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A new method to measure the rationalities of transit route layouts

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ABSTRACT

Public transport routes (especially urban bus routes) may become tedious and lengthy due to undesired deviations from the target destination directions. This makes public transport less attractive compared to other modes. Optimization of bus route layouts (under the name of rationalisation) ought to concentrate on, primarily, the quantification of the shape (geometric) features of these routes. The present paper has therefore developed a numerical method for measuring the benefits of improving these route layouts. Using the method developed, over one million public transport journeys on 1242 bus lines in Istanbul Metropolitan City have been analysed. For each bus route, rationality values have been calculated and geocoded on GIS to produce a "digital rationality map" of the whole city. In addition, to be able to see the rationality changes by region, the map has been broken into municipal districts. As a result, particularly irrational bus routes were easily identified. The findings have already been taken on board by the National Research Council for immediate consideration of potential improvements and further research directions.

1. Introduction

1.1. Problem statement

Public transport routes sometimes fail to yield the shortest connections between origins and destinations in urban areas due to topology and the existing texture of the road network. Poorly planned and unjustified extensions of routes, with the aim of reaching more passengers, worsen the situation. Passengers are affected by this situation differently depending on the locations of the stops. The dimension of this effect may change the transport mode preferences of people. The decision making process of the authorities in relation to which bus stops will be served by the public transport routes in question should provide maximum utility for all passengers using that route. This will then encourage a shift from automobile use to the public transport mode. The authorities advocate that the service quality in public transport should be improved in order to be able to create a modal shift from private car use to public transport (Chowdhury et al., 2014a, 2014b). In a study performed to make public transport more attractive, it was stated that improvement of the service quality might be profitable for not only the society but also the companies operating in this field (Rojo et al., 2015).

There are not many studies on circuity of transit routes and the existing ones are based on the calculations of single routes between origins and destinations and the Euclidian distances (Levinson, 1998; O'Sullivan and Morrall, 1996). The present paper however, performs the calculations according to all trip combinations within a given route. Besides, in this paper, for the first time, passenger tolerances against delays have been taken into account to be able to measure route qualities. In addition to the existing public transport routes between given two points, the availability of alternative and shorter routes (for other modes of travel) may cause the users to choose private cars, taxi, and the like. Here, the travel time that is a major factor in a modal change has been expressed by as 'passenger tolerances against delays'. Depending on their geometry, routes may provide passengers with such gains as a shorter distance or journey time. In our previous work, these gains were measured for the journeys by automobile with different methods under the name of 'rationality scales' (Gunay et al., 2018). In a given road network, with the help of these measurements, those regions that require potential improvement were easily identified. Application of the same approach on public transport routes will provide a new tool for the authorities, as quantifiable criteria for success should be generated to achieve sustainable success in public transport (Canci and Onden,

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2013). In this line, a new numerical analysis method which evaluates the geometric rationalities of the routes of public transport vehicles will be developed. Then, the rationalities of the sampled bus lines of Istanbul will be quantified by this method, and the geometrically problematic regions will be determined. The interim target of the paper is to measure the geometric rationality of public transport routes (the circuity factor). The public transport passenger volumes are deliberately excluded in the analyses for clarity and simplicity purposes. A separate publication as part of the ongoing work will include the effects of various aspects other than the geometry. In the present paper, while the term circuity refers to the ratio of 'the travel distance between two points' to 'the Euclidian distance', the term Rationality merely denotes the average of the ratios of 'the distances of all the travel combinations of a public transport line' to 'the Euclidian distances'. For simplicity, the terms trip, travel and journey are used interchangeably throughout the paper as the differences among the meanings of these terms play no critical role in the scope of the study in the present form. In the paper, the term journey refers to a single and direct trip (no transfers) from a boarding bus stop to an alighting bus stop. When a passenger makes a transfer it becomes a separate trip. The terms public transport and transit were also used interchangeably throughout the paper. The term O-D (origin–destination), unlike its common use (zonal ends), refers to pairing a boarding bus stop and an alighting bus stop in the paper. Finally, for the term accessibility, Hansen's definition is used in the paper to refer to a continuous variable which is measured by counting the number of activities available at a given distance from an origin, and discounting that number by the intervening travel time (Hansen, 1959).

1.2. Literature

The interests of authorities and passengers generally contradict concerning the enhancement of transport performance (Vreeswijk et al., 2015). Such cases as the failure to deal adequately with the travel behavior of people in transport-oriented policies and the failure to increase the competitive power of public transport are among the problems which must urgently be solved in the transport sector (Garcia-Sierra et al., 2015; Raveau et al., 2014; Sun et al., 2016). Taking passenger needs into consideration and drawing up standards about meeting these needs will contribute to the improvement of the public transport service quality (Yildirim, 2013). Effective solutions which improve the public transport service quality for sustainable transport systems and encourage its use will be effective in reducing the pressure on the transport sector (Davison and Knowles, 2006; Vitale et al., 2014). In this way, public transport service levels will be designed and potential public transport users can be reached (Beirão and Sarsfield Cabral, 2007). Hadas and Ranjitkar (2012) stated that developing the public transport connections was one of the most important duties of transport planning and that poor connections might lead to the non-preference of public transport. In a study where the routes of public transport vehicles were designed to remain at a specific service level, it was determined that there was potential for about 50% modal shift from private car use (Gunay et al., 2016). This shows the importance of making public transport routes more effective and productive by organizing them carefully in transport policies (Buchari and Ndiaye, 2008).

The studies focusing on the public transport network structures and topology have multiplied in the recent years (Lin and Ban, 2013). Yan and Wang made empirical analyses in order to examine topological properties on static public transport networks. They proposed a simulation model with accelerated growth and based on nonlinear preference rules in order to see the evolutionary development of public transport networks. In conclusion, they stated that their model performed satisfactorily in reproducing basic topological properties of the real-world public transport networks (Yan and Wang, 2009). According to Derrible and Kennedy (2011), the network structures of public transport systems are well known but remain relatively limited in terms of topology. That is why plenty of work falls to planners regarding better designed public transport systems for a good future. Curtis and Scheurer (2010) emphasized that the share of the public transport mode in planning policies should be increased. They touched upon the importance of accessibility in planning and stated that making the practices of accessibility widespread by means of the media would make the right contribution to urban mobility in the future. According to Hadas, public transport networks have a complex structure owing to their various physical properties. In the study he carried out to develop these hard-to-evaluate networks, he made an analysis with a methodology based on the GIS techniques. With this analysis, he examined the transport network in terms of coverage level, average speeds, intersection coverage level, transfer potential, and route overlap (Hadas, 2013).

Transport planning is a rationality process in which alternative options are generally compared (Cascetta et al., 2015). The concept of rationality in transport was studied by some researchers in terms of regional planning and economy as well as with its social, legal, and political aspects (Breheny and Hooper, 1985; Diesing, 1962; Sager, 1994). The planning stages of transport and its interaction with people were examined in another study where rationality was divided into two as instrumental and communicative rationality by taking these studies into consideration (Langmyhr, 2001). In another study, the public transport network connection was measured by using Google Transit in terms of walking distance, comfort, method of payment, and security and it was stated that Paris was more rational than London and Auckland (Chowdhury et al., 2014a, 2014b). On the other hand, in a different study, rationalities of road networks were measured by taking into account the unnecessary network areas (Matisziw and Demir, 2016). However, these studies do not provide authorities with a tool of making a quality assessment in terms of the geometry of routes in public transport-oriented policies.

Public transport networks (including bus and rail) have been built, improved, or expanded in many cities to maximise access to public transport systems and encourage public transport ridership (Cervero, 2004). In transport planning, urban public transport networks are often designed to ensure a large spatial coverage for political reasons (Taylor, 1991), resulting in circuitous lines (Black, 1995; Murray et al., 1998). However, the high indirectness of public transport lines that trades off coverage for frequency (Walker, 2012) may discourage ridership, because people could choose other modes giving less trip circuity.

Correlations between automobile mode share and accessibility in road and public transport networks have been previously tested with a local example (Owen and Levinson, 2015) and in multiple metropolitan areas (Levinson, 2012). It has been reported that an increase in public transport accessibility may reduce commute time by public transport (because jobs are closer to workers), which should reduce automobile mode share (Huang and Levinson, 2015).

Circuity on road networks, i.e. the ratio of the route length to the Euclidian distance, has been studied by a number of researchers (Huang and Levinson, 2015). This ratio theoretically takes the value of '1.0' when the route length is equal to the Euclidian distance. In order to be able to evaluate global (general) performance of the road network, Vragović et al. (2005) calculated the average of all the circuity ratios of the journeys that took place on that network. It is obvious that the smaller the value of this ratio the better the efficiency of the road network considered. Newell (1980) measured the circuity value as 1.2 for the networks he studied. Ballou et al. (2002) found that this value ranges from 1.21 to 1.23 for public transport networks. In general, the circuity value of public transport journeys is thought to be higher than that of private car journeys, as public transport vehicles aim to serve larger areas (Love and Morris, 1979). Circuity values can be facilitated to estimate journey distances as they represent the efficiency of road networks (Ballou et al., 2002; Dill, 2004). Wolf et al. (2004), many years ago, used a similar concept to estimate the distances between a given pair of points in plant locationing problems. The circuity values for pedestrians and cyclists were found to be smaller than that of private car journeys at national level (Samaniego and Moses, 2008). Levinson and

Table 1
A template for the trip matrix.

	1st station	2nd station	3rd station	⋯	(n-1) th station	(n) th station
1st station	–	d_{12}/r_{12}	d_{13}/r_{13}	⋯	$d_{1,n-1}/r_{1,n-1}$	d_{1n}/r_{1n}
2nd station		–	d_{23}/r_{23}	⋯	$d_{2,n-1}/r_{2,n-1}$	d_{2n}/r_{2n}
3rd station			–	⋯	$d_{3,n-1}/r_{3,n-1}$	d_{3n}/r_{3n}
⋮				–	⋮	⋮
(n-1) th station					–	$d_{n-1,n}/r_{n-1,n}$
(n) th station						–

El-Geneidy (2009), using the GPS data of floating agents, found that many routes exhibited higher circuity values than initially expected. Bachok et al. (2012) have discovered that in the design and planning of the road networks, the extent of the prolonged journeys (as a result of high circuity values) had been underestimated, when they studied the origin destination pairs between the central business districts and the associated journey sources. Selvidge (2003) studied the problem of choosing home locations for a number of workers with respect to the associated work locations, and found that the circuity values of randomly paired home-work links are bigger that the purpose-configured home-work links. They then concluded that in the determination of the workers' home locations, the circuity value plays an important role.

