Railway Escape Velocity

Balázs Kotosz[1]

The borders of the agglomerations can be located by the administrative units, but these limitations do not reflect the borders of functional spaces. The aim of this paper is to show and apply a special locating method by the example of Budapest. The main idea is the motorway effect (the shortest way is generally not the quickest) applied to passenger railway traffic.

The travellers of the agglomeration towards cities far from the capital have a choice: going back to the centre and take a direct fast train or take a stop-train for getting to the first station out of the agglomeration where fast trains stop. We can terminate the settlements from where the return is quicker. This boundary can be perceived as the limit of the gravitational space of the main city.

Keywords: time-space map, railway traffic, gravitational law, agglomeration location

1. Introduction

The borders of the agglomerations can be located by the administrative units, but these limitations do not reflect the borders of functional spaces. The aim of this paper is to show and apply a special locating method by the example of Budapest.

The structure of the paper is the following. In the first part we present the motorway effect, the gravitational model and the gravitational law, as well as the theoretical background of time-space maps. Here we offer a new method to investigate our problem called "railway escape velocity". The second part is considered to the practical problems of the applied method, while in the third part we summarize the empirical evidence of the calculations. So, the problem is discussed in sociological and engineering perspectives (Wegener 2001).

[1] Balázs Kotosz, PhD, assistant professor, Corvinus University of Budapest, Faculty of Economics, Hungary.

2. Theoretical background

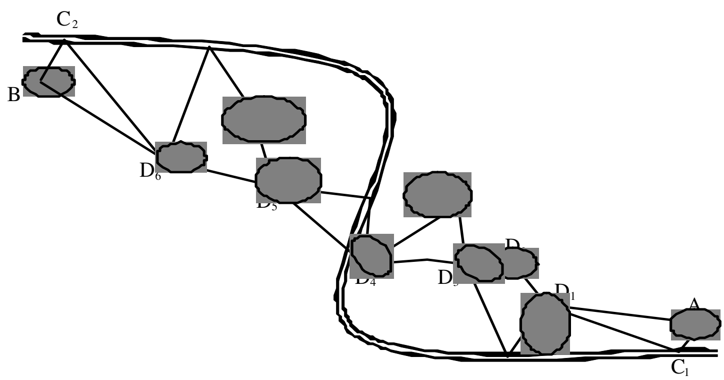
2.1. The motorway effect

The basic idea of the paper is the motorway effect. In transport analysis it is obvious that the shorter way is not always the faster, on the road it is quicker to find the nearest motorway, and to follow it to the nearest exit to the target. (See Figure 1: The shortest way from A to B is via D1 – D2 – D3 – D4 – D5 – D6, but it can be faster to avoid these settlements and take the motorway from C1 to C2.)

This model is also popular in economic policy theory: if the economy is not in an equilibrium growth path, the first step should be a stabilization program, and then the equilibrium growth path is easily sustainable.

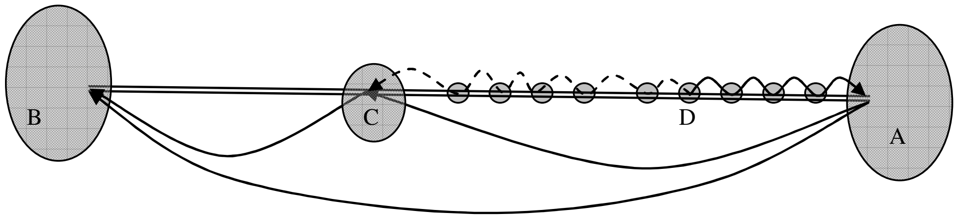
In the railway traffic the motorway effect is little bit different. In passenger transport, generally different types of trains run parallel between cities. Stop trains stop at (almost) every station, fast and mainly Intercity or high-speed trains serve only largest cities. Additionally, stop trains' itinerary is not longer than 60-100 km. Thereby, if travellers of the agglomerations (D) of large cities (A) would like to get to cities out of this 60-100 km circle, they have to change train somewhere (C) (See Figure 2). We have to mention that in some cases, long-run stop trains also circulate, but mostly it is faster to change. Practically, the only question is the place of the change. Is it faster to go back to the centre (D→A→B) or to crawl out of the agglomeration by a stop train (D→C→B)? It depends on the distance from the centre, the density and the speed of the trains and on the current time. We have to remark that these journeys may be atypical (Levinson-Kumar 1993, Ecostat 2006).

Figure 1. The motorway model in road transport



Source: own creation

Figure 2. The motorway model in railway passenger transport



Source: own creation

2.2. *The physical model*

The physical analogy is clear, if the kinetic energy of a body is small, the body cannot leave the gravitational zone of the other body. For the first sight, it is a case of the gravity model often applied in spatial analysis. The gravity model is really a wholesome method in the modelling of flows (see Fotheringham-Haynes 1988, Reilly 1929, Rodrigue et al. 2006), but the possible applications are limited (for this limits see Dusek 2003; Rodrigue et al. 2006). If our question was whether the traffic from D is larger to A than to B, the gravity model would be applicable. As Dusek (2003) enlightens it, the gravitational model and the gravitational law have the same roots, but not all phenomena of the gravitational law can be handled by the model. As in our case it is the law we apply, only some of Dusek's warnings should be minded.

