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Quantitative Analysis of the Possible Sites of a New Danube Bridge to Bypass Budapest on Rail – Part 2[1]

Bence TÓTH,[2] Zsolt LÉVAI[3]

Since 1920, almost all the traffic on rail crossing the Danube in Hungary, crosses it in Budapest via the Southern Railway Bridge which makes it overloaded. This is a very disadvantageous situation not only for commercial shipping but also for military uses as there is certain heavy military equipment that can only be transported via rail.

In our two-part article, we examine the locations of new bridges that could be alternatives to bypass Budapest and thus to reduce the traffic load on the railway lines of the capital. In this second part, we examine the situation on the river Tisza by simulating the existence of several bridge alternatives, both newly built and developed existing ones. We also suggest a combined way of development to treat the capacity changes in the context of the whole network by building two new bridges, one on each river.

Keywords: *railway, bridge, graph theory, redundancy, military engineering*

Introduction

The railway network of Hungary has developed to be central to Budapest. The lines that currently form the core network were built at the second half of the 19th century and the function of the branch lines were to help to transport the goods to the stations at the main lines. Therefore, the main directions led from the big cities to the capital. As a result, the railway crossing over the Danube was not a priority at that time. An eclectic example: while nine railway bridges were built on the river Tisza, only five were built on the Danube.[4]

But as the need for transportation grew over the different regions of Hungary, an efficient way of transportation, which was at that times solely the trains, was missed more and

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2 Assistant Professor, University of Public Service, e-mail: toth.bence@uni-nke.hu

3 PhD student, University of Public Service, Faculty of Military Science and Officer Training, Doctoral School of Military Engineering, e-mail: levai.zsolt@kti.hu

4 Lévai 2020: 198–223.

more. To enable the fast transverse movement of trains without the need to enter Budapest, the then Minister for Transportation, Gábor Baross, led the construction of a railway ring through which the bigger cities could be circumnavigated. This ring line connected the cities (from northwest clockwise) Lučenec, Rožňava, Košice, Chop, Korolevo, Satu Mare, Oradea, Arad, Timișoara and Subotica. However, these cities are nowadays in Slovakia, Ukraine, Romania and Serbia due to the Treaty of Trianon of 1920 which, after losing World War I, cut these regions from the Kingdom of Hungary. Only three bridges over the Danube remained in the country, two at Budapest and one at Baja, 144 km south of the capital close to the southern border. On the river Tisza, there are seven bridges: at Tokaj-Rakamaz, Tiszafüred, Kisköre, Szolnok-Szajol, Tiszaug, Szentes-Csongrád and Algyő.

In Part 1 of our paper, we analysed where a new bridge on the Danube can be built. The main criteria for the locations were that existing branch lines or at least railway tracks be present on both banks of the Danube between which a bridge can be built, and that the bridge should not only be an effective bypass route for the Southern bridge but also an important element of the undisrupted network. The optimal solution was calculated for a bridge between Dunaújváros and Szalkszentmárton, where the former TS floating bridge has already existed.

But as traffic is expected to grow over the Danube, the capacity of the Tisza bridges have to be increased, too. We cannot ignore the traffic impact of the new Danube crossing on the railway crossing on the river Tisza, therefore, in this paper, we will discuss the possible solutions for a new Tisza bridge which would not only enable a higher traffic but could also play an important role in the defence preparations of the country.[5]

The existing bridges in the network

The increasing share of rail freight transport and the growing environmental consciousness of transport mode choice will increase the number of freight trains.[6] The Institute for Transport Sciences (KTI) has recently carried out several publications on the transformation of the rail freight market, which identify the rail sub-sector as one of the possible means of bringing Chinese goods to Europe.[7] This could have a significant impact on the already significant east–west rail traffic.

The railway infrastructure of Budapest has not changed since the 1950s, and the circular railway system established then is still in operation, with the major disadvantage that it does not offer the possibility of a round trip, so the two railway bridges over the Danube in the capital are not an alternative to each other.[8] All these reasons have led Budapest to become a bottleneck as the Southern Railway Bridge, which carries significant passenger and freight traffic, and is the only realistic alternative for east–west traffic, is operating at the limits of its capacity.[9] This bridge is double-tracked and electrified and a third track

5 Számszi 2010: 101–118.
6 Berényi–Lévai 2020.
7 Schváb–Lévai 2022: 172–183.
8 Szászi 2013b: 98–107.
9 Lévai 2020: 198–223.

is currently being built. The two other bridges, the Újpest bridge in the northern part of Budapest and the Türr István bridge at Baja have only a regional role. This is because only the Southern bridge is double-tracked and electrified. The Újpest bridge is singe-tracked, and though it is electrified, it lies on line No. 2 (Budapest–Esztergom) and it is connected to the core network via line No. 4 (Esztergom–Almásfüzitő), which is also a single-tracked line but not electrified. Therefore, the electric locomotives cannot be used to bypass Budapest through these lines.

The Baja bridge is a single-tracked road–rail bridge with no electrification. This suggests that neither the road nor the rail traffic is so heavy that a separate bridge is needed. Also, the loss of one bridge necessitates the use of a significant length of bypass.[10]

The bridge at Komárom connects the Hungarian and Slovakian railway network and has neither a domestic role nor can play a part in the defence preparations of the country.

The state of the Tisza bridges is similar. From the seven bridges, only two, the Tokaj–Rakamaz and the Szolnok–Szajol bridges are electrified and only the Szolnok–Szajol bridge is double-tracked. The Tokaj–Rakamaz bridge would make an efficient bypass route was it double-tracked[11] as it is the connection between lines No. 100 (Budapest–Cegléd–Szolnok–Debrecen–Nyíregyháza) and 80 (Budapest–Hatvan–Miskolc–Nyíregyháza).

The Szolnok–Szajol bridge is at a good location, i.e. the middle of the country and is in good condition. It was reconstructed in 2015, the common structure of the two tracks was changed for two single-tracked truss structures and the *Überleitstelle* Millér was installed to increase the capacity of the line section. However, in case of the (temporal) loss of this bridge, no real alternative is available to handle the traffic.[12] Therefore, a solution has to be found.