2. Data

The information about the sequential station coordinates of the bus lines in Istanbul and the travel distances between the stations were used for the analyses. These data and the maps to be subsequently used to visualize the results of the analyses were obtained from a national research institution which had previously carried out public transport studies pertaining to Istanbul. These data encompass the names of 1353 bus lines, the names of sequential stations of each line, the coordinates of these stations, and the travel distances between the stations. Whilst some of these lines use similar routes as outbound and inbound lines, some of them use a circular route and return to the origin station. A total of 1242 lines – 621 outbound directions and 621 inbound directions – were examined in this study. In the network studied, there are 6139 bus stops (nodes) and 14,664 links. The data in relation to these lines were analyzed with a program written in MATLAB. As a result, a total of 1,190,995 journeys were evaluated and R_m (the rationality value obtained from the trip matrix of a line), R_{m2} (the rationality value that is disregarded with the assumption that the private car user would also be exposed to the same effect) and R_{d2}(the rationality value designed according to both distance and delay tolerance) were calculated for these 1242 lines. The only limitation of the data used in the study was the unavailability of the transfers between the bus lines. However, since the interim aim of the work was to study geometric rationality, the inclusion of the passenger movements with transfers would obscure (by-pass) the effect of the layout problems on the network. Hence, an integration of the passenger movements has been kept as a separate work for ongoing research.

3. Method

In journeys by automobile, it is generally desired to provide transport between two points at the shortest time or distance. Hence, in order to compare different routes geometrically, only knowing the ratios of the travel distance to the Euclidian distance between an origin and a destination may give an idea about the rationality of a route. On the other hand, the case is not so simple in public transport. All journey combinations likely to be performed between different stations within a public transport line should be evaluated. For this purpose, trip matrices of the lines (Table 1) should be first created. Later, the travel distances (d) and the Euclidian distances (r) should be computed for each journey alternative in this matrix. So, the average of 'd/r' ratios calculated for all journeys will yield the 'rationality value' of the line.

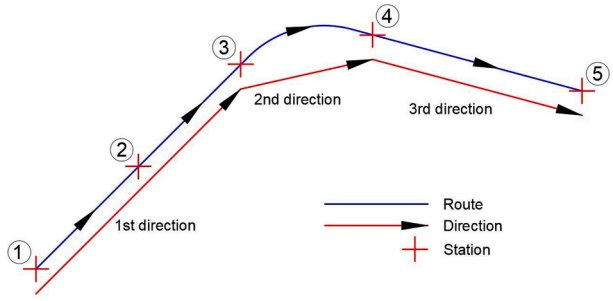

Fig. 1. Directional components of a schematic public transport route.

To program this value and compute it more easily, the following formulae (1), (2), (3), and (4) were generated.

$$R = \frac{d}{r} \tag{1}$$

$$\sum R = \sum_{i=2}^{n} \frac{d_{1i}}{r_{1i}} + \sum_{i=3}^{n} \frac{d_{2i}}{r_{2i}} + \cdots + \sum_{i=n}^{n} \frac{d_{n-1,i}}{r_{n-1,i}} = \sum_{j=2}^{n} \sum_{i=j}^{n} \frac{d_{j-1,i}}{r_{j-1,i}} \tag{2}$$

$$n_c = \frac{n \cdot (n-1)}{2} \tag{3}$$

$$R_m = \frac{\sum R}{n_c} \tag{4}$$

where

R: the circuity value,
d: the travel distance between two points,
r: the Euclidian distance between two points,
d_{ji}: the travel distance from station 'j' to station 'i',
r_{ji}: the Euclidian distance from station 'j' to station 'i',
n: the number of stations in the line,
n_c: the number of journey combinations generated for the line,
R_m: the rationality value obtained from the trip matrix of a line.

This rationality figure gives a numeric value about the route's status by evaluating the route geometrically. There are two factors which affect the rationality value. The first one is the directions on the route, whereas the second one is the quality of the road network through which the route passes. To better explain the concepts of direction and quality of the road network, a representative public transport line is shown in Fig. 1. The route generally consists of three directions, i.e. the sections between stations 1 and 3, stations 3 and 4, and stations 4 and 5. Here are 3 different journey combinations on the 1st direction (one-way), namely the journey between 1 and 2, the journey between 2 and 3, and the journey between 1 and 3. Since the direction remains unchanged in these journeys, each circuity value calculated will positively affect the rationality value. Hence, more rational public transport routes can be obtained by multiplying the journey combinations likely to be performed in the same direction.

When we look at the example of the representative line in Fig. 1 again, we see that the route does not proceed straight between stations 3 and 4. We often encounter this situation in real life too. Road networks fail to take us directly to the desired point. Hence, unavoidable deflections may occur particularly as the travel distance increases. For

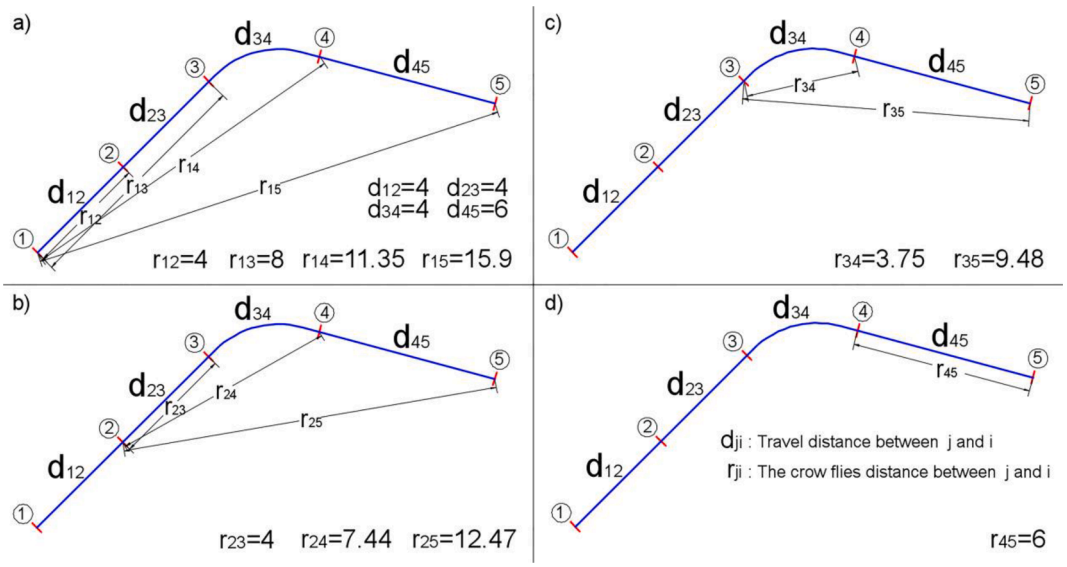

Fig. 2. Rationality combinations of a simple public transport route (The distances in the figure are in units).

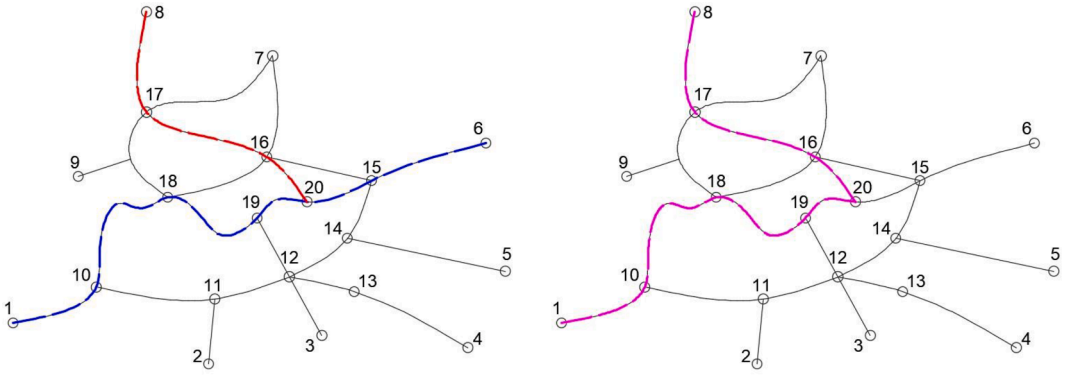

Fig. 3. A formation of virtual-route due to a transfer point (20) on the network.

instance, a person intending to go to station 5 from station 1 in Fig. 1 may have to use this route as he/she has no other road alternatives. This shows that road networks have a significant effect on the rationality of routes. To examine the rationality of public transport routes geometrically, one-way journey combinations for a 5-station public transport route are demonstrated in Fig. 2.