In almost all spatial analysis we face the problem point of the territories: they have to be analysed as points. Where is the middle of a country, region, or even a village? This problem is not essential in the railway gravity case, because the size of small stops is negligible (regarding the used distances), and the journey time from great cities or capitals is counted from the relevant railway station.

Our model by the physical analogy is that of escape velocity. In the physics, the necessary speed of a body to leave the gravitational space of another body can be calculated by the following form:

$$v_2 = \sqrt{\frac{2 \cdot G \cdot M}{r}} \tag{1}$$

where G is the gravitational constant (6.6742*10-11 $\mathrm{Nm^2kg^{-2}}$), M is the mass of the body being escaped from, and r is the distance between the centre of the body and the point at which escape velocity is being calculated. (Holics 1986) In socio-economic analysis, the escape velocity is a growing function of the socio-economic importance (mass) of the centre, and a decreasing function of the distance from the centre. In the adaptation to the railway traffic, the formula is as following:

$$v_{er} = c \cdot \frac{M^{\alpha}}{r^{\beta}} \tag{2}$$

where v_{er} is the "railway escape velocity", c is a constant, α and β are parameters. The v_{er} has a complex meaning of the frequency and average speed of stop trains, while M is definitively influenced by the importance of the centre in the national/international railway system. In this applied model, c, α and β have to be calibrated by the empirical evidence. For a starting point, we can assume that $\alpha=1/2$ and $\beta=1/2$, as it is in the physical model. In the literature we could not find any precedent for the measurement and calibration.

The main problem is the definition of the mass, as the importance of a city can be represented by several measures. The illustration of railway mass of the city is more complicated. The number of train departures from the city or from the relevant station, in absolute or in relative terms can be the appropriate measures.

The distances are measured along the railway line (in km), but the optimization was made by time. Sometimes even the ranks of distance and time are not correlated, so the real space and the time space are distinct. (Janelle 1969, Janelle 1975, Knowles 2005)

2.3. Time-space maps

The time-space and the geographical space are quite often different. Geographical distances – mainly in the case of relevant distances of our paper – are more stable, than necessary time to get from one point to another. The distance in time terms depends on many factors, including the mean of transport, the state of the infrastructure, etc. Maps including time data are constructed to show the accessibility – in the form of isochronous maps or average accessibility time maps. (Dusek-Szalkai 2007) Another possibility is the strictly defined time-space map, where the original map is transformed as the distance of two points is proportional to the time-distance. (Dusek-Szalkai 2008)

2.4. Detailed description of possible zones

The space between points A and C can be separated to different zones: (1) the always attracting area (***R1***), (2) the typically attracting area (***R2***), (3) the typically not attracting area (***R3***), and (4) the never attracting area. So $\mathbf{R1} \subseteq \mathbf{R2} \subseteq \mathbf{R3}$. The exact definition of ***R2*** and ***R3*** sets can be found in chapter 3. Similar delimitation is not known in the literature (Kotosz 2010), other methods use journey time and costs. See (Levine et al. 2005), or (Iacono et al. 2008).

3. Methodological questions

We have several points to make them clear about the applied method.

In this paper, all calculations are made for journeys from the agglomeration to a far city. As the timetable is not symmetrical, the results of backward journeys can be slightly different. This is a typical problem of the time-space asymmetries.

All calculation of this paper is based on the official, first printed version timetable of the Hungarian State Railways (MÁV) for each timetable year (e.g. we call 2007 timetable that one valid from December 2006 to December 2007). As all timetable data is on minute exactness, we used this in all calculations. The timetable reading was manual, we did not use any journey planner software – in the random traveller case it would not be efficacious. The calculations were made in Excel.

3.1. The choice of the target city

If the target is close, some long-run stop trains can reach it or fast and Intercity trains do not halt there, and the results are misleading. Specially, in the case of the Western European high-speed trains, journey of two hours means 5-600 km, so applicable target is far from the starting-point. If the target is too far and/or has few direct connections from the main city, the results will better flash the contingency of the railway traffic, but not the gravitational zone. We suppose that a viable distance is that of a journey of three hours, in Eastern European context, this is 200-300 km.

3.2. Rational/random traveller

The starting time of the travel can be chosen in two different ways. First, we can suppose a rational traveller who arrives to the station just in the minute of the journey. In this case, we use a pure travelling time that excludes the density of trains. Generally, local stop trains run more frequently than Intercity or international trains, thereby in this model the rational traveller arrives to the local station when she gets the last stop train providing connection to the next fast train. Second, we can assume a random traveller who arrives to the station at random time (in this paper it means uniform distribution, e.g. she arrives with the same probability at 2:05 AM and at 8:05 AM). This version prefers frequent connections between the centre and the far city. For example, in the first case, if we have only one fast train per day, the average journey time is the same as we have hourly connection; but it is not true anymore in the second case.

3.3. Periodicity

At this point, another periodicity of the timetables has to be mentioned. Some stop trains do not circulate every day, so for the seven days of the week, separated calculations have been made. Finally, the average journey time was calculated by the uniform distribution principle, with the same probability for the days of the week.