Building a second track for the Tokaj–Rakamaz bridge would be important. However, as three of the four Danube bridge alternatives presented in the first part of this paper is to the south of the Szolnok–Szajol bridge, both the shortest and the fastest paths would pass through the river Tisza at Szolnok.[13] This suggests that a bridge over the river Tisza should be built in the southern region of the country.

Bridge alternatives

Szeged

Until 1944, a bridge existed between Szeged and Újszeged. This was part of the Budapest–Arad–Timișoara line and was part of the line leading to Subotica. Line No. 140 approached Szeged from the north and after Szeged-Rendező station it took a leftward curve to the main station of the city. Here, the tracks were already elevated and arrived at the second floor of the station building as it was the beginning of the bridge: after the station, the

10 Kerényi–Tóth 2020: 79–99.
11 Tóth 2019: 74–86.
12 Szászi 2007: 32–59.
13 Szászi 2014: 25–48.

tracks turned right with a 90-degree curve on the bridge at the end of which was the station Újszeged.

Nowadays, both Szeged and Újszeged are head stations and handle a minimal freight traffic. Also, it is impossible to rebuild the bridge on the same route, as there are buildings in the path, only a new line in a tunnel would be possible. However, there were already plans in the 1930s to substitute the steep curve in the downtown. This meant that the line would continue straight after Szeged-Rendező station and cross the Tisza south of the city. This would have meant that the downtown station was to be used only by the passengers and the freight trains would bypass the city on the southern route and connect to the line on the other bank at Szőreg station. This plan was revived in 2006 when a plan was made by the Department of Highway and Railway Engineering of the Budapest University of Technology and Economics.[14]

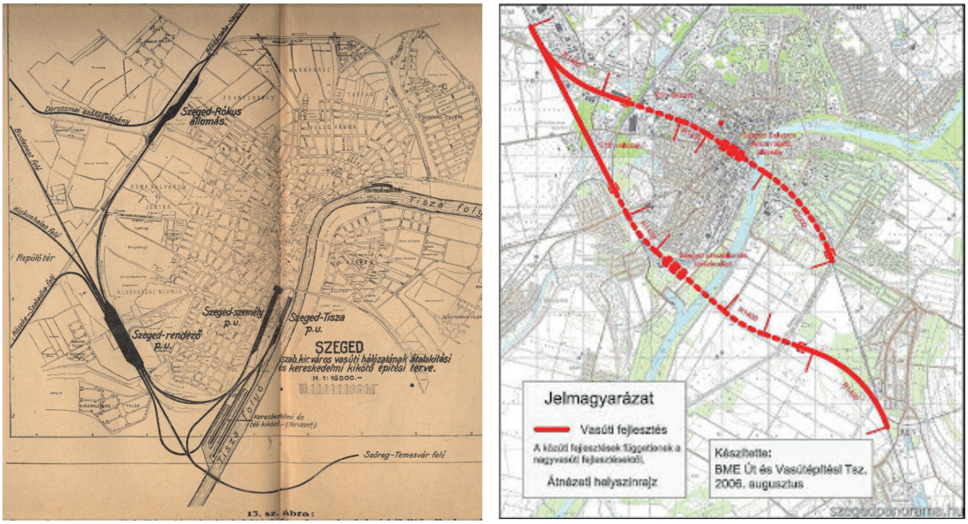

Figure 1: The southern alternative of the Szeged bridge

Source: https://szegedpanorama.blogspot.com/2013/07/a-transzbalkani-vasut-hajdanvolt.html

[14] *A Szeged–Szőreg vasútvonal fejlesztésének megvalósíthatósági tanulmányterve* 2006.

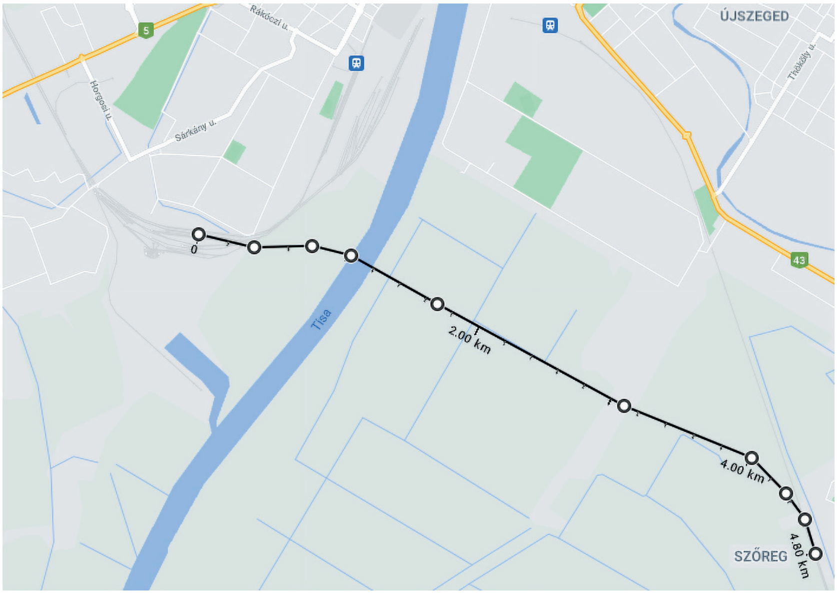

Figure 2: The Szeged-Rendező–Szőreg bridge and planned railway line

Source: [*maps.google.hu*](maps.google.hu)