For the public transport route in this example, the rationality value is computed as follows by the help of the formulae provided in (1), (2), (3), and (4).

$$R_m = \frac{\frac{4}{4}+\frac{8}{8}+\frac{12}{11.35}+\frac{18}{12.47}+\frac{4}{4}+\frac{8}{7.44}+\frac{14}{12.47}+\frac{4}{3.75}+\frac{10}{9.48}+\frac{6}{6}}{\frac{5\cdot(5-1)}{2}} = \frac{10.51}{10} = 1.051$$

where the values d_{12}, d_{23}, d_{34} and d_{45} and the Euclidian distances are directly taken from Fig. 2. The remaining values d_{13}, d_{14}, d_{15}, d_{24}, d_{25} and d_{35}, however, are derived from the distance between the given

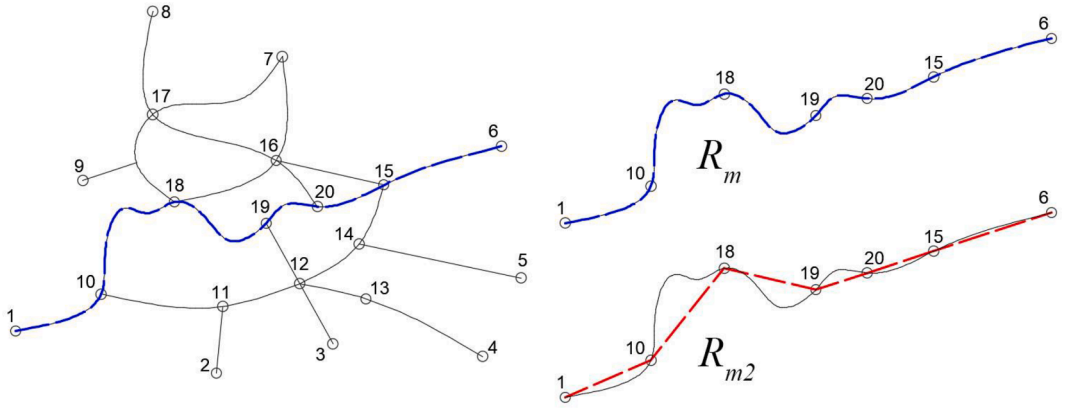

Fig. 4. A demonstration of an example route on a network, used in the calculation of an adjusted rationality value.

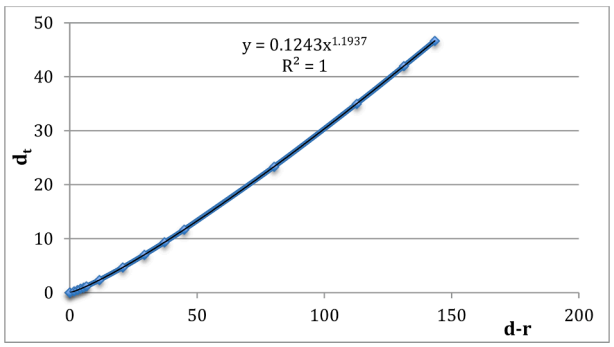

Fig. 5. The correlation between d-r and d_t.

stations. As a result, the rationality value of the route turned out to be 1.051. Here, the journeys performed in the same direction were effective on the fact that the result was close to 1.

Although the data set used for the present study did not have the transfers, the method developed has the potential and flexibility of treating transfers for other users of the method who have suitable data. For example, let us assume two bus lines between 1 and 6, and 8 and 20 on the network shown in Fig. 3. If Node 20 is a transfer point for these two lines, the method handles the route between 1 and 8 as a separate entity.

Some irrational cases to which automobile users are also exposed at the same rate and which are caused by the road network will be eliminated through this adjustment. In this way, a rationality calculation to be more effective in creating a modal shift will be made. For instance, if the journey that a public transport vehicle performs between two stations is also the same for the shortest journey likely to be performed by automobile, making an improvement in the route will only be possible through constructing a new road (Fig. 4). Since this will affect both modes at the same rate, this will not create any shift between the modes. Considering this case in the calculations, it has been decided to take the travel distances between the successive stations as the Euclidian distances between the stations. So, the travel distances will be computed again (for the second time), thereby obtaining the adjusted rationality values. Used for travel distances, d_{ji} should be re-calculated as d_{2ji} (5). For the adjusted rationality value (R_{m2}), (4) has been reorganized as in (6).

$$d_{2ji} = \sum_{j}^{i-1} r_{j,j+1} \tag{5}$$

$$R_{m2} = \sum_{j=2}^{n} \sum_{i=j}^{n} \frac{d_{2j-1,i}}{r_{j-1,i}} / n_c \tag{6}$$

According to this formula, whereby the travel distances are calculated for the second time, the rationality value (R_{m2}) turns out to be 1.032 for the public transport line given in Fig. 2. That is, there is a more rational situation than that calculated according to the formula of R_m. This situation is due to the curve between stations 3 and 4. In the formulation of R_{m2}, this effect was disregarded with the assumption that the private car user would also be exposed to the same effect. In this way, the rationalities of the routes are linearly calculated according to the d/r ratios. For instance, a journey whose distance as the crow flies between two points is 1 km and whose route length is 2 km and a journey whose distance as the crow flies is 10 km and whose route length is 20 km are regarded as being equal to each other in terms of their rationalities. Nevertheless, traveling for an extra 1 km for a distance of 1 km and traveling for extra 10 km for a distance of 10 km during urban journeys will not create the same effect among passengers. Hence, some delay tolerance will be needed here depending on the distance, which will also affect the calculations of rationality. This tolerance is a relative concept which will vary by region (e.g. city and country) and even by

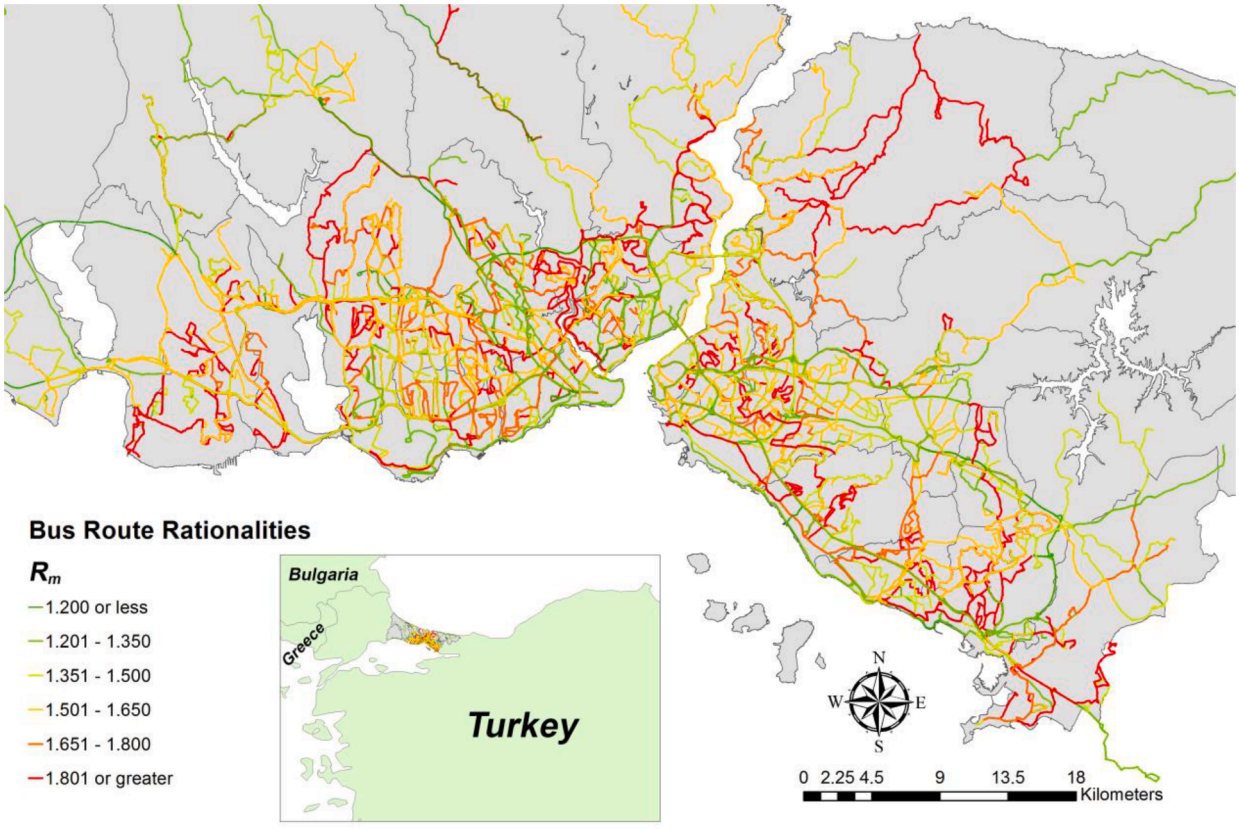

Fig. 6. Bus route rationalities based on 'R_m'.

person. In this study, it was thought that a 10-minute delay could be tolerated for a 10-minute journey and a 45-minute delay at the most for a 180-minute journey during the journeys to be performed with public transport in the city.

Chopde and Nichat (2013), Robusto (1957) used regression analysis to measure passenger tolerances against transit delays and found that as delays increased shifts toward other transport modes also increased. Cao et al. (2017) stated that people have varying delay tolerances for varying factors. Hence, extra mileages in transit have different effects on passengers. Since no direct study exist on this issue with particular numeric values, only certain hypotheses are made here.

The R value used in the calculation of rationality by obtaining an exponential distribution between these values was designed as in formula (7).

$$R = \frac{d + ((d-r)^{1.1937}) \cdot 0.1243}{r} \tag{7}$$

For this formula, first of all, the travel time tolerances have been converted to extra mileage tolerances (d_t) of the route. This was achieved by a correlation analysis between travel times and tolerable travel times. Then the difference between route lengths (d) and the Euclidian distances of these routes (r) are calculated to be able to ascertain the effect of this difference on the distance to be tolerated. Finally, the correlation between this difference and extra mileage tolerances was shown as an exponential curve (Fig. 5).

Eq. (7) was therefore reached from this correlation. Hence, the rationality value (R_{d2}) designed according to both distance and delay tolerance is calculated as in formula (8).

$$R_{d2} = \sum_{j=2}^{n} \sum_{i=j}^{n} \frac{d_{2j-1,i} + ((d_{2j-1,i} - r_{j-1,i})^{1.1937}) \cdot 0.1243}{r_{j-1,i}} / n_c \tag{8}$$

Again, when we proceed in the example (Fig. 2), the rationality value (R_{d2}) turns out to be 1.036, which is a value between R_m and R_{m2} but closer to R_{m2}. The rationality value has therefore increased slightly due to the delay tolerance effect. For instance, when we calculate the same rationality values by doubling all distance data in Fig. 2, values R_m and R_{m2} remain unchanged. However, R_{d2} rises to 1.037. Nevertheless, this increase does not have any direct effect on the rationality values. It affects depending on the rationality of the route.