3.4. Transfer

We can decide whether we consider any time for transfer. In double-track lines, it may happen that a stop train arrives and in the same minute the fast train starts to the opposite direction. We applied a five minutes period for the transfer – any connection shorter than five minutes are neglected. For an average traveller without huge baggage, this time could be enough. At this point, we have to mention that delays are also neglected; it is an important, but hardly measurable factor in this analysis.

3.5. Indicator of limitation

Finally we have to decide the critical indicator of the limitation. At a chosen moment, we can surely see which direction is better. But what means generally? First, we can calculate the average inward and outward journey time; and the lower will be better. Second, in the case of the random traveller, we can compare the time periods of the day when one or other direction is faster; then the direction having more than 12 hours a day is the winner. From a practical point of view, it may lead to favour the direction of the first train in the morning. In the case of the rational traveller this method is less complicated: we have to count the better choices.

4. Empirical evidence

Originally, the technical frame of the research was constructed for the Budapest-Győr-Wien line. First, we demonstrate the details of this line, after we synthesize the characteristics of two special lines, finally we show the maps made on the basis of the numerical analysis.

4.1. Budapest-Győr-Wien line

Table 1. Summary output for the Budapest-Wien line (2005)

Start	**Distance (km)**	**Rational traveller**		**Random traveller**		**Best choice rate (%)**
		average time (min)	**average speed (km/h)**	**average time (min)**	**average speed (km/h)**	
Budapest	273	173	94.9	344	47.6	-
Budaörs out	253	245	62.1	407	37.3	0.0
Budaörs in	265	212	75.3	380	41.8	100.0
Budaörs opt	-	211	75.4	379	46.2	-
Törökbálint out	249	240	62.3	402	37.2	27.8
Törökbálint in	269	216	74.6	385	41.9	72.2
Törökbálint opt	-	215	73.1	383	44.9	-
Biatorbágy out	241	233	62.1	395	36.6	44.4
Biatorbágy in	277	223	74.5	392	42.4	55.6
Biatorbágy opt	-	215	72.0	382	43.7	-
Herceghalom out	234	226	62.2	388	36.2	64.8
Herceghalom in	284	231	74.0	399	42.7	35.2
Herceghalom opt	-	214	70.3	380	42.5	-

Source: own creation

We summarize here the particular results for the Budapest-Győr-Wien railway line, so we are curious about the Budapest agglomeration and the target city is Wien. The distance of the two cities is 273 km by rail. All times and distances are calculated from the terminus of the line (Budapest-Keleti). As all these international trains stop at Budapest-Kelenföld, journeys from the agglomeration via Budapest can be shorter.

First, about the 2005 year. The running time of the six direct trains was between 170 and 179 minutes. For rational and also random travellers, the average journey time from Biatorbágy with returning to Budapest is shorter than the direct way out. Additionally, in most cases the inward travel is quicker than outward. From Herceghalom (otherwise the last settlement in Pest county) all indicators change; the better choice “generally” is not returning to Budapest. Thereby the limit of the gravitational zone is clearly between Biatorbágy and Herceghalom.

Table 2: Summary output for the Budapest-Wien line (2006)

Start	Distance (km)	Rational traveller average time (min)	Rational traveller average speed (km/h)	Random traveller average time (min)	Random traveller average speed (km/h)	Best choice rate (%)
Budapest	273	174	94.0	345	47.4	-
Budaörs out	253	239	63.5	403	37.7	0.0
Budaörs in	265	189	84.0	369	43.1	100.0
Budaörs opt	-	189	85.0	369	49.5	-
Törökbálint out	249	234	63.8	398	37.6	18.4
Törökbálint in	269	194	83.1	374	43.1	81.6
Törökbálint opt	-	193	83.7	372	48.4	-
Biatorbágy out	241	227	63.6	391	37.0	20.4
Biatorbágy in	277	201	82.7	381	43.6	79.6
Biatorbágy opt	-	197	83.2	372	46.9	-
Herceghalom out	234	220	63.7	384	36.6	30.6
Herceghalom in	284	208	81.9	388	43.9	69.4
Herceghalom opt	-	202	80.7	373	44.9	-
Bicske out	224	191	70.3	357	37.6	83.7
Bicske in	294	209	84.5	387	45.5	16.3
Bicske opt	-	189	73.9	355	44.1	-

Source: own creation

In 2006, the supply of Budapest-Wien trains was broadened by an additional train. The running time from Budapest to Wien varied between 156 and 185 minutes. At the same time, in out-of-peak times, a rhythmical timetable of stop trains was introduced. By default, this rhythm was not in accord with other outgoing trains, so the limit of the agglomeration moved out, it was between Herceghalom and Bicske (where inland fast trains stop).

In 2007, the situation turned round. Over the addition of two international trains (with running time between 176 and 182 minutes), the outgoing timetable is rhythmical, with good connections towards Győr (change in Tatabánya). The stop trains from the agglomeration arrive to Budapest at the same minute when international trains depart, so travellers should wait to the connection almost one hour. As Table 3 suggests, if inward stop trains went 5 minutes earlier, the average inward travel time would be much shorter (the general time saving would be 55 minutes), so the end of the gravitational zone would be more far from Budapest. In that year, there is not clear solution for the limitation. The rational traveller's average journey time from Törökbálint is shorter in the case of outward travel, but in more than half of the cases (possible starting times) the inward journey is faster. The random traveller – on the average – should start inward. Nevertheless, the limit should not be between two stops, but in Törökbálint.

