ABSTRACT
Motivating people to switch to public transport from using their own car is one of the most important parts on the way to accomplishing the Green Deal 2050 challenge. In the Czech Republic, where the number of passengers was rapidly rising in the pre-pandemic times, individual car transport still offers many more travel benefits than railway lines for most long-distance relations. How to strategically develop the railway infrastructure? Will the planned high-speed railways really be the appropriate solution to this problem in time? Will they satisfy all the different requirements of passengers who are potentially able to switch from car to train?

KEYWORDS
modal split; railway transport; sustainable mobility; gravitation model; service quality.

1. INTRODUCTION
This article is an ongoing output of a long-term project whose goal is to recognise what quality of public transport could motivate passengers to not use individual car transport. A dependence of demand for and quality of public transport will be investigated. Input data will be represented by an origin destination matrix obtained from telephone SIM cards and by quantified quality parameters of public transport.

2. THE ROLE OF RAILWAYS IN SUSTAINABLE MOBILITY
Europe has decided to become a climate-neutral region by 2050 [1]. As is known, transport makes a very significant contribution to the current carbon footprint, and ways to serve population mobility and freight transport will be a key aspect of meeting the goals set by the Green Deal for Europe.

The transport of both cargo and passengers using motorised means of transport always places a burden on the environment. Ultimately, energy can be saved and pollutants can be avoided through choice of transport mode. Train is an energy-efficient and environmentally friendly method, and modern electric railways even more so. In terms of environmental impact, the railway system performs significantly better than cars, heavy good vehicles or aircraft. Rail transport provides a particularly favourable energy input to transport capacity ratio. In comparison with cars, railways only require around half as much energy for the same passenger transport volume. It is mainly because of low rolling resistance (steel wheel on steel rail instead of rubber tyres on asphalt). Plus, travel in a long distance train is almost three times more energy efficient than air traffic [2]. Detailed comparison is shown in Figure 1.

In addition, in some cases railways may be improved compared to the present state, and their standard energy consumption can be further reduced, for example by electrifying lines not yet electrified, expanding the possibilities of braking energy recovery etc.

For the environmental objectives to be achieved at all, railways need to significantly increase their share of the modal split. However, passengers will not start using them just because they are environmentally friendly. What they require is a modern and high-quality mobility product. To reduce the environmental impact of transport, it is necessary to offer railways in the form of an attractive and customer-oriented part of mobility as a service concept [4].
However, travel speed plays a very important role in making the decision whether the passenger will use a long-distance train or a car ride [5, 6]. It is mainly influenced by infrastructure parameters. Therefore, in this sense, the railway network should be developed by building high-speed lines as well as conventional lines to achieve competitive and systemic travel times between cities [7].

Of course, there is a lot of other factors that influence the demand of public transport. An important part of the total quality is the level of train sets and single carriages. It also includes, for example, operational intervals, ticket prices, reliability of operation, level of on-board services (Wi-Fi, air conditioning, train bistro) and services in stations.

4. SITUATION IN THE CZECH REPUBLIC

Although the Czech Republic has one of the densest railway networks in the world, most of the lines do not meet the requirements of contemporary fast and modern railway transport due to their
parameters, especially line speed and state of technology. As a result, more than 70% of rail transport (passenger and freight) is carried out on approximately 30% of the rail network. These are mainly lines that have been upgraded over the past thirty years as part of the so-called rail transit corridor modernisation programme. This typically included renewal of the railway substructure and superstructure, modernisation of stations, increase in line capacity, basic modernisation of signalling equipment and increase in line speed. The map of transit corridors is shown in Figure 3.

Generally speaking, the realisation of rail transit corridors modernisation programme (the programme is still ongoing, some sections and key nodes are not yet complete) created conditions for the development of modern passenger and freight railway transport in Czechia. This programme was financed primarily from various EU funds (up to 80 percent), as well as through loans from the European Investment Bank.

The popularity of passenger rail transport is growing in Czechia. Two segments of passenger rail transport are particularly successful – suburban rail transport as part of regional integrated public transport and long-distance (interregional or interstate) rail transport. Over the last 10 years, the number of passengers has increased by 18%. The development of demand could be seen in Figure 4.
The medium distance travelled is also on an upward trend, suggesting that long-distance transport is the main driver of railways’ success. This positive development is due to several aspects:

- The liberalisation of the rail market and the related emergence of competition have led to an increase in the range and quality of the transport offer.
- Modernised infrastructure has created the conditions for a better and more reliable offer.
- Generally higher perception of environmental aspects and sustainability in society.