To sum up, a series of formulae were developed to geometrically evaluate the rationalities of the routes of public transport lines (e.g. bus and minibus) using the same road network as private cars. Three different rationality values are obtained with these formulae. Of these values, i.e. R_m, R_{m2}, and R_{d2}, R_{d2} is the one which yields the most comprehensive result. The reason why it is called R_{d2} is that the travel distance is calculated for the second time and that it includes the delay tolerance. The Euclidian distances used in the analyses were calculated with the Haversine formula by using trigonometry according to latitudes and longitudes (coordinates) (Huang and Levinson, 2015).

$$r = 2 \cdot r_w \cdot sin^{-1} \sqrt{sin^2\left(\frac{x_j - x_i}{2}\right) + cos(x_i) \cdot cos(x_j) \cdot sin^2\left(\frac{y_j - y_i}{2}\right)} \tag{9}$$

where

x_i: the latitude of the 'i' th station (coordinate x),
y_i: the longitude of the 'i' th station (coordinate y),
r: the distance as the crow flies between the stations,
r_w: the radius of the earth.

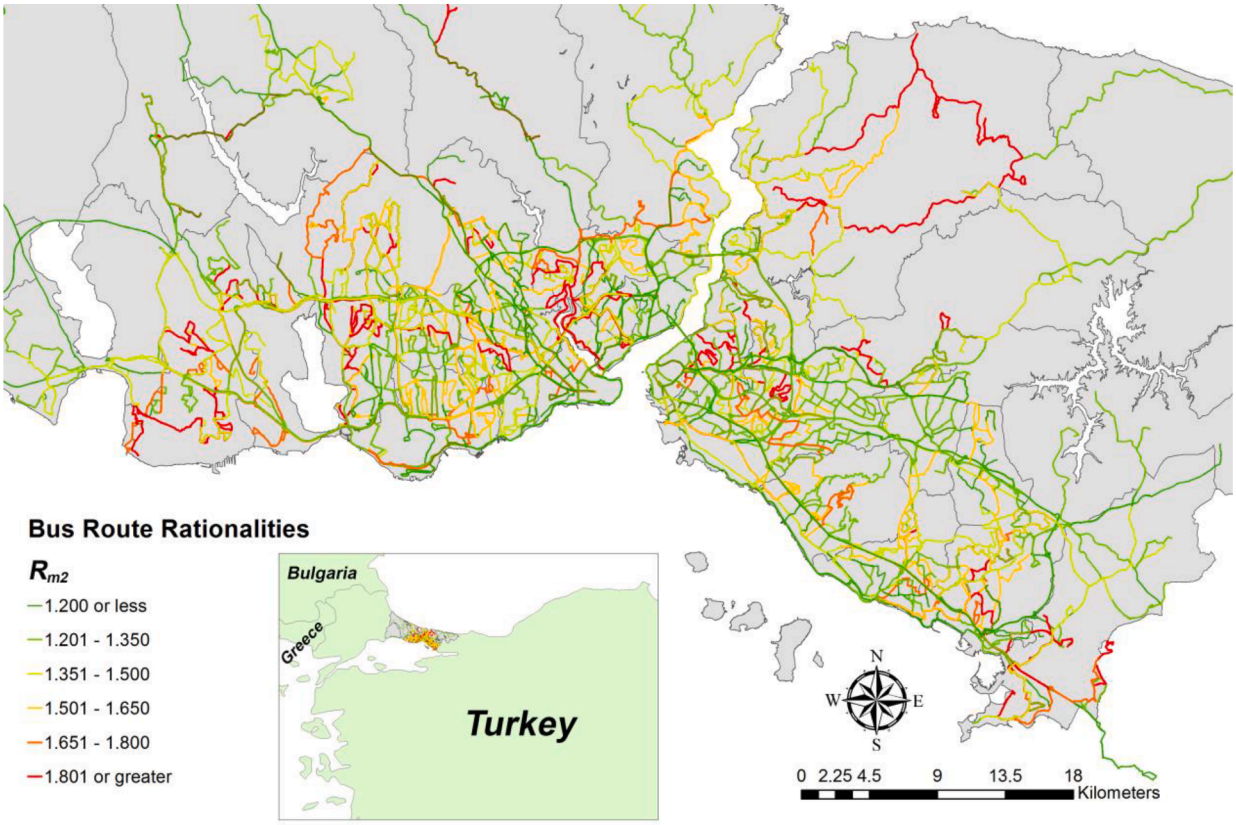

Fig. 7. Bus route rationalities based on 'R_{m2}'.

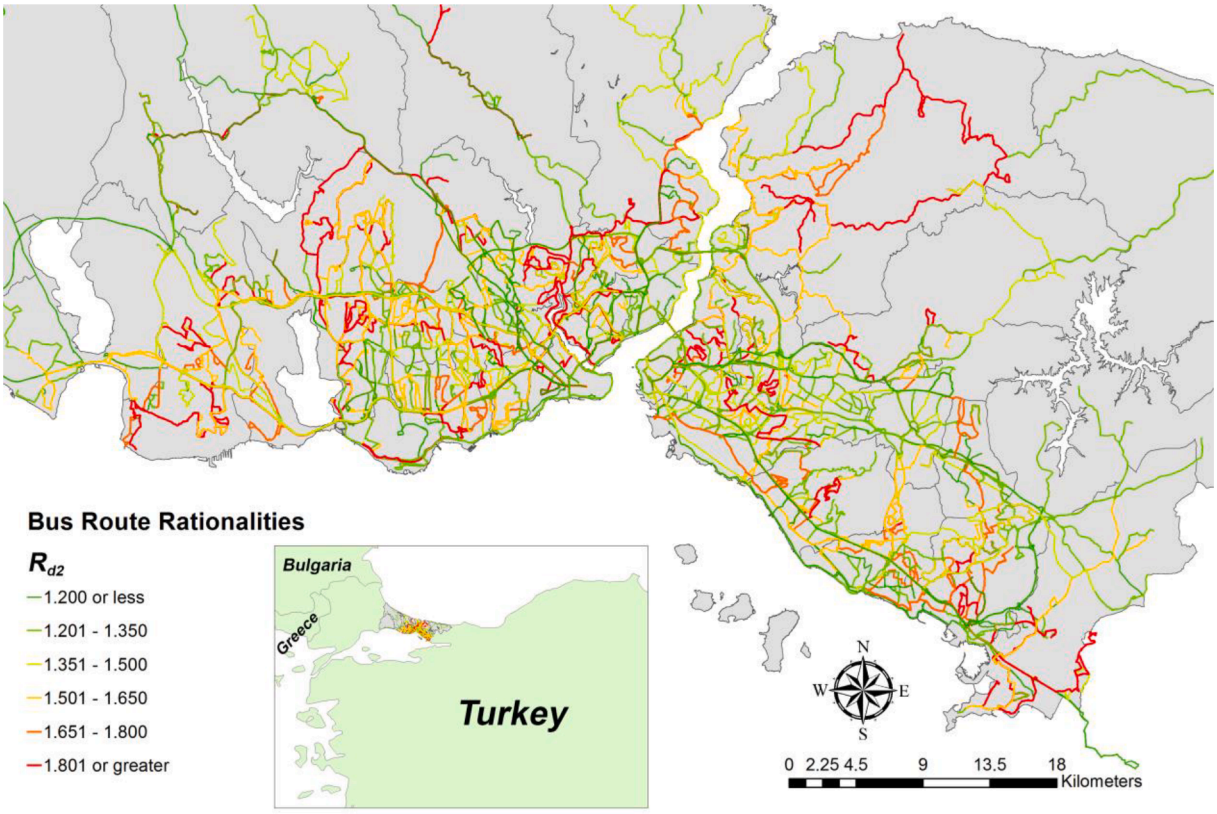

Fig. 8. Bus route rationalities based on 'R_{d2}'.

4. Results

4.1. Rationality results

After the rationality values of the lines had been calculated, these data were matched with the data of the routes of the bus lines in the GIS and Figs. 6–8 were drawn up. To facilitate an easy comparison, the figures are given together in Appendix A. The rationality values are shown at 6 different levels on these maps. When Figs. 6 and 7 are compared, significant differences in the rationality values catch the eye. If an evaluation of rationality had been made merely according to the R_m values, it would have been concluded that a large number of lines should

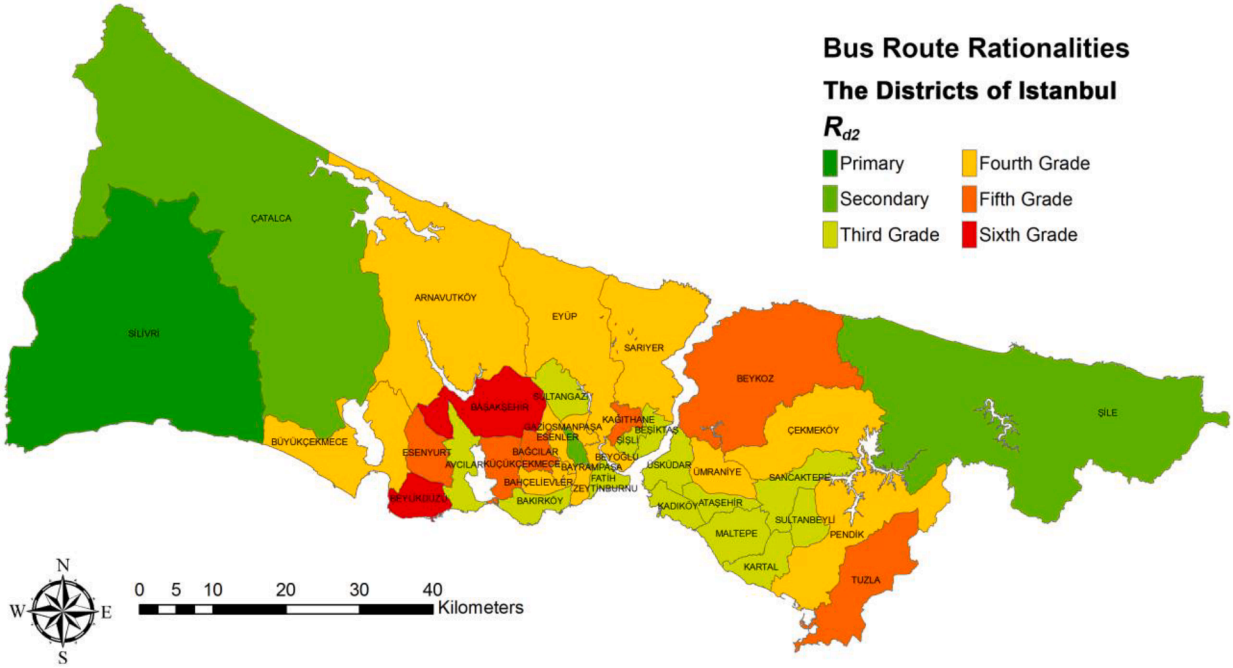

Fig. 9. Average bus route rationalities for the districts of Istanbul.