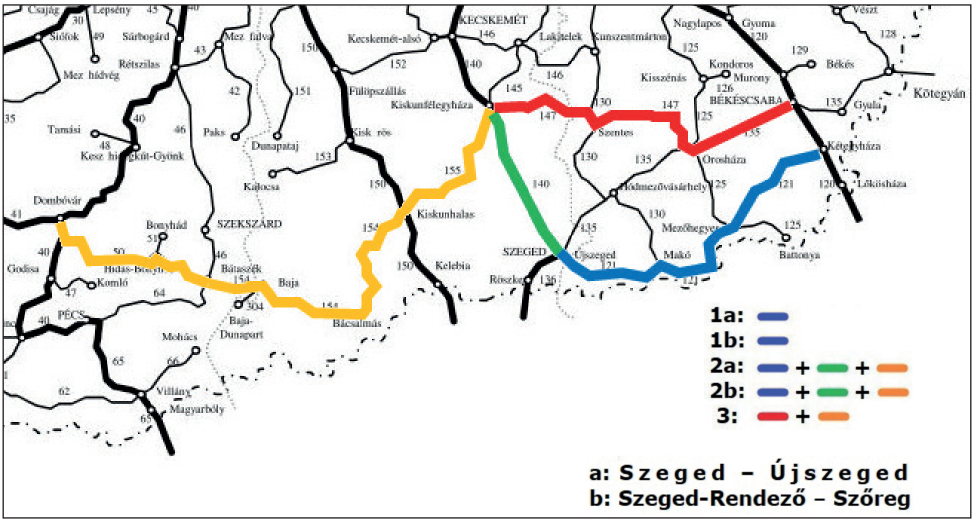

Figure 3: The five alternatives of the new Tisza bridge and the railway lines to be developed

Source: Compiled by the authors based on [*www.logsped.hu/vasutterkep.htm*](www.logsped.hu/vasutterkep.htm)

Here, we analyse five route alternatives. In the 1a and 1b alternatives, line No. 121 (Újszeged–Makó–Kétegyháza) was assumed to have a line speed of 120 km/h, instead of the current

30 km/h. The difference between them is the location of the bridge. In Alternative 1a, the former Szeged–Újszeged bridge was assumed with 60 km/h line speed between Szeged and Újszeged stations. In Alternative 1b, the Szeged-Rendező–Szőreg bridge was assumed with 120 km/h line speed on the whole line (see Figure 3, blue line).

In Alternatives 2a and 2b, the line speed of lines No. 140 between Kiskunfélegyháza and Szeged and lines No. 50 (Dombóvár–Baja), 154 (Baja–Kiskunhalas) and 155 (Kiskunhalas–Kiskunfélegyháza) was assumed to be 120 km/h. Additionally, a wye at Kiskunfélegyháza and Kétegyháza was added in order to make the direct connection available between lines No. 155–140 and 121–120, respectively. The distinction between Alternatives a and b was the same as previously: the downtown and the southern route (see Figure 3, blue, green and orange lines).

However, Szeged is very close to the border of the country and there is a 3.5 km section of line No. 121 where it runs parallel with the Hungarian–Romanian border in only 50 m distance. This situation makes it a vulnerable line and one should look for another possible alternative that is deeper inside the country.[15]

Szentes–Csongrád

Therefore, an existing bridge was chosen to analyse the effect of its development: in Alternative 3, the Szentes–Csongrád bridge and the line it lies on, line No. 147 (Kiskunfélegyháza–Szentes–Orosháza) and the Orosháza–Békéscsaba section of line No. 135, which connects it to the core network was assumed to be developed to 120 km/h line speed. A wye at Kiskunfélegyháza and Békéscsaba was planned to make lines No. 155 and 147 and lines No. 135 and 120 accessible for each other without a need for a change in the direction (see Figure 3, red and orange lines).

The graph model of the railway network of Hungary

The graph model used for our calculations has been presented in detail in a previous paper,[16] thus we will only discuss it here briefly.

A weighted directed graph was used to model the railway network of Hungary. The nodes of the graph represented the stations where a change in the direction is possible, i.e. not the middle stations of a railway line.[17] Stops with no switches were not included in the model either. As our goal was to analyse the effect of the developments on the defence preparations of Hungary, the sidings of the Hungarian Army were also included in the model.[18]

[15] Horváth 2006: 321–336.
[16] Tóth 2021: 567–587.
[17] Jenelius et al. 2006: 537–560.
[18] Government Decree 277/2014 (XI.14.) on the Amount of Fine the Railway Authority Can Issue and Detailed Rules of Its Payment, 2nd Appendix.

The edges of the graph represented the line sections between these stations. Two weights could be assigned to each edge: the length of the corresponding line section or the ratio of the length of the line sections and the line speed, the so-called pure travel time, which gives the lowest limit a path could be run within, as it does not take into account any speed limit or acceleration/deceleration time. If the value of the line speed was lower for trains with locomotives than for ECMs, then the former, the lower value was used.

For locomotive reversal and direction change, 15 extra minutes were to be added. Therefore, the graph describing the network had to be expanded in order for the algorithm calculating the shortest path to add the extra time of direction changes when needed. No extra trip length or travel time was assigned to passing a station and no extra distance was assigned to reversing.[19]

The data used is publicly available on the website of the Hungarian Rail Capacity Allocation Office (Vasúti Pályakapacitás-elosztó Kft.).[20] With these data, the length and the duration of every path can be calculated and the shortest and the fastest path between any pair of station can be determined.

The calculations and the visualisation of the results were performed in the R programming language and environment[21] using the *igraph* package[22] developed by Gábor Csárdi and Tamás Nepusz. The graph describing the network is encoded as a two-column matrix, a so-called edge list.[23] Each line describes a line section, the first number being the index of the origin and the second the number of the destination station of the line section. For each edge, a weight can also be assigned, using a vector with a dimension equal to the number of edges, which in our case was either the distance between the nodes representing neighbouring stations or the corresponding travel time. The shortest distance (in distance or time) between any two stations can be determined by the *distance()* function of the *igraph* package, which uses Dijkstra's algorithm[24] in graphs with positive weights (such as the one we use) by default. The function *shortest_paths()* can be used to determine which edges and nodes fall on the shortest path.

Results

The distribution of the paths for Alternatives 1a, 1b, 2a and 2b are visually the same (see Figure 4 left). One end of the paths is distributed almost in the entire country but the other end is located in the southeastern part of Hungary. This means that these bridges serve only this small region which is otherwise not too important. Some paths even cross the Szolnok–Szajol bridge, too and thus do not make its traffic decrease but increase.

19 Tóth 2018: 505–519.
20 See www.vpe.hu/takt/vonal_lista.php
21 R Core Team s. a.
22 Csárdi–Nepusz 2006: 1–9.
23 Tóth 2017: 52–66.
24 Dijkstra 1959: 269–271.