Table 3. Summary output for the Budapest-Wien line (2007)

Start	Distance (km)	Rational traveller		Random traveller		Best choice rate (%)
		average time (min)	average speed (km/h)	average time (min)	average speed (km/h)	
Budapest	273	179	91.3	325	50.4	-
Budaörs out	253	224	67.6	372	40.8	47.6
Budaörs in	265	217	73.3	357	44.6	52.4
Budaörs opt	-	208	74.2	349	49.9	-
Törökbálint out	249	219	68.1	367	40.7	47.6
Törökbálint in	269	222	72.7	362	44.6	52.4
Törökbálint opt	-	208	74.2	351	49.1	-
Biatorbágy out	241	212	68.1	360	40.2	71.4
Biatorbágy in	277	229	72.6	369	45.1	28.6
Biatorbágy opt	-	205	72.8	351	47.9	-

Source: own creation

In 2008 and 2009, only minor changes have been added to the timetable, not disturbing significantly our results, the situation seems to be conserved.

4.2. Budapest-Székesfehérvár-Szombathely/Nagykanizsa line

The choice of target city is open in this case, as the railway lines towards the middle Transdanubia are separated in Székesfehérvár (or over the city). According to the methodological background, the two potential target cities are Szombathely and Nagykanizsa. Nagykanizsa is a classical target city, as all trains use the same itinerary; while Szombathely is applicable for modelling high speed trains (the Intercity trains circulate via Győr). The latter fact and the difference of the average speed of the two lines a priori forecast pushing out of the boundary of the agglomeration. If we would like to estimate the boundary, this duplicity creates a new problem of how to synchronize the two results. For the estimate of the railway escape velocity this duality does not pose a problem.

We pursued the analysis for the period 2005-2008. Although we had the 2009 timetable, but during the most part of the year special – generally weekly changing – timetables were in function due to current reconstruction works.

Table 4. Summary output for the Budapest-Nagykanizsa line (2005)

Start	Distance (km)	Rational traveller		Random traveller		Best choice rate (%)
		average time (min)	average speed (km/h)	average time (min)	average speed (km/h)	
Budapest	221	203	65.2	441	30.1	-
Bfok-Belváros out	212	255	50.8	482	26.5	51.0
Bfok-Belváros in	221	259	52.1	473	28.0	49.0
Bfok-Belváros opt	-	246	53.5	471	34.1	-
Nagytétény out	205	248	50.4	476	25.9	74.5
Nagytétény in	229	268	52.1	481	28.6	25.5
Nagytétény opt	-	244	52.5	470	33.0	-
Érd alsó/felső out	201	241	51.0	466	25.9	81.6
Érd alsó/felső in	233	267	53.3	476	29.4	18.4
Érd alsó/felső opt	-	239	52.8	461	33.6	-
Tárnok out	197	242	49.7	464	25.6	93.9
Tárnok in	237	274	52.7	482	29.5	6.1
Tárnok opt	-	240	51.8	461	32.6	-
Martonvásár out	188	235	48.0	457	24.7	93.9
Martonvásár in	246	282	52.3	490	30.1	6.1
Martonvásár opt	-	…	…	…	…	-
Baracska out	185	…	…	…	…	98.0
Baracska in	249	…	…	…	…	2.0
Baracska opt	-	…	…	…	…	-
Pettend out	180	…	…	…	…	100.0
Pettend in	254	…	…	…	…	0.0
Pettend opt	-	…	…	…	…	-

Source: own creation

Contrary to the Budapest-Győr-Wien line, the Budapest-Székesfehérvár line has a long (14 km) section inside the territory of Budapest. By the different logic of timetables, in the last five years, there were periods when the boundary of the agglomeration was inside of Budapest.

4.2.1. The Budapest-Nagykanizsa line

The limit of the agglomeration is determined by stop-trains between Budapest-Székesfehérvár and Budapest-Martonvásár. The latter influence only inward travel possibilities (they do not have any connections outwards) and they circulate only on workdays.

The Nagykanizsa line has a very specific train, connecting Budapest and Nagykanizsa on Friday afternoon. This train cannot be reached from any stations between Budapest and Székesfehérvár (with the last stop train one may get the previous fast train also). In some years, this fact was true into one direction, but in 2008 into both directions.

The number of direct trains was between 6 and 7 in the analysed period. The average speed was continuously decreasing, caused by the state of the tracks. In some years, a better timetable could cut back the journey time. The reconstruction works between Tárnok and Székesfehérvár in 2009-2010 will hopefully improve the connection.