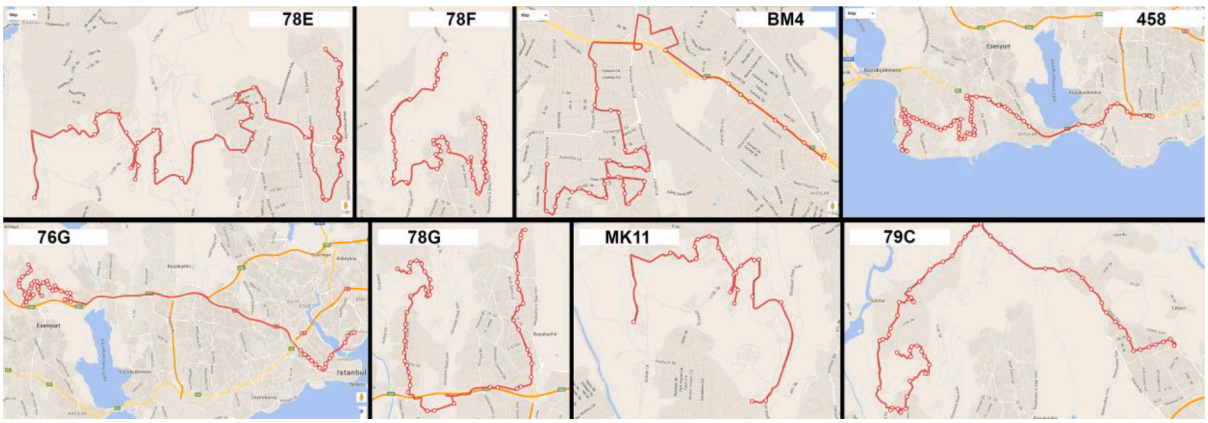

Fig. 10. Eight bus routes with the worst rationalities.

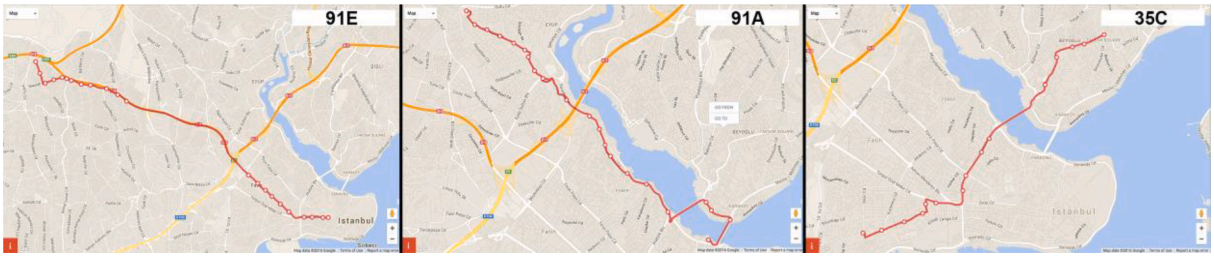

Fig. 11. Examples of the best bus route rationalities.

Table 2
Kolmogorov-Smirnov test.

Relationship with distance	p-value
Circuity	<0.0001
R_{d2}	<0.0001
	alpha 0.05

be improved. On the other hand, the results obtained with R_{m2} envisage that fewer lines likely to create an advantage in comparison with automobile use will be improved. However, when Figs. 7 and 8 are compared, some increase in the number of lines required to be improved is seen. This is due to the acceptance that the tolerance of passengers for a delay to be experienced in travel times as the travel distance extends will decrease. To make a more realistic evaluation of rationality, this was taken into consideration in the analyses. Hence, in this study, an evaluation was made according to the results given by R_{d2}.

Of the rationality values of the routes belonging to the lines seen on the map in Fig. 8, 21% are less than 1.2, 28% are between 1.2 and 1.35, 22% are between 1.35 and 1.5, 13% are between 1.5 and 1.65, 6% are between 1.65 and 1.8, and 10% are greater than 1.8. This reveals that the 120 bus lines with rationality values greater than 1.8 should be examined with priority in the event of structuring the bus lines. These thresholds and boundary conditions are determined by the ArcGIS program using the Standard Deviation method as one of the classification approaches. This method chooses equal intervals according to the deviation from the average values of the data. Other classification techniques use equal data intervals, hence, in solving the problems in question, it does not offer a practical approach to compare the results. Since the Standard Deviation method produces equal intervals by taking a meaningful value as a base value, this method has been adapted in the analysis.

When making an evaluation of rationality, the journeys within the same district were grouped and the rationality values by district were then obtained (Fig. 9).

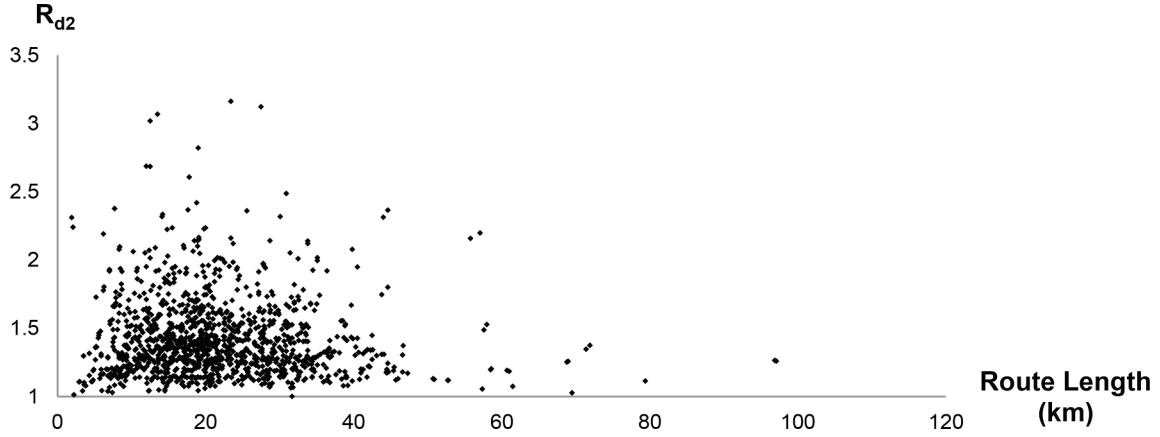

Fig. 12. Nonexistent relationship between rationality and travel distance.

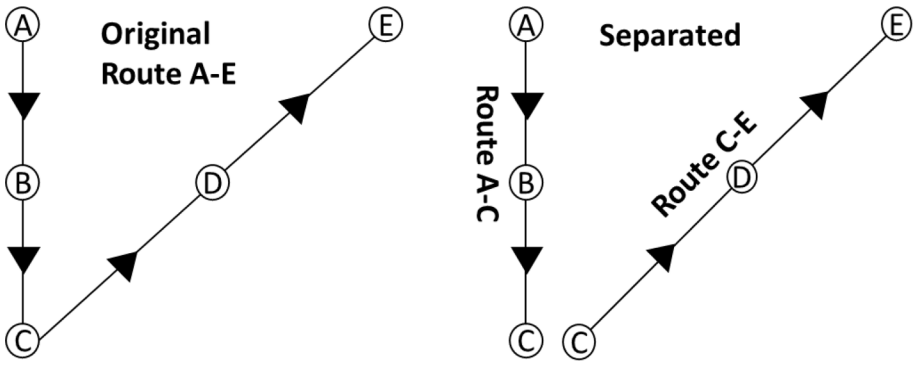

Fig. 13. Route separations.

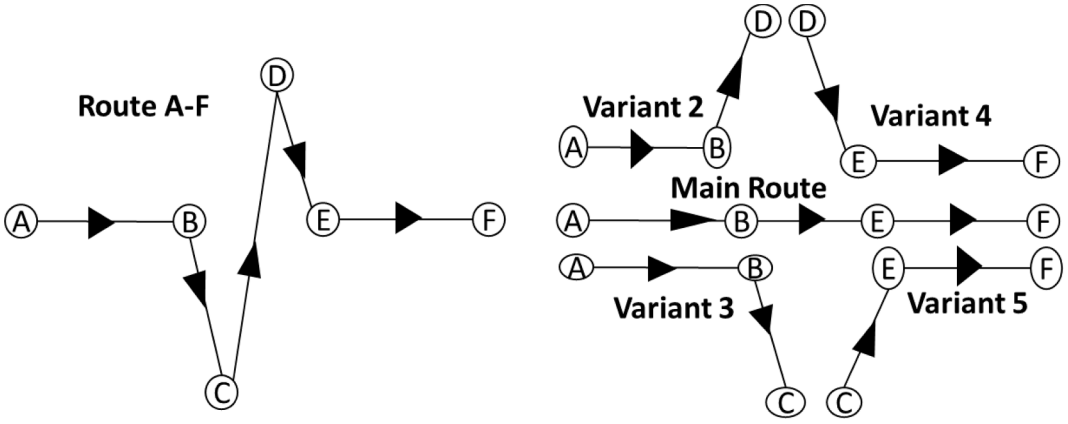

Fig. 14. Generating route variants.

