORT</td>
<td>12,90</td>
<td>12,90</td>
<td>14,19</td>
<td>12,90</td>
<td>11,61</td>
</tr>
<tr>
<td>CONCRETE WORKS AND PORTALS</td>
<td>30,43</td>
<td>30,43</td>
<td>30,43</td>
<td>30,43</td>
<td>30,43</td>
</tr>
<tr>
<td>DRAINAGE AND WATERPROOFING</td>
<td>10,00</td>
<td>10,00</td>
<td>10,00</td>
<td>10,00</td>
<td>9,50</td>
</tr>
<tr>
<td>PAVEMENT STRUCTURE</td>
<td>3,19</td>
<td>3,19</td>
<td>3,19</td>
<td>3,19</td>
<td>3,19</td>
</tr>
<tr>
<td>PLANNING OF THE APPROACH-CUT</td>
<td>1,63</td>
<td>1,63</td>
<td>1,63</td>
<td>1,63</td>
<td>1,63</td>
</tr>
<tr>
<td>WORKS CAUSED BY INCREASE OF THE AXIAL DISTANCE</td>
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<td>3,20</td>
<td>3,20</td>
<td>0,00</td>
<td>0,00</td>
</tr>
<tr>
<td>CROSS-PASSAGES</td>
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<td>2,00</td>
<td>2,00</td>
<td>0,50</td>
<td>0,00</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100,00</td>
<td>116,51</td>
<td>106,49</td>
<td>97,48</td>
<td>92,32</td>
</tr>
</tbody>
</table>

5. Conclusion

As can be seen from the comparative analysis of construction costs (Table 2), the same conclusion is reached in the textual part of this paper. Financially, the better variant is the one of extension of the service tunnel tube to full profile than construction of a completely new tunnel tube. In case this variant is selected, the sub-variant where the origin of extension is in the toe of the service tunnel side nearer to the main tunnel tube is more acceptable. This variant is possible only if permits from respective authorities are obtained since the service tunnel tube shall be turned into a construction site and since there is no adequate alternative of intervention into the main tunnel tube in case of emergency or need for evacuation. If phased construction is applied and considering the type of traffic, one has to take into consideration that certain costs will increase (e.g. Preliminary works).
In case this financially better variant cannot be applied, there is still the variant proposing construction of a new tunnel tube in addition to the service tunnel tube. In that case, having in mind all financial, technological and traffic – safety reasons, it is better that the service tunnel tube is positioned in between the two main tunnel tubes.

Although, as the given table shows, the differences in costs between all sub-variants do not seem significant (maximum difference between the best and the least favourable variant is app. 25%), one has to bear in mind that road tunnels are rather expensive structures and that every cut in their construction costs is significant.

This paper does not offer a definite answer to the question which is the best variant (or sub-variant). This is difficult to determine since every tunnel is specific and should be individually approached. This paper tries to show which factors should be considered when deciding on the method of extension of single tube tunnels. The paper gives the basic framework and shows upon which direction to take in the decision making process on the subject matter.

In order to give the investors as much options as possible and in order to minimises the costs of single tube tunnel extension in the future, some recommendations based on this paper could be given, namely that during the first phase of works, i.e. construction of the main and service tunnel tubes they should plan ahead and leave some options for easier future tunnel extensions. This would mean considering axial distances greater than 25 m (recommended min. 35 m) in case the second variant is used, as well as planning the locations for new cross passages and executing some preliminary works in the form of excavating at least 1-2m as to avoid demolishing the tunnel lining if and when the first variant is applied.

6. References