Table 5. Summary output for the Budapest-Nagykanizsa line (2006)

Start	**Distance (km)**	**Rational traveller**		**Random traveller**		**Best choice rate (%)**
		average time (min)	**average speed (km/h)**	**average time (min)**	**average speed (km/h)**	
Budapest	221	210	63.2	479	27.7	-
Bfok-Belváros out	212	250	50.8	521	24.4	28.6
Bfok-Belváros in	221	251	52.8	494	26.8	71.4
Bfok-Belváros opt	-	238	54.2	493	32.2	-
Nagytétény out	205	244	50.4	514	23.9	71.4
Nagytétény in	229	258	53.3	502	27.4	28.6
Nagytétény opt	-	239	52.1	498	30.9	-
Érd alsó/felső out	201	229	52.7	492	24.5	83.7
Érd alsó/felső in	233	257	54.4	505	27.7	16.3
Érd alsó/felső opt	-	228	53.7	491	30.9	-
Tárnok out	197	224	52.9	487	24.3	100.0
Tárnok in	237	263	54.2	511	27.8	0.0
Tárnok opt	-	224	52.5	487	24.3	-

Source: own creation

Table 6. Summary output for the Budapest-Nagykanizsa line (2007)

Start	Distance (km)	Rational traveller		Random traveller		Best choice rate (%)
		average time (min)	average speed (km/h)	average time (min)	average speed (km/h)	
Budapest	221	234	56.6	488	27.2	-
Bfok-Belváros out	212	268	47.4	519	24.5	16.1
Bfok-Belváros in	221	256	51.8	498	26.6	83.9
Bfok-Belváros opt	-	253	51.3	495	31.8	-
Nagytétény out	205	261	47.1	512	24.0	25.0
Nagytétény in	229	259	53.0	503	27.3	75.0
Nagytétény opt	-	253	51.7	498	30.7	-
Érd alsó/felső out	201	242	49.9	482	25.0	96.4
Érd alsó/felső in	233	255	54.8	497	28.1	3.6
Érd alsó/felső opt	-	242	49.6	482	25.4	-
Tárnok out	197	245	48.2	484	24.5	100.0
Tárnok in	237	267	53.2	508	28.0	0.0
Tárnok opt	-	245	48.2	484	24.5	-

Source: own creation

Table 7. Summary output for the Budapest-Nagykanizsa line (2008)

Start	Distance (km)	Rational traveller		Random traveller		Best choice rate (%)
		average time (min)	average speed (km/h)	average time (min)	average speed (km/h)	
Budapest	221	234	56.6	475	27.9	-
Bfok-Belváros out	212	258	49.3	501	25.4	18.4
Bfok-Belváros in	221	247	53.7	481	27.6	81.6
Bfok-Belváros opt	-	244	53.2	480	32.1	-
Nagytétény out	205	252	48.9	494	24.9	18.4
Nagytétény in	229	247	55.7	485	28.3	81.6
Nagytétény opt	-	243	54.9	483	31.0	-
Érd alsó/felső out	201	237	50.9	482	25.0	95.9
Érd alsó/felső in	233	247	56.7	487	28.7	4.1
Érd alsó/felső opt	-	237	51.4	482	30.6	-
Tárnok out	197	239	49.4	481	24.5	89.8
Tárnok in	237	257	55.4	495	28.7	10.2
Tárnok opt	-	238	50.8	481	30.0	-
Martonvásár out	188	…	…	…	…	100.0
Martonvásár in	246	…	…	…	…	0.0

Source: own creation

We have to see that in 2006 (just like in 2005), the absolute attraction zone (R1 – from where the inward travel is always the best choice) is missing.

4.2.2. The Budapest-Szombathely line

This line has been a new challenge for the modeller. As the passengers of inward and outward travelling have different fast trains (while to Nagykanizsa they tried to reach the same fast train, now they are different – fast train via Veszprém, Intercity via Győr), the optimization process must be changed. In the row of Budapest we show the results of Intercity trains (rational travellers minimize the journey time). The optimal journey data may be peculiar because of this difference.

Table 8. Summary output for the Budapest-Szombathely line (2005)

Start	**Distance (km)**	**Rational traveller**		**Random traveller**		**Best choice rate (%)**
		average time (min)	**average speed (km/h)**	**average time (min)**	**average speed (km/h)**	
Budapest	234	166	84.7	371	37.8	-
Bfok-Belváros out	224	248	54.1	473	28.4	20.0
Bfok-Belváros in	235	216	65.2	418	33.7	80.0
Bfok-Belváros opt	-	213	65.5	408	40.0	-
Nagytétény out	217	243	53.6	467	27.9	20.0
Nagytétény in	242	225	64.5	448	32.4	80.0
Nagytétény opt	-	216	65.9	432	38.6	-
Érd alsó/felső out	213	235	54.3	460	27.8	10.0
Érd alsó/felső in	246	210	70.1	407	36.3	90.0
Érd alsó/felső opt	-	210	68.3	396	41.0	-
Tárnok out	209	230	54.5	455	27.6	10.0
Tárnok in	250	220	68.2	422	35.5	90.0
Tárnok opt	-	218	66.3	411	39.3	-
Martonvásár out	200	223	53.7	448	26.8	45.7
Martonvásár in	259	227	68.3	430	36.1	54.3
Martonvásár opt	-	218	58.8	417	38.1	-
Baracska out	197	220	53.8	445	26.6	77.1
Baracska in	262	237	66.3	443	35.5	22.9
Baracska opt	-	218	55.2	426	36.8	-
Pettend out	192	215	53.6	440	26.2	100.0
Pettend in	267	242	66.2	448	35.8	0.0
Pettend opt	-	215	53.6	440	36.2	-

Source: own creation

In the 2005-2008 period, in both directions 5 trains were circulated that makes easy the comparison (there is no problem with the random traveller bias). The average speed between Budapest and Szombathely is much better than between Budapest and Nagykanizsa. This fact helps the railway to have a strong position against road transport.