As seen in Fig. 9, two districts yielded the worst results according to the rating performed. When we looked at the intersection set of these two districts and the routes with rationalities greater than 1.8 in Fig. 8, we detected 12 bus lines which offered the worst service in terms of route geometry in the journeys performed by bus in Istanbul. Of these 12 lines, five are the same lines as outbound and inbound lines. The routes of these lines are provided in Fig. 10.

When we examined the lines whose rationality values turned out to be the best, we saw that they were lines which generally did not have many deflections on their routes and which proceeded in the same direction (Fig. 11).

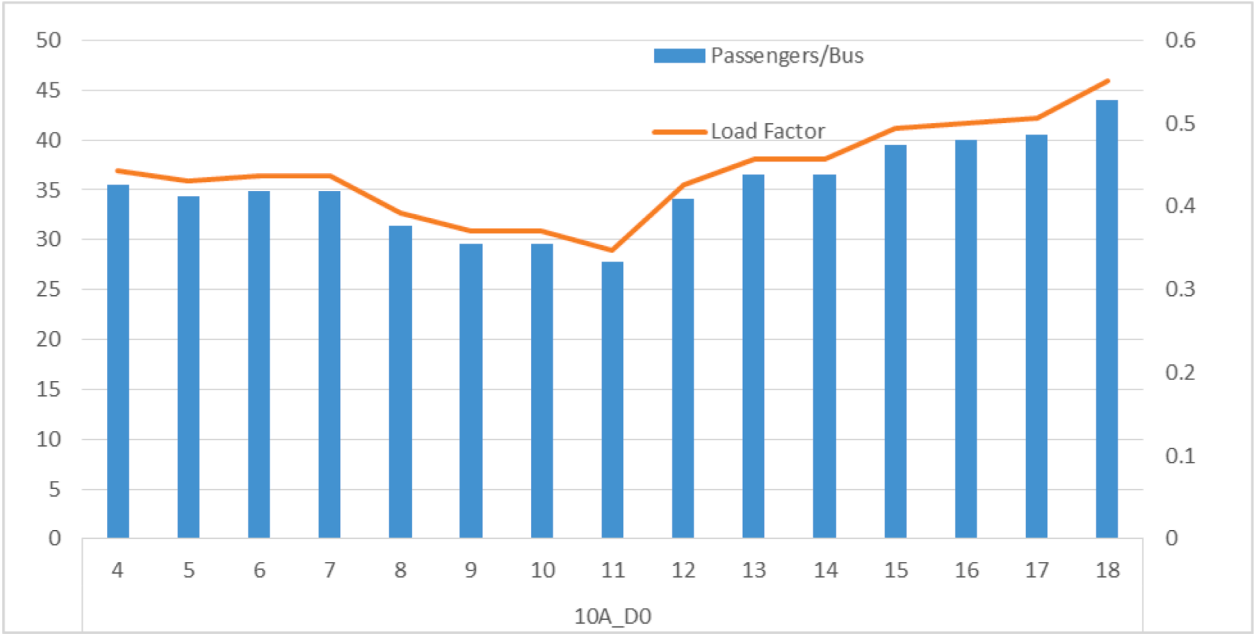

Fig. 15. Uniformly distributed passenger load.

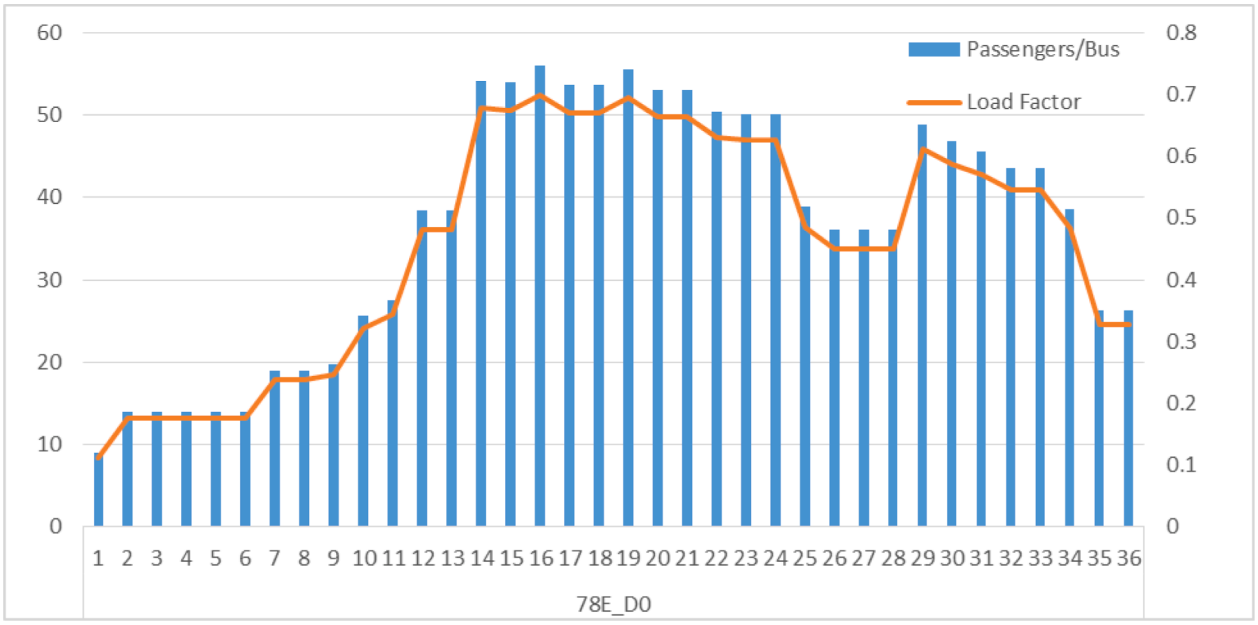

Fig. 16. Unevenly distributed passenger load data along the route sections.

4.2. Regression analysis results

Gunay et al. (2018), using linear regression, established a strong correlation between travel circuity and travel distance/time. With increasing travel distance/time, travel circuity increased. Similarly, Huang and Levinson (2015) showed an exponential relationship between circuity and travel distance using nonlinear regression analysis. These findings enabled analysts to estimate travel distances from known Euclidian distances in a given urban road network. However no single consensus has been achieved due to the existence of both linear and nonlinear relationships between the two distances being offered by the emerging literature. For example, our work found no relationship between these two distances for the city of Istanbul. We first applied the Kolmogorov-Smirnov test to see if the distance, d/r and d/R_{d2} fits to a normal distribution. As shown in Table 2, all the p-values are smaller than 0.05. Hence, we used non-parametric regression analysis to seek a relationship between distance and circuity, and between distance and rationality (R_{d2}).

According to the correlation analysis, which looked at the relationship between travel distance and circuity, the R^2 value was found to be 0.031, namely, there is no meaningful correlation between these values. This could be resulted from two possible sources: the rationality value of the city is poor and/or the planning of transit routes were not made appropriately. It is already known that the rationality coefficient of Istanbul city is worse when compared with that of other major cities (Gunay et al., 2018).

Fig. 12 was drawn up to see the relationship of rationality values with route lengths. When we look at the correlation between public transport route lengths and their rationalities (R_{d2}), the R^2 value was found to be 0.588, which is higher than the other correlation value

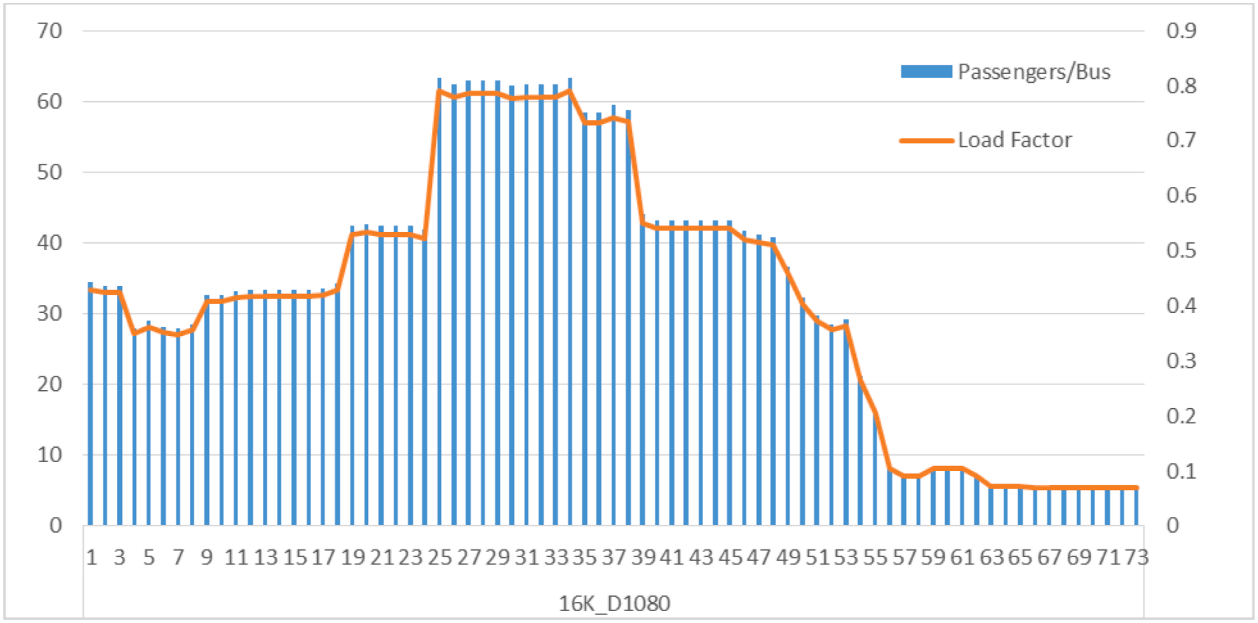

Fig. 17. Unevenly distributed passenger load data where route variants can be utilized.

calculated based on circuity. This is because when calculating the R_{d2} value extra road lengths due to the road network were eliminated and instead delay tolerance was taken into consideration. R^2 was still smaller than the values recommended by literature. This implies that public transport routes are not planned well in Istanbul.

