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ORIGINAL RESEARCH

Tracing rail transformation: the case of passenger services in Slovenia from 1975 to 2015

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Abstract

In the 1990s, Slovenia was part and neighbor of a series of disruptive events, undergoing a change from member state of a diverse socialist federation to a small, independent market economy country. These comprehensive changes were followed (or accompanied by) partially dramatic changes in the transport regime. In order to trace the change of the passenger railway service a method for the analysis and characterization of the timetable offer in public transport is developed and applied to ten timetable years between 1975 and 2015 on the main lines between Ljubljana, Maribor and Zagreb. This method is based on a cluster analysis of origin–destination relations with the three variables of daily direct connections, the number of trains with synchronized intervals as well as the overall regularity of travel times. In general, an overall increase of the quality of the rail service supply is shown, focusing on the decades from 1975 to the end of the 1990s. From 2000 to 2015 relatively little changes were identified. While a very dense offer was developed in regional traffic within the wider urban areas of Ljubljana, Celje and Maribor, the direct cross-border inter-city connections to/from Zagreb have been increasingly neglected. The example of the connection between Ljubljana and Maribor demonstrates the development towards a supply-oriented integral timetable until the 1990s. Thereafter, the timetable was thinned out and gradually developed with a demand-driven principle, where a higher train density was offered to Ljubljana in the morning and to Maribor in the afternoon.

Keywords Railway · Passenger service · Slovenia · Timeline · Timetable analysis

JEL Classification R42 · L92 · O18

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1 Introduction

For the longest part of the twentieth century, Slovenia was part of the Socialist Federal Republic of Yugoslavia. As Yugoslavia was a federation of states, the railway system was organized with an umbrella institution, the Community of Yugoslav Railways (Zajednica Jugoslovenskih Željeznica—JŽ), which was comprised of railway companies from the federation's six member states. As each of these state railway companies had their representation in JŽ, some of their common matters were organized centrally, e.g. rule books, tariff system, international relations and timetable, while other important matters were non-centralized, e.g.: education, health care, procurement of works and rolling stock (Brezina et al. 2018). In the first half of the 1990s the federation was shaken by a series of interwoven civil and ethnic wars: 1991 in Slovenia, 1991–1995 in Croatia and 1992–1996 in Bosnia and Herzegovina. With the dismantlement of the federation also a dramatic change in the economic and societal system started, from centralized socialism to a market economy (Pezdir 2008). And a good decade after gaining independence in 1991, Slovenia joined the EU in 2004 and the Schengen-Area in 2007 (Hösler 2006). As the general society underwent partially quite dramatic changes, so did the transportation system, too. Not only did the organizational structures change as the federal organisation JŽ broke apart in separate companies of the follow-up nations (Howkins 2005)—Slovenske Železnice (SŽ) in Slovenia—so, too, did the travel habits and offered connections between the new states (Brezina et al. 2018).

A rapid change in the national as well as local transport regimes was noted over the 1990s (Bole 2004; Bole and Gabrovec 2012; Ogrin and Dovecar 2014). The popularity of the private car rose increasingly, as did the provision of road infrastructure (Brezina 2011; Brezina et al. 2018), while a dramatic decline in the provided public transport services and in the number of transported passengers took place over a rather brief period of time. For example, from 1981 to 2002 the share of public transport rapidly declined from 58 to 10% for daily work commuters, while the use of cars soared from 27 to 85% (Bole and Gabrovec 2012). Also the following transport parameters increased notably: commuting distances and motorization rates (Bole 2004) as well as the number of people commuting, up to two-fold on particular routes (Bole and Gabrovec 2012). Meanwhile, the population remained stable at around 2 million.

Hence, on the crossroads and national transition, the key question in need of addressing is: How did passenger rail services change over time and how were they affected by these substantial societal changes? In this work we consider the following five aims and two boundary conditions.

Aims

- Development of a method for timetable analysis with a customer perspective.
- Development of a flexible analysis scheme that may cope with changes in timetable design priorities possibly arising over this 40-year time period.

- Derivation of parameters that characterize the timetable supply from a customer perspective.
- Application of these parameters to selected lines for the given time series.
- Distinction of characteristics that appear for direct connections and how they change over the course of the inquiry period.

Boundary conditions

- This analysis is based solely on timetable information for direct connections between train stations.
- No consideration of tariffs, alternative modes, interchanges or access/egress to/from these stations as variables.

The scrutiny needs to consider that results may reflect a representation of different orders of magnitude of the selected quality parameters and include a tracing over time (and space).