In this case, the Martonvásár-Budapest trains add a strong support for inward travels for the stops of these trains, so the typical limit of the best choice based agglomeration is around Martonvásár.

Table 9. Summary output for the Budapest-Szombathely line (2006)

Start	**Distance (km)**	**Rational traveller**		**Random traveller**		**Best choice rate (%)**
		average time (min)	**average speed (km/h)**	**average time (min)**	**average speed (km/h)**	
Budapest	234	175	80.1	379	37.1	-
Bfok-Belváros out	224	246	54.6	471	28.5	0.0
Bfok-Belváros in	235	208	67.7	414	34.1	100.0
Bfok-Belváros opt	-	208	67.7	402	40.8	-
Nagytétény out	217	240	54.2	465	28.0	0.0
Nagytétény in	242	214	67.7	419	34.6	100.0
Nagytétény opt	-	214	67.7	407	40.4	-
Érd alsó/felső out	213	231	55.3	457	28.0	6.1
Érd alsó/felső in	246	200	74.0	403	36.7	93.9
Érd alsó/felső opt	-	199	73.5	390	42.6	-
Tárnok out	209	226	55.5	452	27.8	12.2
Tárnok in	250	206	73.2	408	36.8	87.8
Tárnok opt	-	204	72.2	394	41.9	-
Martonvásár out	200	216	55.5	440	27.3	26.5
Martonvásár in	259	214	72.8	417	37.3	73.5
Martonvásár opt	-	209	68.1	399	40.8	-
Baracska out	197	212	55.6	436	27.1	100.0
Baracska in	262	239	65.8	443	35.5	0.0
Baracska opt	-	212	55.6	419	37.6	-

Source: own creation

The results of 2007 show how the agglomeration is getting out and out. For the random traveller, the average journey time is the same from Pettend, even if the distance by inward travel is 39% longer.

Table 10. Summary output for the Budapest-Szombathely line (2007)

Start	Dis-tance (km)	Rational traveller		Random traveller		Best choice rate (%)
		average time (min)	average speed (km/h)	average time (min)	average speed (km/h)	
Budapest	234	171	82.0	376	37.3	-
Bfok-Belváros out	224	247	54.5	473	28.4	0.0
Bfok-Belváros in	235	198	71.4	401	35.2	100.0
Bfok-Belváros opt	-	198	71.4	389	42.6	-
Nagytétény out	217	241	54.0	468	27.8	0.0
Nagytétény in	242	198	73.2	402	36.1	100.0
Nagytétény opt	-	198	73.2	390	43.2	-
Érd alsó/felső out	213	233	54.8	461	27.7	0.0
Érd alsó/felső in	246	186	79.4	401	36.8	100.0
Érd alsó/felső opt	-	186	79.4	390	44.2	-
Tárnok out	209	228	54.9	456	27.5	32.7
Tárnok in	250	206	72.7	414	36.3	67.3
Tárnok opt	-	205	67.6	397	42.3	-
Martonvásár out	200	218	55.0	443	27.1	60.0
Martonvásár in	259	215	72.2	423	36.8	40.0
Martonvásár opt	-	203	66.0	401	41.5	-
Baracska out	197	214	55.2	439	26.9	60.0
Baracska in	262	222	70.9	428	36.8	40.0
Baracska opt	-	203	66.0	404	40.8	-
Pettend out	192	208	55.4	433	26.6	100.0
Pettend in	267	227	70.6	433	37.0	0.0
Pettend opt	-	208	55.4	433	39.6	-

Source: own creation

The results of 2008 were shocking. The limit of the agglomeration (based on the average journey time) is around Baracska, but at some points of time, from the board of Lake Velencei is better to go back to the capital, instead of starting outwards. We have to remark that the average journey times are not typical ones in 2008, the dispersion of the data is relatively large.

Table 11. Summary output for the Budapest-Szombathely line (2008)