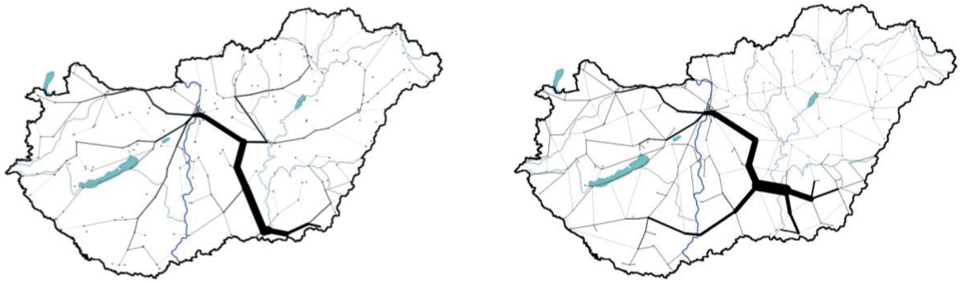

Figure 4: The geographical distribution of the paths passing through the Szeged bridge (left) and the Szentes–Csongrád bridge (right)

Note: The thickness of the lines is proportional to the number of paths. The number of paths passing through the new bridge is taken to be 100%.

Source: Compiled by the authors.

On the contrary, Alternative 3 is used by paths from smaller regions like the northwestern and the southwestern parts of the country and paths that also pass through core lines (see Figure 4 right). The other end of the paths occupy a larger portion of the southeastern region of the country and it is obvious from the figure that it could be used as an alternative for line No. 120 in approaching this region. These paths do not cross the Tisza via other bridge(s) and therefore it could be a real alternative for the Szolnok–Szajol bridge even in the undisrupted network.

Table 1: The percentile change in the measures used to describe the alternatives

	Distance					**Time**				
Alternative	**1a**	**1b**	**2a**	**2b**	**3**	**1a**	**1b**	**2a**	**2b**	**3**
Decrease in the total network path length/travel time if the new bridge is implemented (%)	0.18	0.32	0.16	0.30	0.33	0.50	0.34	1.2	1.1	0.57
Decrease in the traffic of the most heavily loaded line section if the new bridge is implemented (%)	0.70	1.3	0.59	1.2	1.5	0.59	1.2	0.48	1.0	1.4
Ratio of paths passing through the new bridge (%)	1.9	2.7	2.2	2.7	3.5	1.7	2.4	2.0	2.6	3.1

Source: Compiled by the authors.

In Table 1, the percentile values of the decrease in the total network path length/total network travel time if the new bridge is implemented, the decrease in the traffic of the most heavily loaded line section if the new bridge is implemented and the ratio of paths passing through the new bridge are shown. Overall, the values are quite disappointing. The decrease in the total network trip length and the total network travel time is very low, only in two cases higher than 1%. This means that neither of them has such a good overall effect on the total network to be worth building it.

Neither causes the new bridge a decrease in the traffic of the line section with the heaviest traffic, which is the Ferencváros–Kelenföld line section with the Southern Railway Bridge.

In the view of the traffic passing through the new bridge, Alternative 3 is the best solution. This is due to its more central location, i.e. the paths do not have to travel down to Szeged which decreases both the path length and the travel time. The alternatives with the city bridge are in every case worse than the alternatives, which include the path that bypasses Szeged to the south. In addition, the alternatives which assume the Baja bridge and its connecting lines to have a higher line speed are better than the ones that do not. However, it is obvious from these measures that neither of these alternatives causes alone a significant improvement of the network.

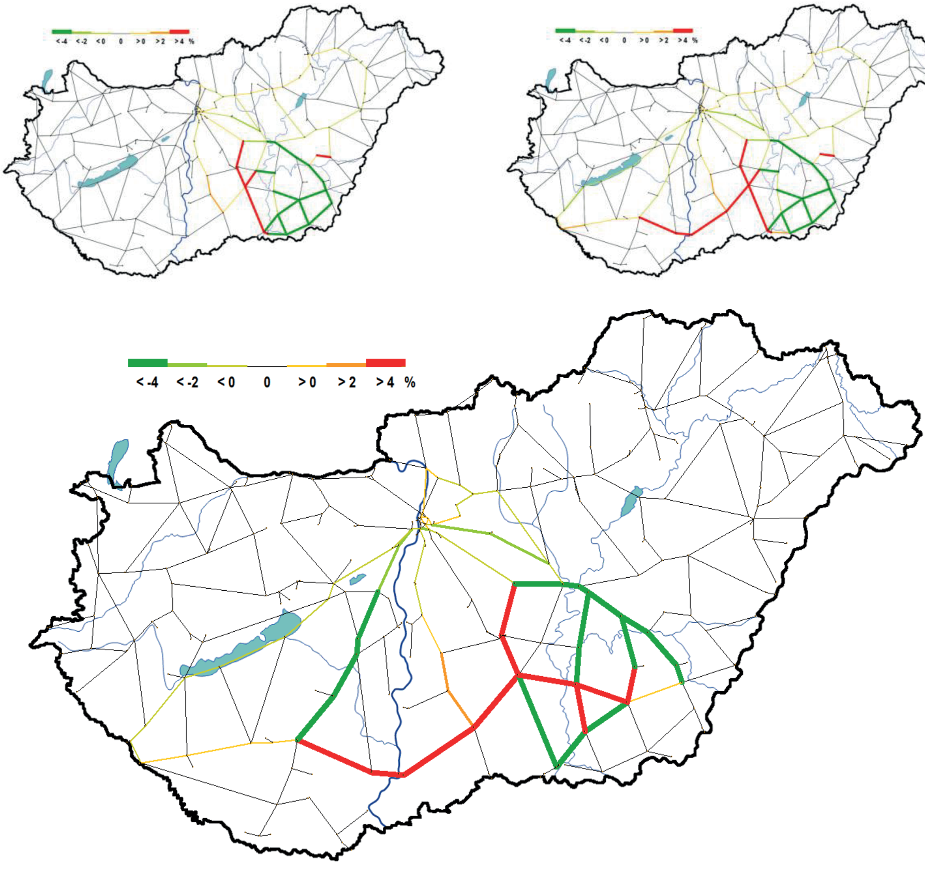

Figure 5: The change in traffic caused by each alternative of the Szeged bridge for minimal path length (top left) and for minimal travel times (top right) and for the Szentes–Csongrád bridge (bottom) compared to the present situation

Source: Compiled by the authors.