However, this development is happening almost exclusively on modernised lines. There is therefore a large disparity in the quality and transport offer across the network.

Before the pandemic, in 2019, the modal split of passenger railway transport in the Czech Republic achieved 9.9%. It is not that bad compared to Austria (12.9%) or Netherlands (11.3%), but the Green Deal challenge requires far better values [9].

### 4.1 Capacity problems and missing links

As the development of passenger railway transport has been concentrated on corridor lines, the capacity of these lines is practically exhausted, especially in the vicinity of large railway junctions (Prague, Brno). It has become clear that the corridor modernisation programme significantly underestimated the issue of line capacity around these junctions. For example, nowhere was it planned to increase the number of tracks around these junctions in order to segregate intensive suburban and long-distance rail traffic. Unfortunately, Správa železnic, the Czech railway infrastructure manager, does not publish information on the level of capacity utilisation of the railway infrastructure. However, it is clear that line capacity is or will very soon become a limit to the development of passenger rail transport. Freight transport is operated primarily at the night because almost all the capacity is reserved for passenger transport.

A chronic feature of the development of the railway network and, to a significant extent, of the transport policy, is the neglect of the development of the Prague – Munich and Prague – Linz routes. Bavaria is the Czech Republic’s largest trading partner. Although the D5 motorway linking Prague with Nuremberg and Munich was quickly built in the 1990s, there is still no fast, high-capacity railway line of equivalent importance between the Czech Republic and Bavaria. There are even only single-track non-electrified lines. The official development plans promise electrified double-track line Pilsen – Domažlice – Germany with a maximum speed of 200 kmph to be built until 2030. The situation between Prague and Linz is similar. However, it should be noted that even Germany and Austria do not give this connection much priority in their infrastructure planning.

### Table 1 – List of Czech-Austrian and Czech-German railway lines (sorted clockwise)

| Track number | Track journey                      | Number of rails | Electrification | Main track       |
|--------------|------------------------------------|-----------------|-----------------|------------------|
| 002          | Česká Třebová – Brno – Břeclav – Vienna (A) | 2               | Yes             | Yes (corridor 1, 2) |
| 248          | Znojmo – Retz (A)                  | 1               | Yes             | No               |
| 199          | České Budějovice – České Velenice – Vienna (A) | 1               | Yes             | No               |
| 196          | České Budějovice – Rybnik – Linz (A) | 1               | Yes             | Yes (corridor 4) |
| 183          | Klatovy – Bayerisch Eisenstein – Plattling (D) | 1               | No              | No               |
| 180          | Pilsen – Domažlice – München (D)   | 1               | No              | Yes              |
| 179          | Cheb - Nuremberg (D)               | 1               | No              | No               |
| 148          | Cheb – Aš – Hof (D)                | 1               | No              | No               |
| 145          | Sokolov – Kraslice – Zwotental (D) | 1               | No              | No               |
| 142          | Karlovy Vary – Johanngeorgenstadt (D) | 1               | No              | No               |
| 137          | Chomutov – Cranzahl (D)            | 1               | No              | No               |
| 083          | Děčín – Bad Schandau (Dresden, Berlin) – Rumburk | 2               | Yes             | Yes (corridor 1, 4) |
4.2 Inconsistent level of quality

The offer of modern railway long-distance passenger transport in the Czech Republic is limited almost exclusively to corridor lines. However, the level of quality varies considerably. It is logical that the level of quality varies between the different open-access long-distance rail products (e.g. SC Pendolino, RegioJet, LeoExpress). However, the level of quality is significantly different in a number of aspects also for express services operated under a public service obligation, i.e. ordered by the public administration (in the Czech Republic, long-distance transport is governed by the Ministry of Transport of the Czech Republic). The highest standard of services offered in express trains includes, for example, first and second seat class, air conditioning, free unlimited Wi-Fi connection, train restaurant, cinema for children. However, on some lines, for example, there is a systematic lack of a dining car and related service. There is also an enormous difference in the quality of train sets. The carriages of most of the trains consist of restored vehicles dating back to the last century.

There is no uniform level of quality across the express network. Moreover, the express network basically follows only the corridor lines and does not even serve some major cities (Hradec Králové, Jihlava, Karlovy Vary).

4.3 Travel speed as a key parameter

Travel speed is a key parameter for the competitiveness of passenger rail transport. Achieving a certain travel speed is also a crucial parameter for the design of infrastructure and its line speed.