Start	Distance (km)	Rational traveller average time (min)	Rational traveller average speed (km/h)	Random traveller average time (min)	Random traveller average speed (km/h)	Best choice rate (%)
Budapest	234	175	80.1	385	36.4	-
Bfok-Belváros out	224	246	54.5	468	28.7	5.7
Bfok-Belváros in	235	188	75.0	395	35.7	94.3
Bfok-Belváros opt	-	187	75.1	384	43.4	-
Nagytétény out	217	241	54.0	463	28.1	5.7
Nagytétény in	242	189	76.7	398	36.5	94.3
Nagytétény opt	-	188	76.8	386	43.9	-
Érd alsó/felső out	213	234	54.7	455	28.1	5.7
Érd alsó/felső in	246	196	75.3	404	36.5	94.3
Érd alsó/felső opt	-	194	75.5	391	43.2	-
Tárnok out	209	229	54.9	450	27.8	5.7
Tárnok in	250	201	74.6	409	36.7	94.3
Tárnok opt	-	198	74.9	394	42.9	-
Martonvásár out	200	219	54.7	441	27.2	40.0
Martonvásár in	259	209	74.3	417	37.2	60.0
Martonvásár opt	-	205	69.0	397	42.2	-
Baracska out	197	215	54.9	437	27.1	60.0
Baracska in	262	213	73.8	421	37.4	40.0
Baracska opt	-	205	65.2	399	41.8	-
Pettend out	192	209	55.1	431	26.7	60.0
Pettend in	267	218	73.5	426	37.6	40.0
Pettend opt	-	…	…	…	…	-
Kápolnásnyék out	189	205	55.3	427	26.6	60.0
Kápolnásnyék in	270	221	73.3	429	37.8	40.0
Kápolnásnyék opt	-	…	…	…	…	-
Velence out	186	202	55.2	424	26.3	80.0
Velence in	273	225	72.8	433	37.8	20.0
Velence opt	-	…	…	…	…	-
Velencefürdő out	185	199	55.8	421	26.4	100.0
Velencefürdő in	274	228	72.1	436	37.7	0.0
Velencefürdő opt	-	…	…	…	…	-

Source: own creation

4.2.3. Suggestion for zone limitations on Budapest-Székesfehérvár line

In Table 12 we summarise the limits of the different zones of the agglomeration. R1 stands for always better to go back to Budapest (the absolute attraction zone), R2 for the average or typical better zone (based either on average journey time, or on best choice), and R3 is the first station with always starting outwards label. In the case of ambiguity for R2, we computed the mean of the distances from Budapest.

According to the empirical evidence, the limit of the R1 zone should be Budapest-Kelenföld, so it can be linked to the planned inner zone of Budapest (congestion fee zone). The following limits can be Tárnok (the last morphologically homogenous settlement with Budapest), and Baracska (as the most far settlement with an important ratio of communing people to Budapest).

Table 12. Suggestion for zone limitations (with distances from Budapest-Kelenföld)

Zone	2005	2006	2007	2008	Suggestion
R1	—	—	—	—	Budapest-Kelenföld 0
	—	Nagytétény 12	Érd 16	—	
R2	—	—	Érd 16	Érd 16	Tárnok 20
	Martonvásár 29	Baracska 32	Baracska 32	Pettend 37	
R3	Pettend 37	Tárnok 20	Tárnok 20	Martonvásár 29	Baracska 32
	Pettend 37	Baracska 32	Pettend 37	Velencefürdő 44	

Source: own creation

4.3. Budapest-Vác-Szob- Štúrovo-Bratislava

The Budapest-Štúrovo-Bratislava line is very sensitive to the stops of international trains. In 2005, the stop-trains did not cross the state border, while the international trains did not stop in Hungary (except for Budapest); accordingly, for a journey of Szob-Štúrovo (neighbouring stations on the two sides of the border) one had to travel to Budapest and back. In that case, the boundary of the agglomeration is the state border. The physical analogy suggests Budapest to be a black hole attracting every object. In 2006 and 2007, three stop-trains crossed the state border, and an international fast train was *de facto* stop-train in Hungary, the gravitational zone decreased significantly. Since 2008, international trains have a stop in Vác, pulling in the boundary of the agglomeration.

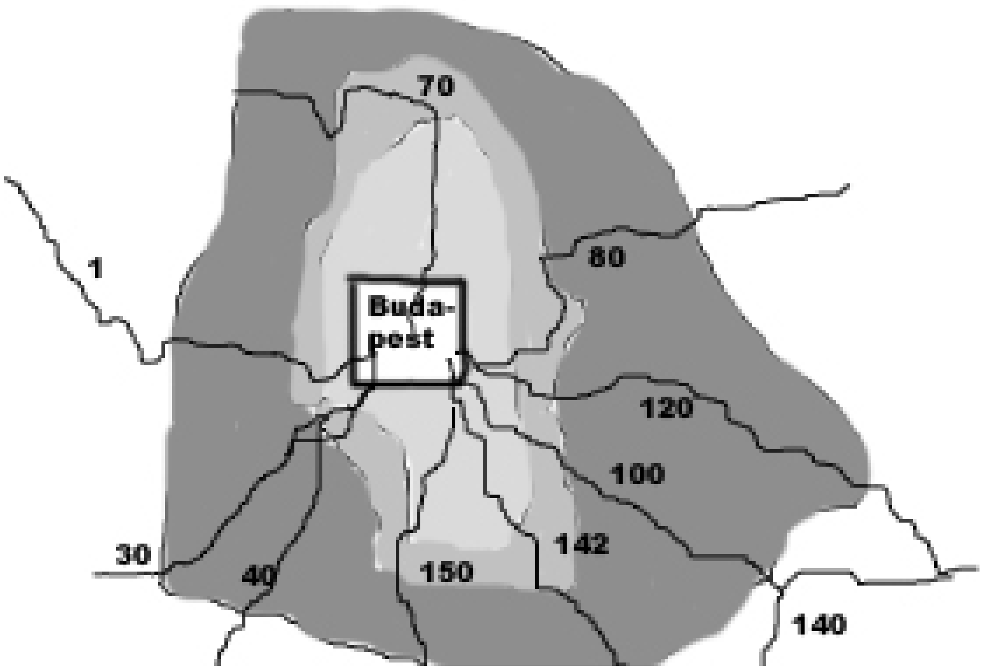
4.4. General empirical results

The empirical evidence highlights the sensitivity of the analysis. The limit of the gravitational zone depends on the frequency and the scheduling of the trains, not definitively on the speed difference of stop and fast trains. A good or bad timetable to one or other direction may halve or double the zone. The responsibility of (timetable) scribes is serious to the local population.