As it is seen from Figure 5 (in accordance with Figure 4) that the Alternatives 1a, 1b, 2a and 2b do not cause a decrease in the traffic of Budapest but as the traffic on lines No. 80 and No. 100 is slightly increased, so do the lines inside the capital. Thus, due to the way the paths redistribute in the country in the presence of this bridge the traffic passing through Budapest becomes higher.

The bridge according to Alternative 3, however, causes the traffic of the main lines leading to Budapest to decrease, for some even with a ratio greater than 4%. This should clearly have a positive effect on the traffic load of the capital because fewer paths have to pass through it using its railway infrastructure. As it can be seen in Figure 5, the redistribution makes the traffic on the Baja bridge increase significantly, which was the goal of its assumed reconstruction. As the traffic of core line No. 120 is decreased.

Redundancy

If a shortest path passes through line section *v* in the undisrupted network, on the disruption of line section *u* there are three scenarios, two of which are irrelevant for us. First, if the shortest path passes through line section *v* in the disrupted network, too, then the disruption has no effect on *v* as it is still useable. Second, if the disrupted line section, *v*, makes at least one pair of stations unreachable for each other, then there is no possible alternative path (see Figure 2). Therefore, these two scenarios are left out of the calculations.

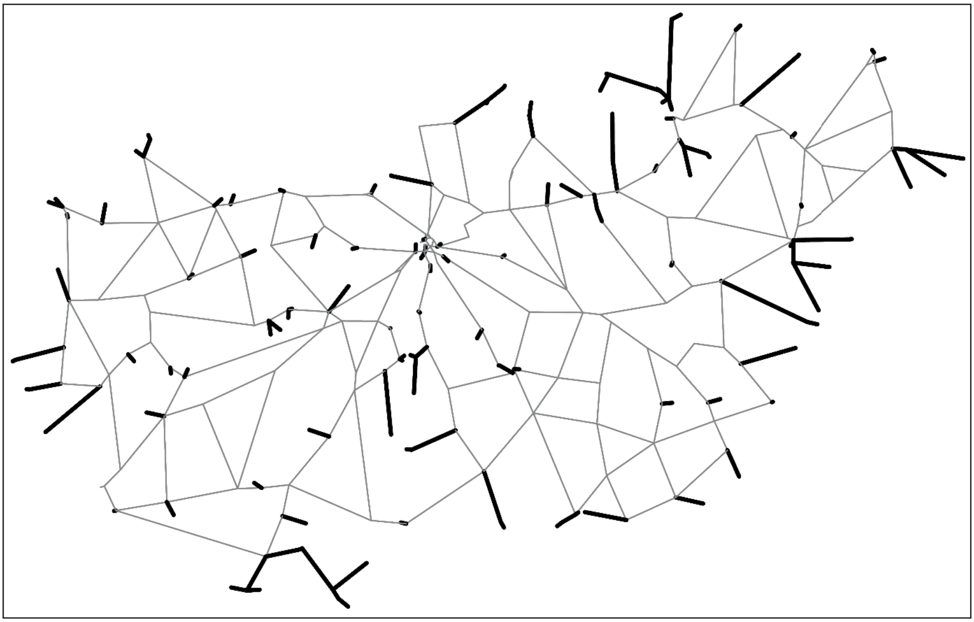

Figure 6: Line sections the disruption of which make stations unreachable for others

Source: Tóth 2020: 358–367.

The Network Robustness Index

The Network Robustness Index (NRI) was introduced by Scott et al.[25] as a global measure to quantitatively describe the overall resilience of a network against disruptions. The NRI can be calculated for all edges of the graph based on which the importance of the individual line sections can be determined.

To calculate the NRI for line section v, the shortest paths between all pairs of stations in the undisrupted graph have to be determined. Then, the lengths or durations of these paths have to be summed, the value of which is denoted by c.

Then, the edges representing line section v are deleted from the graph. Again, the shortest paths between all pairs of stations are determined and their lengths or durations are summed. This value is denoted by c^v. The NRI is calculated as the difference of these two values and is denoted by q^v:

$$q^v = c^v - c \tag{1}$$

The difference is made in this order for q^v to be non-negative since for most kinds of weights the deletion of a line section increases the sum of the weights of the shortest paths (or at least does not decreases it, but for a famous exception that occurs in flow models, the Braess paradox[26]). This can be done for all line sections or for multiple line sections. If line sections v and u are simultaneously deleted, the NRI is calculated as

$$q^{uv} = c^{uv} - c \tag{2}$$

The value of q^v_{ab} (the difference in the shortest path between stations a and b in the disrupted and in the undisrupted network) shows if the shortest path in the undisrupted network passes through line section v. If $q^v_{ab} = 0$, then line section v is not part of the shortest path between stations a and b neither in the undisrupted network nor in the network without line section v. If $q^v_{ab} > 0$, then by deleting line section v, the length or duration of the shortest path between station a and b increases compared to the shortest path in undisrupted network. This means that line section v was part of the shortest path in the undisrupted network but there is still a non-infinite route between stations a and b in the disrupted network.

The redundancy index

The Network Robustness Index measures the increase in the total network trip length or the total network travel time in case of the deletion of a line section. But on the disruption of line section v, the exact route of the shortest path between stations a and b changes compared to the shortest path in the undisrupted network.

Let us assume that the shortest path between stations a and b in the undisrupted network did not pass through line section u but in the network without line section v it does. How

[25] Scott et al. 2006: 215–227.

[26] Braess 1968: 258–268; Braess et al. 2005: 446–450.

much would be the additional increment in the shortest path if *u* would be deleted, too? This increase is the redundancy provided by line section *u* to line section *v*. Paths that pass through line section *u* neither in the undisrupted nor in network without line section *v*, or pass through it in both are not relevant, since they are not sensitive for the disruption of line section *v*.