Czech Republic today

In order to accurately describe the current situation in the Czech Republic, we have selected the twenty-two largest Czech cities, where 32% of the country’s total population live, and analysed all interconnections between them using rail transport
is only 47 kmph but cars achieve 67 kmph. The complete summary statistics of this comparison are shown in Table 3.

| Table 3 – Comparison in years |
|-------------------------------|
| Size                         | 2021 | 2050 |
| Ratio of routes realized faster by train [%] | 9    | 52   |
| Average travel speed of trains [kmph]        | 47   | 84   |
| Average travel speed of cars [kmph]          | 67   | 74   |
| Average train operation interval [min]       | 86   | 61   |
| Average number of train transfers           | 0.93 | 0.79 |

Currently (i.e. in 2021), the travel speed of rail transport is higher than the travel speed of individual car transport one in only 20 of 231 analysed routes (8.7%). The average travel speed of trains and individual car transport. This selection, including all cities that are the administrative centres of Czech regions, is shown in Table 2.

Note that most of these cities are not connected by lines that were parts of the rail corridor modernisation programme.

A total of 231 routes were analysed. With the help of the digital road map and railway timetables, all intercity distances, travel times, travel speeds and operating intervals (only for railway lines) were obtained, and every pair of connections was compared (car vs. train).

Currently (i.e. in 2021), the travel speed of rail transport is higher than the travel speed of individual car transport one in only 20 of 231 analysed routes (8.7%). The average travel speed of trains is only 47 kmph but cars achieve 67 kmph. The complete summary statistics of this comparison are shown in Table 3.

The connections between Prague (the capital city and the largest passenger rail hub in the country) and other major cities is shown in Figure 6.
will change the competitiveness of railway services (in terms of travel speed), we have carried out the same analysis for the 2050 model. The year 2050 was chosen because it is the year in which the goals of the Green Deal are to be accomplished [11].

The model includes the completion of all planned high-speed lines and planned upgrades to conventional lines. At the same time, the planned development of the motorway network is also included in the model calculation.

In 2050, the travel speed of rail transport is higher than the travel speed of individual car transport one in 119 of 231 analysed routes (51.5%).

Routes marked with a black number are parts of corridor lines. It is evident that even on the reconstructed corridor lines, the travel speeds achieved are not higher than those of road transport.

**Czech Republic – projected 2050**

The Czech Republic is currently preparing to implement a programme for the construction of high-speed lines with an expected completion in 2045. The programme promises three new complexes of high-speed tracks dimensioned for the speeds of 200 to 350 kmph. Many of the conventional lines should be modernised too, for example, Prague – Liberec or Pilsen – Domažlice – Germany (Munich). In order to see how this programme
Average travel speed of trains is only 47 kmph, but cars achieve 67 kmph. The summary statistics of this comparison are shown in Table 3.

The connections between Prague (the capital city and the largest passenger rail hub in the country) and other major cities is shown in Figure 8.

The biggest improvement will be perceptible in routes coming from Prague. Unfortunately, the situation in cities that do not lie on the corridors or new high-speed tracks will be almost the same.

We can look forward to some extreme improvements. For example, there are some routes where the train will be three or four times faster than car, with major improvements to the operation interval (Table 4).

For comparison, see the Table 5 with data for the three biggest cities:

On the other hand, there are some routes where the state of railway transport beside the individual one will be the same or even worse. An unpleasant situation threatens, for example, in Kladno or Zlín (Table 6).

The planned high-speed rail and modernisations will definitely improve the situation, but there will still be many routes in unsatisfactory condition, and this deficiency may subvert the whole system.

**Comparison with Western Europe**

For a comparison with the Czech situation, a few routes in foreign countries were analysed. Four high-speed lines in France, Spain, Austria and Germany were chosen. These four lines are great

| Route                          | Travel time [min] | Travel speed [kmph] | Air distance [km] | Ratio | Operation interval [min] |
|-------------------------------|-------------------|---------------------|-------------------|-------|--------------------------|
| Pardubice – Prague            | 81                | 72                  | 291               | 0.25  | 12                       |
| Hradec Králové – Prague       | 77                | 79                  | 306               | 102   | 0.26 30                  |
| Brno – Jihlava                | 56                | 83                  | 308               | 77    | 0.27 60                  |
| Olomouc – Ostrava             | 62                | 75                  | 231               | 77    | 0.32 60                  |
| Prague – Ústí n/L.            | 59                | 70                  | 207               | 69    | 0.34 20                  |

| Route                          | Travel time [min] | Travel speed [kmph] | Air distance [km] | Ratio | Operation interval [min] |
|-------------------------------|-------------------|---------------------|-------------------|-------|--------------------------|
| Brno – Ostrava                | 102               | 81                  | 207               | 138   | 0.39 30                  |
| Brno – Prague                 | 118               | 95                  | 186               | 186   | 0.51 10                  |
| Ostrava – Prague              | 211               | 79                  | 152               | 278   | 0.32 30                  |