Railway performance may be assessed from various perspectives, such as evaluating the performance of national passenger rail systems over time (Fraszczyk et al. 2016), passenger trip speeds including access, egress and interchange (Brezina and Knoflacher 2014), the competitiveness in reference to air travel (López-Pita and Robusté Anton 2003; Macoun and Leth 2017). In terms of timetable-related analysis, for example, the following aspects have been studied: fitting of arrival and departure train times to a dynamic demand (Canca et al. 2014), calculation of a relative train path efficiency index for the evaluation of timetabling quality (Jiang et al. 2017) as well as analyses of service regularity (van Oort and van Nes 2009) and timetable stability (Goverde 2007).

The success of public transportation systems depends on both system-immanent factors defining its service characteristics as well as other parameters such as service quality of other transport modes (Redman et al. 2013; Soza-Parra et al. 2019), regulatory and organizational boundaries by public authorities as well as historical and cultural background thereof (Ingvardson and Nielsen 2019). The present paper focuses solely on the public transport systems' service quality in the area of inquiry. However, a service's quality is perceived differently among the actors involved. While ridership has a very subjective approach and rate how their personal mobility demand was covered, operators and planners usually frame the bigger picture (Eichmann et al. 2006).

Based on the available datasets, only parameters that describe the service quality can be assessed and further analyzed. While there is a wide variety of factors influencing public transport's service quality, base factors such as availability and travel time and travel speed are widely recognized as key parameters for general acceptance of public transport systems (Eboli and Mazzulla 2012; Paulley et al. 2006; Probst et al. 2001). Without a good performance regarding these underlying base factors, other factors cannot unfold their full positive effects.

The available timetable data allowed us to quantify key *base factors* in order to analyze and thereafter compare the service quality within certain timeframes. *Performance factors* and *factors of enthusiasm* cannot be taken into account and have to be subject of further research. The chosen parameters derived from the timetable information will be further elaborated on in the following section.

Out of the former Yugoslav states we chose Slovenia as area of inquiry, because:

- The availability of timetable data appears to be best among all former Yugoslav states. For the war-torn countries such as Croatia and Bosnia and Herzegovina rather large gaps were identified for this period (Brezina et al. 2018).
- The war in 1991 lasted very shortly (just 10 days) and thus may be neglected from the perspective of a limiting impact on human movement patterns and rail operations.
- In comparison to the other states, no major social disruptions or territorial losses were encountered due to the armed conflict.

For a general inquiry (Sect. 3.1) we choose the following three main rail lines, all of them being double-tracked, electrified and containing local, regional and international train services (see Fig. 1).

- Ljubljana–Celje–Maribor & vice versa,
- Maribor–Celje–Zagreb & vice versa and
- Zagreb–Ljubljana & v.v.

As timetable data were available only for Slovenia, the stations between the Croatian border at Dobova and Zagreb main station itself—Savski Marof, Brdovec, Zaprešic and Zagreb zapadni kolodvor—could not be included. The detailed analysis (Sect. 3.2) focuses on Slovenia's trunk line Ljubljana–Maribor.

The paper is structured as follows: Sect. 2 introduces the used data and the applied methods. Section 3 shows the results on a general and a line-specific level, which are then discussed in Sect. 4. In the end, Sect. 5 draws conclusions based on the findings.

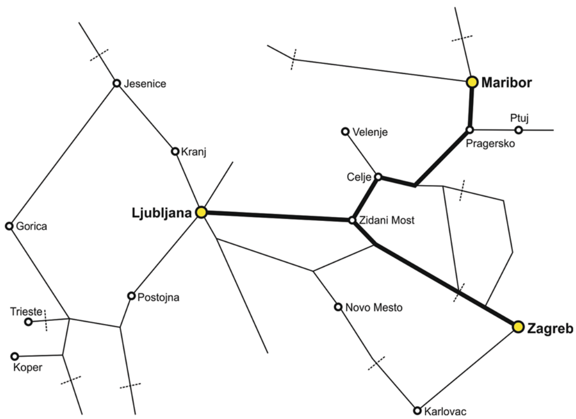


Fig. 1 Topography of Slovene rail network. Highlighted are selected stations and the studied lines. Dashed lines indicate state border crossings

2 Data and methods

The development of the passenger rail supply along the time series from 1975 to 2015 is evaluated through the analysis of the following ten timetable years: 1975/1976, 1979/1980, 1985/1986, 1989/1990, 1992/1993, 2000/2001, 2002/2003, 2004/2005, 2009/2010 as well as 2015/2016 (see Table 1). Since it is common in Slovenia to provide different timetables for the summer period—usually from June to September—than for the rest of the year, the analysis focuses on the regular supply with trains running from Monday to Friday outside of the summer months. For the analysis, the printed timetables have been digitalized with train numbers as well as arrival and departure times at each stop. At stops without published arrival times, a general dwell time of one minute is assumed.