5. Policy implications

Making improvements in the routes according to the findings of the paper has the potential for causing a shift from automobile use to public transport. Creating this potential requires an adjustment in the calculations of rationality of the public transport vehicles using the same road network as private cars. Promotion of public transport use against traffic problems is among the most effective proposals of solutions on this matter. However, the routes of public transport vehicles in themselves may sometimes be the reason why this transport mode is not preferred. Hence, organizing the routes of public transport vehicles to provide the maximum utility for passengers not only may reduce the interest in private car use but also has the potential for attracting passengers from this type of transport. A control mechanism to enable those authorities who would take decisions about public transport to reach more productive results was generated with the numerical analysis method developed. The improvements to be made in the routes will contribute to making public transport more attractive. Creating a modal shift by making public transport attractive will successively provide other benefits too. For instance, solutions like route designs which require no extra costs before the infrastructural investments to be made will create savings which will benefit the national economy.

Authorities can benefit from rationality measures in several ways; such as, construction of efficient road network, better routes and route variants, effective scheduling, and in cost reduction. In Fig. 9, the worst two districts (Basaksehir and Beylikduzu) are observed to be newly developing areas. While shaping the land use policies and development plans; the rationalities of the roads had to be considered since this would affect the travel times and inefficient paths will increase traffic problems on the roads. Therefore poor rationality values on the road network are the early signs of emerging traffic problems.

For a public bus route with poor rationality value, this measure is an indication to reconsider route itself. Solutions like route designs which require no extra costs before the infrastructural investments to be made will create savings which will benefit the national economy. To redesign routes, the rationality calculations will help to identify routes that require new alternative paths, or routes that need to be divided into separate routes or routes that should utilize route variants. For example; “U-shaped” or “V-shaped” routes like in Fig. 13, will generate poor rationality value. And for these kinds of routes, dividing the route into multiple separate routes would be better. Without separation, this kind of routes will also cause confusion in defining direction whether it is South/North bound or East/West bound.

Moreover, a route with zigzag turns will result poor rationality measure as well. Authorities should consider the variants of the routes as Fig. 14 suggests. The route that goes in the direction from A to F has 15 possible variants (selecting two terminals out of six stations) where five major variants including the main route are shown in the Fig. 14.

While dividing the routes in to multiple routes or generating the route variants, the ridership data, should definitely be analyzed. Passenger demand and bus load factors (number of passengers passing through between two stations divided by capacity of the busses) will affect the decision. Therefore rationality measures and passenger loads at the sections of a route should be analyzed together. An effective trip for a bus will be observed when a uniform and acceptable passenger load is observed along the route sections as shown in Fig. 15.

If passenger loads are not distributed evenly, as shown in Fig. 16, and have poor rationality performance (Fig. 10), separating/dividing a route to multiple routes would be a choice.

As shown in Fig. 16, as an example, the route has one of the worse rationality measures in a V-shape. Passenger load data suggest that it is possible to have one route that will be serving to bus stops 1–10, another one serving to bus stops 11–28 and a third route serving to bus stops 29–36.

Observing a poor rationality value, taking to many turns in the route, and having passenger load data as shown in Fig. 17, the route variants should be considered. For the route in the Fig. 17, one variant can start serving from bus stop 25 till to the end of the line. Another variant can be considered serving only between bus stops 1–53. Main route variant can skip some of the bus stops to have better rationality measure. By doing so, some of the trips for this route will have shorter travel time while making it possible to increase service frequency. Also there will be some room to decrease the distance (km) traveled, number of buses utilized and bus operators employed. Therefore the rationality measures can be applied for cost cutting purposes as well.

In addition, making improvements in the routes according to the findings of the paper has the potential for causing a shift from automobile use to public transport. Creating this potential requires an adjustment in the calculations of rationality of the public transport vehicles using the same road network as private cars. Promotion of public transport use against traffic problems is among the most effective proposals of solutions on this matter. However, the routes of public transport vehicles in themselves may sometimes be the reason why this transport mode is not preferred. Hence, organizing the routes of public transport vehicles to provide the maximum utility for passengers not only may reduce the interest in private car use but also has the potential for attracting passengers from this type of transport. A control mechanism to enable those authorities who would take decisions about public transport to reach more productive results was generated with the numerical analysis method developed. The improvements to be made in the routes will contribute to making public transport more attractive. Creating a modal shift by making public transport attractive will successively provide many benefits.

6. Conclusion

A method which could quantify the maximum utility that passengers would be provided with was developed in this study. The public transport lines using the urban highway network were evaluated in terms of all journey combinations likely to be performed with these vehicles. So, the maximum utility that passengers would be provided with by the route of a public transport line was quantified under the name of the concept of rationality.

It is known that a modal shift towards public transport from private car use can be achieved by improving the service quality of public transport infrastructure and operations. Any improvement made along the existing routes should be measurable so that optimisation attempts can become viable. Although the Euclidian distance, discussed by a limited number of studies in the literature, can be an indicator of the quality of routes in general, it may be misleading when applied in public transport networks, since a public transport line may possess a number of different travel alternatives. All possible alternative journeys must therefore be included in the quality calculations. Hence the term ‘rationality’ has been purposefully preferred in the present paper and the concept has been applied in the public transport network of Istanbul City.

As a result of employing this method to the bus lines of Istanbul, the rationality values of a total of 1242 bus lines as outbound and inbound lines and of 1,190,995 journeys likely to be performed in these lines were examined one by one. Furthermore, the journeys within the same district borders were grouped, thereby scrutinizing regional rationalities. As a consequence of these evaluations, it was established that the rationality values of two districts yielded the worst results according to the rating performed and the bus lines causing this were determined. Whether the route lengths had a misleading effect on the rationality values was examined and it was seen that the lengths had no misleading

effect on the results and that the most effective factor on the results was the deflections occurring on the routes. In this way, the rationalities of the routes of the public transport vehicles were first quantified geometrically with the numerical analysis method developed and a methodology to help authorities to determine the routes of public transport vehicles was proposed.

No study was found in the circuity literature using network distances rather than the Euclidian distances. Hence the contribution of the present study to science is on the evaluation of all trip combinations, distance adjustments, and the calculation of the delay tolerances.

7. Data availability statement

Some or all data used during the study are proprietary or confidential in nature and may only be provided with restrictions by Turkish Management Sciences Institute (TUSSIDE). The programming codes generated by the authors are also considered to be within the Intellectual Property Rights and hence copyrighted.

Conflict of interest

There is no conflict of interest.

CRediT authorship contribution statement

Kadir Akgol: Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Visualization, Writing - original draft, Writing - review & editing. **Banihan Gunay:** Conceptualization, Project administration. **Fahrettin Eldemir:** Resources. **Mesut Samasti:** Resources, Data curation.

Appendix A

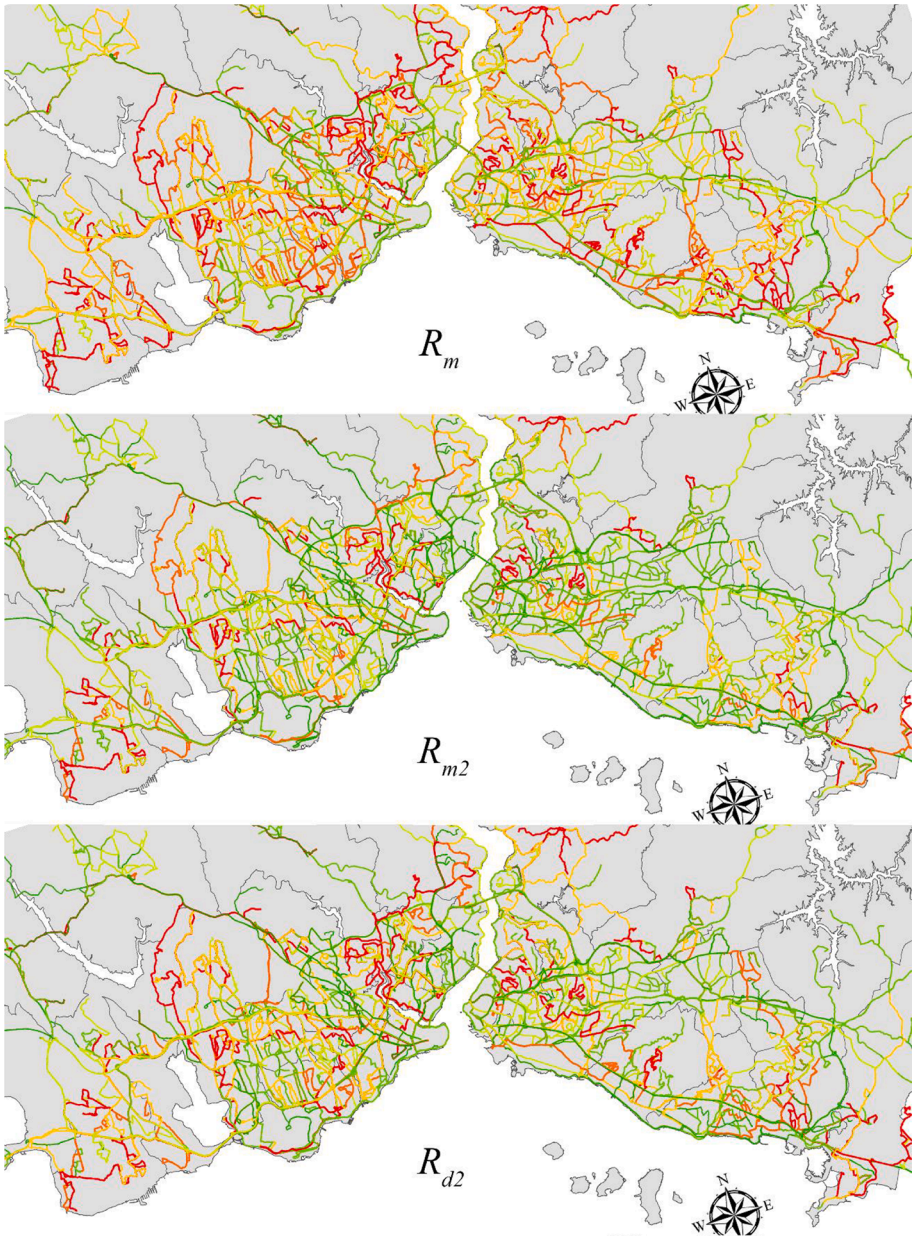

Fig. A1. A combined demonstration of Figs. 6–8.