Figure 8 – Comparison of travel speed in 2050

Table 4 – List of very fast train routes

Table 5 – List of routes among three biggest cities
In the next step, the difference of travel speeds of cars and trains from the target year 2050 was multiplied by the gravity model. The equation is shown below:

\[ \text{rationing of speed} = (v_{\text{train}} - v_{\text{car}}) \cdot G \cdot k_2 \]  

where:
- \( k_2 \) – weighting coefficient 0.01
- \( v \) – speeds of individual types of transport in 2050 [kmph]
- \( G \) – gravity model

The multiplication of the gravity model and the difference of travel speeds gives a specific result, which can be used to compare the relations on the basis of their importance. As the gravity model indicates, importance is determined by size of the cities and their mutual air distance. Simply, the result of the equation is a dimensionless number that shows the future dependence of competitiveness of public transport on the size of examples of functional high-speed railway lines with large differences between car and train travel speed. The comparison is shown in Figure 9.

At first glance, it is obvious that travel speeds of western railways are much higher than in the Czech Republic.

Dependence of travel speed and gravity model

As indicated above, primarily the biggest cities are connected by modernised transit corridors. However, let us find out how well are the smaller cities connected. As a key parameter for this research, the principle of the gravity model was used:

\[ \text{gravity model} = G = k_1 \frac{(P_1 \cdot P_2)}{l_{1,2}} \]  

where:
- \( k_1 \) – weighting coefficient 0.0001
- \( P_1, P_2 \) – population of two measured cities
- \( l_{1,2} \) – air distance between cities [km]
have been revived, and it can be seen that, if the conditions are right, they can offer a competitive modern service that passengers like to use. This is an important conclusion, as it confirms that if the public administration creates the conditions for the development of passenger rail transport in a strategically correct and sufficiently generous way, there is a great potential for increasing the share of rail transport in the modal split, and that is essential to meet the Green Deal goals.

As seen in the tables in the previous chapter, the largest rationings of speed are held only by relations connecting the most populated cities linked by the transit corridor. Cities that are not located on these modernised corridors are positioned substantially lower in the result table. However, it is quite surprising that even in the table showing the worst results, some of the most important connections could be found (Prague – České Budějovice, Prague – Liberec). These are the routes where the road infrastructure is significantly better than rail-way infrastructure, but also the ones that depreciate the whole public transport system.

Currently, the development of railway transport in the Czech Republic is limited by wrong strategic decisions made in the relatively recent past:

- The development of railway infrastructure was limited to railway corridors instead of being systematically oriented towards connecting the largest and most important cities in the country.
- The scope of modernisation was too small. There have been no significant upgrades in terms of capacity or signalling.
- Instead of setting the line speed based on the competitive travel speed in each route, a fixed limit of 160 kmph was chosen. However, even this limit has not been reached on a significant part of the corridor lines after the reconstruction.

These poor strategic decisions could have been avoided. Both the principles of the integral timetable and the good practice examples of the network approach to rail transport were well known in the 1990s when these strategic decisions were made.

Rail transport and increasing its modal share will play a crucial role in meeting the targets set by the Green Deal. The Czech Republic must therefore systematically develop fast, modern and high-quality railways.

5. CONCLUSION

After an exceedingly long stagnation (practically from the 1960s until the first decade of the 21st century), the railways in the Czech Republic

---

| Relation                     | Gravity | Rationing of speed |
|------------------------------|---------|--------------------|
| Karlovy Vary – Prague        | 57 321  | -13 221            |
| Brno – Zlin                  | 37 600  | -12 807            |
| Liberec – Prague             | 157 712 | -8 440             |
| Děčín – Prague               | 82 502  | -7 188             |
| České Budějovice – Prague    | 100 883 | -7 033             |
| Hradec Králové – Liberec    | 11 735  | -6 331             |
| Frýdek-Místek – Havířov     | 32 964  | -5 045             |
| Havířov – Karviná           | 30 929  | -5 037             |
| Hradec Králové – Olomouc    | 7 606   | -3 797             |