The r^{uv} redundancy index is defined by the sum of the increase of the shortest paths in the network without line section *v* and *u* compared to the sum of the shortest paths in the network without *v:*

$$r^{uv} = q^{uv} - q^{v} = (c^{uv} - c) - (c^{v} - c) = c^{uv} - c^{v} \qquad (3)$$

By calculating r^{uv} for all *u* line sections that are only in the shortest paths between stations *a* and *b* in the network without line section *v* but are not in the shortest path in the undisrupted network and summing them up one gets the total redundancy that line section *u* provides to the network:

$$r^{u} = \Sigma_{v} r^{uvv} = \Sigma_{v}(q^{uv} - q^{v}) = \Sigma_{v}(c^{uv} - c^{v}) \qquad (3)$$

This definition was introduced by Erik Jenelius.[27]

Application on 1-edge-connected graphs

It can be seen from the definition, that if such line sections are deleted from the graph that make at least one station unreachable from the others, the value of both q^{v} and r^{u} becomes infinity. The railway network of Hungary has this property, which means that the graph describing it is a so-called 1-edge-connected graph.

In several cases, by deleting only one line section from the network, the graph will remain connected. However, if two line sections are deleted, the number of reasonable results will rapidly decrease. If all these line sections were excluded from the calculations, only a few would remain and if only those line sections were excluded which give infinity as a result in that particular calculation, then different line section would be taken into account for each *v* line section, which would make the obtained r^{u} values incomparable to each other.

Therefore, it is practical to use the reciprocals of the travel time and trip length values of the shortest paths. By changing the order in which the difference is calculated in the summation of Equation (2), the redundancy index remains positive since longer distances mean shorter values in the reciprocal space.

By summing the values of the redundancy indices calculated in the reciprocal space for all *v* line sections one gets the total redundancy of a line section *u:*

$$\sum_{v} r_{\ell}^{uv\prime} = \sum_{v}(c_{\ell}^{v\prime} - c_{\ell}^{uv\prime}) = \sum_{v}\left(\sum_{\langle a,b\rangle}\frac{1}{\ell_{ab}^{v}} - \sum_{\langle a,b\rangle}\frac{1}{\ell_{ab}^{uv}}\right) \qquad (5)$$

[27] Jenelius 2010: 129–137.

$$\sum_v r_t^{uv\prime} = \sum_v (c_t^{v\prime} - c_t^{uv\prime}) = \sum_v \left(\sum_{\langle a,b \rangle} \frac{1}{t_{ab}^v} - \sum_{\langle a,b \rangle} \frac{1}{t_{ab}^{uv}} \right) \tag{6}$$

However, it is more informative to normalise these values with values of the total trip length or the total travel time of the undisrupted network (which value is denoted by c_ℓ' and c_t', respectively):

$$r_\ell^{u\prime} = \frac{\sum_v r_\ell^{uv\prime}}{c_\ell'} = \frac{\sum_v (c_\ell^{v\prime} - c_\ell^{uv\prime})}{c_\ell'} = \frac{\sum_v \left(\sum_{\langle a,b \rangle} \frac{1}{\ell_{ab}^v} - \sum_{\langle a,b \rangle} \frac{1}{\ell_{ab}^{uv}} \right)}{\sum_{\langle a,b \rangle} \frac{1}{\ell_{ab}^0}} \tag{7}$$

$$r_t^{u\prime} = \frac{\sum_v r_t^{uv\prime}}{c_t'} = \frac{\sum_v (c_t^{v\prime} - c_t^{uv\prime})}{c_t'} = \frac{\sum_v \left(\sum_{\langle a,b \rangle} \frac{1}{t_{ab}^v} - \sum_{\langle a,b \rangle} \frac{1}{t_{ab}^{uv}} \right)}{\sum_{\langle a,b \rangle} \frac{1}{t_{ab}^0}} \tag{8}$$

The $r^{u\prime}$ redundancy index is the total relative decrease in the reciprocal trip length or travel time for those shortest paths that do not pass through the line section *u* in the undisrupted network but pass through it in case of the disruption of line section *v* with line section *u* fixed for the calculation.

Results – Danube

The redundancy value of the three existing Danube bridge and the modelled fourth one was calculated for each alternative. The results can be seen in Figure 7. In general, the redundancy of the bridges become more even than it is currently. This is a good indication that a new bridge would make a good replacement of any of the others.

The highest redundancy value is the one of the Dunaújváros–Szalkszentmárton bridge, the site where the TS floating bridge has once been.[28] Thus, from these results (and also combined with the traffic values presented in Part 1 of this study) this site is the optimal one to build a new bridge on the Danube.