When the railway escape velocity is computed, the transfer time has to be included in the case of stop trains. Thereby the railway escape velocity is a relative measure (in the form of a ratio). The denominator includes the average speed of inwards travel; the numerator is for the average speed of outward travel. If we use the average speed for railway escape velocity, the same measure must be used for the delimitation of the agglomeration.

In Figure 3, we show a map of gravitational zones.

Figure 3. Example map of gravitational zones



Source: own creation

4.5. Limitations of the model

We have to acknowledge that the applied method have a series of deficiencies. For the analysis of the gravitational zone, we have the following problems:

- the location can only be made along the main railway lines (the map is not continuous),
- where the scanned city has special physical geographical nature (f.i. it is in a narrow valley, or on the coast), the ineluctable asymmetry of the railway system will distort the analysis (some obstacles are passed by other means of communication),
- the asymmetry of timetables results in an asymmetric delimitation,
- national borders have distortion effects.

While modelling of railway escape velocity, our problems are:

- the definition and measuring of mass is problematic, the quantity of necessary information is huge,
- the railway escape velocity is a strongly complex measure; one average speed is not satisfactory.

5. Summary

The first phase of the research on the railway escape velocity helps to measure and define the elements of the escape velocity. The achieved results are suitable to clearly see the possible problems of the method and to develop the adequate techniques to aim our goals. For the full calibration we need the analysis of all railway lines around Budapest, so the constant and the parameter of the distance can be calibrated. For the calibration of the mass parameter, at least several important railway nodes have to be scanned.

Our model is applicable to discover the gravitational space of any important city with extended railway network. Furthermore, we can draw maps of agglomeration and proposed fare zones. The latter may be constructed even in the lack of objective counting of travellers and without the use of gravity models (based on flows).

By the empirical evidence, well-constructed timetables with good transfer possibilities compensate the deteriorative infrastructure. The road transport is equal to the random traveller (departure is possible at any point of time by car), so the comparable average speed of 25-40 kmph of the railway transport is not competitive.

References

Dusek, T. 2003: A gravitációs modell és a gravitációs törvény összehasonlítása. *Tér és Társadalom*, n. 1, pp. 41-58.

Dusek, T.; Szalkai, G. 2007: Területi adatok ábrázolási lehetőségei speciális kartogramokkal. *Területi Statisztika*, n. 1, pp. 3-19.

Dusek, T.; Szalkai, G. 2008: *Differences between geographical space and time spaces: theoretical consequences and Hungarian examples*. 48th Congress of the European Regional Science Association, Liverpool, UK, August 27-31 2008.

Ecostat 2006: *A gazdasági növekedés hosszú távú előrejelzése. A gazdasági szerkezet termelékenység, munkaerő-kereslet, globális előrejelzés*. Ecostat, Budapest; 2006.

Fotheringham, A. S.; Haynes, K. E. 1988: *Gravity and Spatial Interaction Models*. SAGE Publications, London.

Holics, L. (szerk) 1986: *Fizika*. Műszaki Könyvkiadó, Budapest.

Iacono, M.; Levinson, D.; El-Geneidy, A. 2008: Models of Transportation and Land Use Change: A Guide to the Territory. *Journal of Planning Literature* n. 4, pp. 323-340.

Janelle, D. G. 1969: Spatial reorganization: a model and concept. *Annals of the Association of American Geographers*, n. 2, pp. 348-364.

Janelle, D. G. 1975*: Time space convergence and urban transportation issues.* In Blong, C. K. (ed) *Systems Thinking and the Quality of Life*. The Society for General Systems Research, Washington DC, pp. 594-600.

Knowles, R. D. 2005: *Transport shaping space*. Paper presented at Annual Meeting of The Association of American Geographers, Denver, Colorado, USA.

Kotosz B. 2010: Gravitációs modellek a területi statisztikában. In: *Gondolatok közös javainkról*. Budapesti Corvinus Egyetem Közgazdaságtudományi Kar, Budapest, pp. 147-161.

Levine, J.; Inam, A.; Torng, G-W. 2005: A Chioce-Based Rationale for Land Use and Transportation Alternatives:Evidence from Boston and Atlanta. *Journal of Planning Education and Research*, n. 24, pp. 317-330.

Levinson, D. M.; Kumar, A. 1993: Multi-modal Trip Distribution: Stucture and Application. *Transport Research Record*, n. 1466, pp. 124-131.

Reilly, W. J. 1929: *Methods for the Study of Retail Relationship*. University of Texas, Texas.

Rodrigue, J-P et al. 2006: *The Geography of Transport Systems*, Hofstra University, Department of Economics & Geography, Hofstra, USA.

Wegener, M. 2001: New spatial planning models. *International Journal of Applied Earth Observation and Geoinformation,* n. 3, pp. 223-237.