---

| Relation                     | Gravity | Rationing of speed |
|------------------------------|---------|--------------------|
| Pardubice – Prague           | 125 229 | 274 437            |
| Hradec Králové – Prague      | 120 664 | 273 327            |
| Brno – Prague                | 271 510 | 248 224            |
| Prague – Ústí nad Labem     | 177 944 | 243 482            |
| Brno – Ostrava               | 79 576  | 100 126            |
| Ostrava – Prague             | 137 176 | 99 568             |
| Most – Prague                | 121 455 | 94 174             |
| Pilsen – Prague              | 275 642 | 67 357             |
| Olomouc – Ostrava            | 37 646  | 58 911             |
"Transport accounts for a quarter of the EU’s greenhouse gases and its share is still growing. To achieve the climate neutrality, transport emissions need to be reduced by 90% by 2050. Both road, air, rail and waterborne transport must contribute to this reduction. Achieving sustainable transport means prioritising users and obtaining them more affordable, accessible, healthier and cleaner alternatives to the means of transport to which they are currently accustomed." [1]

Our analysis has confirmed that the planned construction of high-speed lines and modernisation of existing lines will make rail transport in the Czech Republic significantly more competitive with road transport than at present. However, rail transport will still be speed-competitive on only about half of the selected routes. Little consolation can be taken from the fact that this half includes all the largest cities except Pilsen, which is senselessly excluded from the high-speed system. Equally alarming, however, is the long-unresolved connection with European cities such as Munich, Nuremberg or Linz in Austria. These three cities with several million inhabitants represent an immense potential for connection to the high-speed system. Unfortunately, the Czech plans so far completely ignore these traditional trading partners and tourist destinations.

Overall, the 2050 route plan, however ambitious and developmental, is still quite inadequate. The railway transport simply needs to offer even better-quality connections between at least all our selected settlements, so that the incentive for the passenger hesitating between individual and public transport is clearly on the side of the public transport.

The Green Deal is an opportunity to catch up with these internal debts of the Czech infrastructure in relation to its European neighbours, but this opportunity must be grasped well. In this particular case, it means not relying entirely on the 2050 plan, but developing rail lines on a much larger scale and building the railway system in the Czech Republic in a conceptual and systematic way.

**ACKNOWLEDGEMENTS**

At the 19th European Transport Congress “European Green Deal Challenges and Solutions for Mobility and Logistics in Cities” held in Maribor, October 2021, by the European Platform for Transport Sciences (EPTS), the scientific chair chose the best-presented papers for publishing in extended form in the journal Promet – Traffic&Transportation.

**REFERENCES**

[1] EUR-Lex. Green Deal for Europe. 2019. https://eur-lex.europa.eu/legal-content/CS/TXT/?qid=1596443911913&uri=CELEX:52019DC0640#document2 [Accessed 11th Dec. 2019].

[2] EcoTransIT. Ecological Transport Information Tool, Environmental Methodology and Data. 2014. https://eur-lex.europa.eu/legal-content/CS/TXT/?qid=1596443911913&uri=CELEX:52019DC0640#document2 [Accessed 4th Dec. 2014].

[3] Knörr W, Hüttermann R. Environmental Methodology and Data. Heidelberg, Germany: Institut für Energie- und Umweltforschung; 2016. http://ecopassenger.hafas.de/hafas-res/download/Ecopassenger_Methodology_Data.pdf [Accessed 17th Nov. 2016].

[4] Hensher DA, et al. Understanding Mobility as a Service. 2020.

[5] Gärling T, Axhausen KW. Introduction: Habitual travel choice. Transportation. 2003;30(1): 1-11. doi: 10.1023/A:1021230223001.

[6] Graham-Rowe E, Skippon S, Gardner B, Abraham Ch. Can we reduce car use and, if so, how? A review of available evidence. Transportation Research Part A. 2011;45(5): 401-418. doi: 10.1016/j.tra.2011.02.001.
Lauda V., Novotný V. Role of Railway Transport in Green Deal 2050 Challenge – Situation in the Czech Republic

[7] Bahn 2000. Rail 2000 – A public transport network for the third millennium. https://web.archive.org/web/20041205012701/http://www.bahn2000.ch/ids/default.asp?TopicID=423.

[8] Sydos. Ročenky dopravy. 2020. https://www.sydos.cz/cs/rocenky.htm [Accessed 30th June 2022].

[9] Eurostat. Modal split of passenger transport. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=tran_hv_psmod&lang=en [Accessed 7th July 2021].

[10] Czech statistical office. Population of Municipalities - 1 January 2021. https://www.czso.cz/cs/csu/population-of-municipalities-1-january-2021 [Accessed 30th June 2022].

[11] Ministry of Transport of Czech Republic. Program rozvoje rychlých železničních spojení v ČR. https://www.mdcr.cz/getattachment/Media/Media-a-tiskove-zpravy/Ministr-Tok-Vysokorychlostni-trate-potrebuji-novy/MD_Program-rozvoje-rychlych-spojeni-v-CR.pdf.aspx.