28 Szászi 2013a: 101.

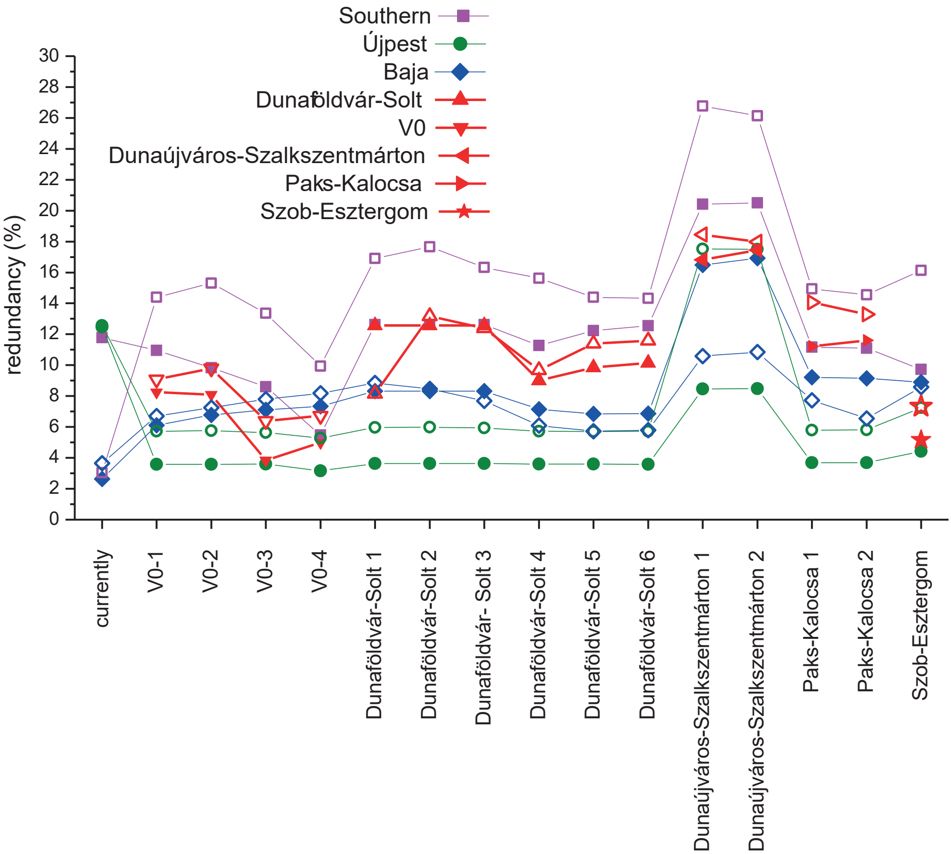

Figure 7: The redundancy values of every Danube bridge in case of each alternative for the new bridge

Source: Compiled by the authors.

Results – Tisza

The redundancy value of the existing Tisza and Danube bridges and the modelled new Tisza bridge was calculated for each of the five alternatives. The results can be seen in Figure 7 (if the bridge at Szeged is assumed, the redundancy of the Szentes–Csongrád bridge is not plotted).

The results show that no matter which alternative is chosen, the redundancy of the new Tisza bridge is the same. This means that the increase in both path length and travel time is the same if the new bridge is disrupted and its bypass route is through the Szolnok–Szajol bridge.

The redundancy values of the Danube bridges alter in the presence of a new Tisza bridge only a little, which is due to the slight redistribution of the paths to the Baja bridge as the new Tisza bridge is in the geographical latitude range between Budapest and Baja. The values become more evenly distributed, so the new Tisza bridge is also efficient in balancing the roles of the existing Danube bridges.

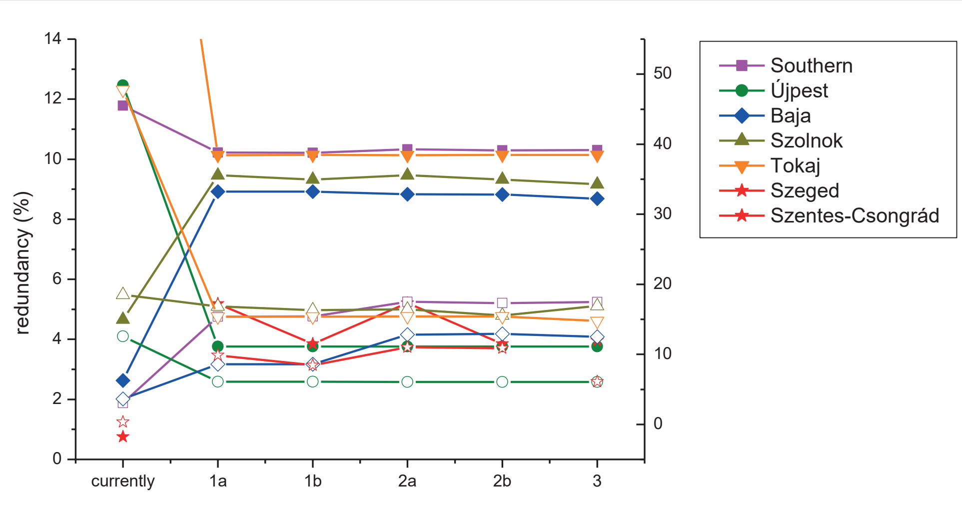

Figure 8: The redundancy values of the existing Danube bridges, the two main Tisza bridge and the new Tisza bridge in case of each alternative for the new bridge

Source: Compiled by the authors.

The redundancy values of the existing Tisza bridges change drastically (Figure 8.). As the three are distributed evenly along the river and due to its geographical position the Szolnok–Szajol bridge remains the most important one, both of them is a similar replacement for it. These results indicate that no matter which of the five modelled alternatives is built, not only the substitution of Tisza bridges become possible on more reasonable routes in case of a disruption but also the traffic on the Danube bridges becomes more evenly distributed.

One new bridge on both rivers

As we have seen here and in Part 1 of the study, the Dunaújváros–Szalkszentmárton and the Dunaföldvár–Solt bridges can be an effective new crossing over the Danube. But as we have emphasised there, without a new bridge over the Tisza, the increase in the traffic through the Danube and through the country the new bridge could handle, could not pass through the existing Tisza bridges. This problem would not have been solved by the planned V0 railway either as it would lead until Szolnok, at maximum.[29]

As it was seen, the best alternative for a new Tisza bridge is to develop the Szentes–Csongrád bridge and the lines connecting it to the core network to have a second track and

[29] Tóth–Horváth 2019: 109–129.

a line speed of 120 km/h, i.e. Alternative 3 but without a reconstructed Baja bridge. This bridge also has the advantage of being more centrally located in the country than a bridge at Szeged which is important in its military applications.

Therefore, we adjusted our graph to include Alternative 3 and either of the two Dunaújváros–Szalkszentmárton and Alternatives 4, 5 and 6 of the Dunaföldvár–Solt bridge. The first two alternatives will be referred to as Dunaújváros Szentes 1 and 2, the latter three as Dunaföldvár–Szentes 4, 5 and 6 to make comparison with previous results easier.

Note, that these scenarios only include a new bridge over the Danube and a developed one on the Tisza as the Baja bridge and its connecting lines were not assumed to be developed. This is due to its southern position in the country and that the traffic should pass through the new bridge which is not too far from Budapest, unlike the Baja bridge. A train in a northwest–northeast direction, which is the most common in the freight transport corridor of Hungary,[30] will not travel that south if there is a bridge halfway.