References

Bachok, S., Osman, M.M., Khalid, U.A., Zainaldin, M.F., 2012. The application of regression analysis on users' tolerance to prolonged waiting times: The case of KTM komuter services of Malaysia, in: WIT Transactions on the Built Environment. DOI: 10.2495/CR120251.

Ballou, R.H., Rahardja, H., Sakai, N., 2002. Selected country circuity factors for road travel distance estimation. Transp. Res. Part A: Policy Practice 36, 843–848.

Beirão, G., Sarsfield Cabral, J.A., 2007. Understanding attitudes towards public transport and private car: a qualitative study. Transp. Policy 14, 478–489. https://doi.org/10.1016/j.tranpol.2007.04.009.

Black, A., 1995. Urban mass transportation planning.

Breheny, M.G., Hooper, A.J., 1985. The Role of Rationality in Urban and Regional Planning. In: Rationality in Planning. Pion, London, pp. 1–14.

Buchari, E., Ndiaye, A.B., 2008. Reformed Regulation: A Solution of Problems of Implementing Public Transport Routes, Transportation and Management Science. Hong Kong Soc Transportation Studies Ltd, Hong Kong.

Canci, M., Onden, I., 2013. Determining the success criteria for sustainable bus system creating. In: TRANSİST 6. Transportation Symposium and Exhibition. Istanbul, Turkey, pp. 231–240.

Cao, X., Liang, F., Chen, H., Liu, Y., 2017. Circuity characteristics of urban travel based on GPS data: a case study of Guangzhou. Sustainability 9, 2156.

Cascetta, E., Cartenì, A., Pagliara, F., Montanino, M., 2015. A new look at planning and designing transportation systems: a decision-making model based on cognitive rationality, stakeholder engagement and quantitative methods. Transp. Policy 38, 27–39. https://doi.org/10.1016/j.tranpol.2014.11.005.

Cervero, R., 2004. Transit-Oriented Development in the United States: Experiences, Challenges, and Prospects. Transportation Research Board.

Chopde, N.R., Nichat, M., 2013. Landmark based shortest path detection by using A* and Haversine formula. Int. J. Innov. Res. Compute. Commun. Eng. 1, 298–302.

Chowdhury, S., Ceder, A., Sachdeva, R., 2014a. The effects of planned and unplanned transfers on public transport users' perception of transfer routes. Transp. Plann. Technol. 37, 154–168. https://doi.org/10.1080/03081060.2013.851511.

Chowdhury, S., Ceder, A., Velty, B., 2014b. Measuring public-transport network connectivity using Google transit with comparison across cities. J. Public Transp. 17, 76–92. https://doi.org/10.5038/2375-0901.17.4.5.

Curtis, C., Scheurer, J., 2010. Planning for sustainable accessibility: developing tools to aid discussion and decision-making. Progr. Plann 74, 53–106. https://doi.org/10.1016/j.progress.2010.05.001.

Davison, L.J., Knowles, R.D., 2006. Bus quality partnerships, modal shift and traffic decongestion. J. Transp. Geogr. 14, 177–194. https://doi.org/10.1016/j.jtrangeo.2005.06.008.

Derrible, S., Kennedy, C., 2011. Applications of graph theory and network science to transit network design. Transport Rev. 31, 495–519. https://doi.org/10.1080/01441647.2010.543709.

Diesing, P., 1962. Reason in Society: Five Types of Decisions and Their Social Conditions. University of Illinois Press, Urbana.

Dill, J., 2004. Measuring network connectivity for bicycling and walking, in: 83rd Annual Meeting of the Transportation Research Board, Washington, DC. pp. 11–15.

Garcia-Sierra, M., van den Bergh, J.C.J.M., Miralles-Guasch, C., 2015. Behavioural economics, travel behaviour and environmental-transport policy. Transp. Res. Part D-Transport Environ. 41, 288–305. https://doi.org/10.1016/j.trd.2015.09.023.

Gunay, B., Akgol, K., Andreasson, I., Terzi, S., 2016. Estimation of modal shift potential for a new form of dial-a-ride service. J. Public Transp. 19 https://doi.org/10.5038/2375-0901.19.2.5.

Gunay, B., Akgol, K., Raveau, S., 2018. Rationality of route layouts as a quality indicator of urban road networks. Urban Des. Int. 23 https://doi.org/10.1057/udi.2016.8.

Hadas, Y., 2013. Assessing public transport systems connectivity based on Google Transit data. J. Transp. Geogr. 33, 105–116. https://doi.org/10.1016/j.jtrangeo.2013.09.015.

Hadas, Y., Ranjitkar, P., 2012. Modeling public-transit connectivity with spatial quality-of-transfer measurements. J. Transp. Geogr. 22, 137–147. https://doi.org/10.1016/j.jtrangeo.2011.12.003.

Hansen, W.G., 1959. How accessibility shapes land use. J. Am. Inst. Planners 25, 73–76.

Huang, J., Levinson, D.M., 2015. Circuity in urban transit networks. J. Transp. Geogr. 48, 145–153.

Langmyhr, T., 2001. The rationality of transport investment packages. Transportation 28, 157–178. https://doi.org/10.1023/a:1010396029605.

Levinson, D.M., 1998. Accessibility and the journey to work. J. Transp. Geogr. 6, 11–21.

Levinson, D., 2012. Network structure and city size. PLoS One 7, e29721.

Levinson, D., El-Geneidy, A., 2009. The minimum circuity frontier and the journey to work. Regional Sci. Urban Econ. 39, 732–738.

Lin, J., Ban, Y., 2013. Complex network topology of transportation systems. Transport Rev. 33, 658–685. https://doi.org/10.1080/01441647.2013.848955.

Love, R.F., Morris, J.G., 1979. Mathematical models of road travel distances. Manage. Sci. 25, 130–139.

Matisziw, T.C., Demir, E., 2016. Measuring spatial correspondence among network paths. Geogr. Anal. 48, 3–17.

Murray, A.T., Davis, R., Stimson, R.J., Ferreira, L., 1998. Public transportation access. Transp. Res. Part D: Transport Environ. 3, 319–328.

Newell, G.F., 1980. Traffic flow on transportation networks.

O'Sullivan, S., Morrall, J., 1996. Walking distances to and from light-rail transit stations. Transp. Res. Rec. 19–26.

Owen, A., Levinson, D.M., 2015. Modeling the commute mode share of transit using continuous accessibility to jobs. Transp. Res. Part A: Policy Practice 74, 110–122.

Raveau, S., Guo, Z., Muñoz, J.C., Wilson, N.H.M., 2014. A behavioural comparison of route choice on metro networks: time, transfers, crowding, topology and socio-demographics. Transp. Res. Part A: Policy Practice 66, 185–195. https://doi.org/10.1016/j.tra.2014.05.010.

Robusto, C.C., 1957. The cosine-haversine formula. Am. Math. Monthly 64, 38–40.

Rojo, M., dell'Olio, L., Gonzalo-Orden, H., Ibeas, Á., 2015. Inclusion of quality criteria in public bus service contracts in metropolitan areas. Transp. Policy 42, 52–63. https://doi.org/10.1016/j.tranpol.2015.05.002.

Sager, T., 1994. Communicative Planning Theory. Avebury, Aldershot.

Samaniego, H., Moses, M.E., 2008. Cities as organisms: allometric scaling of urban road networks. J. Transport Land Use 1, 21–39.

Selvidge, P., 2003. Examining tolerance for online delays. Usability News 5, 1–5.

Sun, D., Chen, S.K., Zhang, C., Shen, S.W., 2016. A bus route evaluation model based on GIS and super-efficient data envelopment analysis. Transp. Plann. Technol. 39, 407–423. https://doi.org/10.1080/03081060.2016.1160582.

Taylor, B.D., 1991. Unjust Equity: An Examination of California's Transportation Development Act.

Vitale, A., Festa, D.C., Guido, G., Rogano, D., 2014. A Decision Support System based on smartphone probes as a tool to promote public transport, in: DeSousa, J.F., DeSousa, J.P., Costa, A., Farias, T., Melo, S. (Eds.), Transportation: Can We Do More with Less Resources? - 16th Meeting of the Euro Working Group on Transportation - Porto 2013. Elsevier Science Bv, Amsterdam, pp. 224–231. DOI:10.1016/j.sbspro.2014.01.055.

Vragović, I., Louis, E., Díaz-Guilera, A., 2005. Efficiency of informational transfer in regular and complex networks. Phys. Rev. E 71, 36122.

Vreeswijk, J.D., Landman, R.L., van Berkum, E.C., Hegyi, A., Hoogendoorn, S.P., van Arem, B., 2015. Improving the road network performance with dynamic route guidance by considering the indifference band of road users. IET Intel. Transport Syst. 9, 897–906. https://doi.org/10.1049/iet-its.2014.0258.

Walker, J., 2012. Human Transit: How Clearer Thinking about Public Transit can Enrich our Communities and our Lives. Island Press.

Wolf, J., Schönfelder, S., Samaga, U., Oliveira, M., Axhausen, K., 2004. Eighty weeks of global positioning system traces: approaches to enriching trip information. Transp. Res. Rec. 46–54.

Yan, X.-Y., Wang, M.-S., 2009. Topological properties of public transport networks: a temporal perspective. ICCTP 2009, 1–6. https://doi.org/10.1061/41064(358)151.

Yildirim, R.O., 2013. Measurement model of service quality. In: TRANSİST 6. Transportation Symposium and Exhibition. Istanbul, Turkey, pp. 381–392.