Results

Calculating the paths that pass through each bridge we get the plots shown in Figure 9.

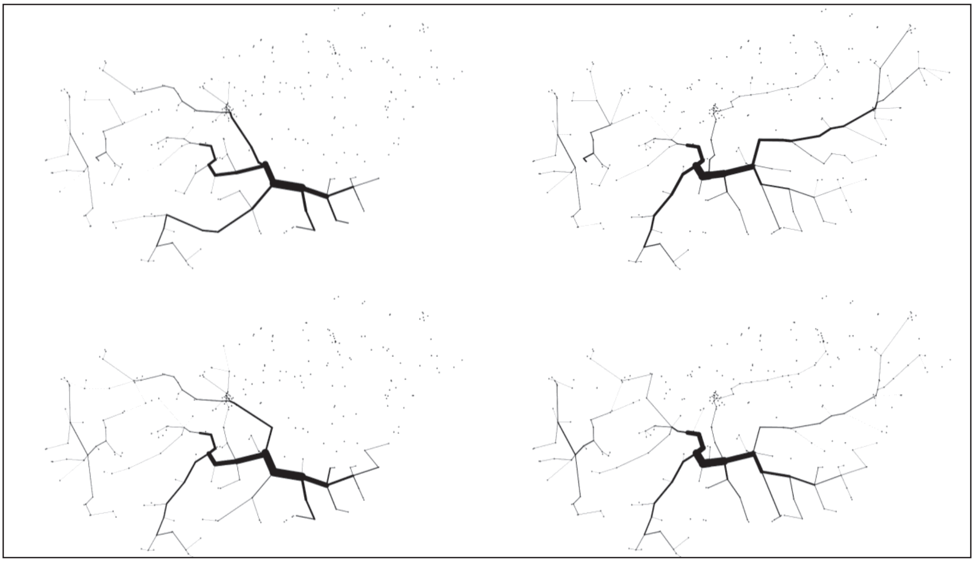

Figure 9: The geographical distribution of the paths passing through the Szentes–Csongrád bridge (left) and the Dunaföldvár–Solt bridge (right) for minimal trip lengths (top) and for minimal travel times (bottom)

Note: The thickness of the lines is proportional to the number of paths. The number of paths passing through the bridge is taken to be 100%.

30 Lakatos et al. 2016: 181–288.

Source: Compiled by the authors.

The results for Alternatives 4, 5 and 6 are practically the same. The Danube bridge connects distant regions of the country including important international border crossings like Hegyeshalom, Rajka, Záhony, Lőkösháza, Röszke or Gyékényes via the core network. The Tisza bridge has the same role, except that the paths of the northeastern part of Hungary do not pass through it, they cross the Tisza via the Szolnok–Szajol bridge.

The numerical values of the measures describing the network as a whole can be seen in Table 2.

Table 1: The percentile change in the measures used to describe the alternatives

Dunaföldvár–Szentes	**Distance**			**Time**		
Alternative	**4**	**5**	**6**	**4**	**5**	**6**
Decrease in the total network path length/travel time if the new bridge is implemented (%)	8.6	8.6	8.8	9.4	9.6	9.6
Decrease in the traffic of the most heavily loaded line section if the new bridge is implemented (%)	11.8	12.3	12.3	14.7	15.4	15.4
Ratio of paths passing through the new bridge (%)	8.3	8.6	9.3	7.2	7.5	7.4

Source: Compiled by the authors.

It seems that the three alternatives are essentially the same, Alternative 6 being a slightly better one. The total network travel time decreases with almost 10% which is an outstanding value compared to the alternatives in the first part of the study where there was no new Tisza bridge just a new Danube bridge. The change in the traffic of the busiest line section, the one of the Southern bridge is the same to the alternatives when there were no development of Tisza bridges which means that a Danube bridge alone would make many of the paths to reroute, though there were no capacity for them to pass through the Szolnok–Szajol bridge.

The effect of the alternatives on the traffic of Budapest is plotted in Figure 10.

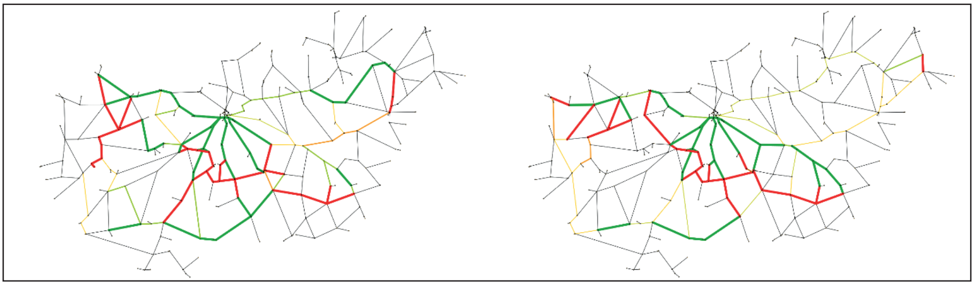

Figure 10: The change in traffic for minimal trip lengths (left) and for minimal travel times (right) compared to the present situation

Source: Compiled by the authors.

Though all three alternatives have practically the same effect on the capital, it is a very positive effect. The traffic of all radial main lines decreases with a significant amount.

This not only makes Budapest less congested but also as seen from the maps of Figure 10, makes use of both the Dunaföldvár–Solt bridge and the Szentes–Csongrád bridge.

Summary

We analysed the possible paths of a new Tisza bridge at Szeged and the possible development of the already existing Szentes–Csongrád bridge. The calculations showed that all alternatives have practically the same effect on the railway network of Hungary but these effects are not as advantageous to suggest the realisation of one of the alternatives.

Comparing with the results of the first part of this study, several locations of both a Danube and a Tisza bridge were tested and the results of this combined development plan was convincing. In summary, we can say on the basis of our model that one bridge alone is not enough as currently there are only one high capacity crossing on each river and thus one new is needed on each. If the exact location is determined in a well-established way, not only the problems of Budapest originating in the high traffic can be treated but more transportation capacity can be put in the network which can boost the economic benefits of the international trade routes passing through the country.

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