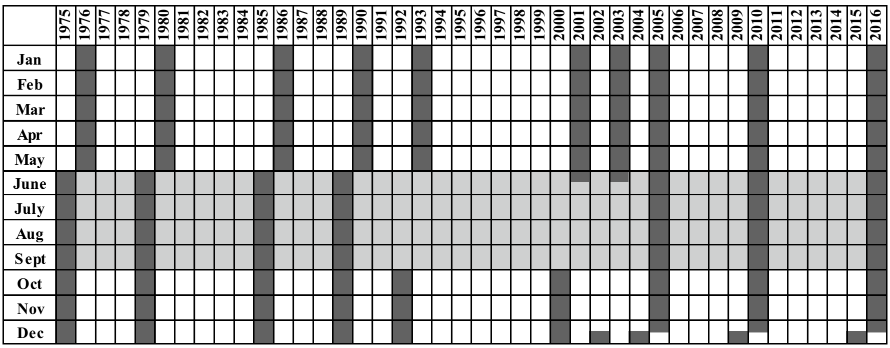
Based on the given timetables, origin–destination (OD) matrices for all stations along the investigated lines are created in order to further assess key parameters for all possible connections. Only direct connections are analyzed, while possible trips with one or more transfers are not taken into account, since they cannot be reliably assessed due to the lack of information about station layouts, service stability, interchange times and actual transfer behavior.

For all OD relations, the key base factors *availability* and *travel time/speed* are described and quantified by the following indicators that serve as parameters for the analysis of the development of service quality of public transport services in the inquiry area within the inquiry time period:

- Total number of daily (direct) connections n_C,
- Average travel speed per connection v_T [km/h],
- Average interval between connections t_I [min].

Travel speed was chosen over travel time to make distance-independent comparisons possible. In order to take into account the high quality of a synchronized timetable for ridership (Tyler 2003), the following parameters are taken into account in order to describe the repeating pattern of such a timetable.

Table 1 Timetable data used for the analysis (summer period shaded)



- Number of daily connections with synchronized intervals n_{SI}
- Regularity of travel times ρ_{RT},
- Qualitative evaluation of service time slots.

While the quantification of the first three parameters is quite trivial and solely based on the timetable information, the number of daily connections with synchronized intervals (n_{SI}) assesses all train departures for an OD relation within a predefined time window of tolerance (±3 min) of an hour. This allows to consider both, strict interval timetables (e.g. a train departure every hour at the minutes 15 and 45) as well as timetables which include a small deviation within a time window of tolerance (e.g. train connections every hour with departure times in the time windows of minute 15±3 min and minute 45±3 min). If there are at least five departures per day within a certain time window for an OD relation, it is considered a connection within a synchronized interval. There can be more than one such time window (for example a 30-min interval leads to two such time windows).

The regularity of travel times is calculated by applying a method based on the Gini coefficient [0; 1]. It is an index for a sequence's inequality based on the deviation of a given distribution from an equal distribution by comparing the area of its Lorenz-Curve with the area underneath the line of equality (Damgaard 2018a, b; Faes 2018). We define the coefficient of travel time regularity ρ_{RT} by subtracting the Gini coefficient from one. If there is only one train departure per day, ρ_{RT} is defined as 0, with more than one departure it is calculated as follows:

$$0 \leq n_C \leq 1 : \rho_{RT} = 0$$

$$1 < n_C : \rho_{RT} = 1 - \left(\frac{2 \bullet \sum_{i=1}^{n_C} i \bullet t_{T,i}}{n_C \bullet \sum_{i=1}^{n_C} t_{T,i}} - \frac{n_C + 1}{n_C} \right) \bullet \frac{n_C}{n_C - 1}$$

where $t_{T,i}$ is the ith element of all travel times (t_T) of the given connection in ascending order. If, for example, an OD relation is always serviced by trains requiring the same travel time (e.g. every connection from A to B takes 22 min), the sequence of travel times would be equally distributed and thus result in a Gini coefficient of 0, leading to a regularity of travel time of ρ_{RT}=1. The more unequal the distribution of travel times for an OD relation gets, the higher will be its Gini coefficient and thus lower the regularity of travel time ρ_{RT}.

The sample of ten timetable years includes a total of 15.600 OD relations (see Table 2 and Fig. 2) with travel distances (s_D) between 2.1 km and 169.6 km. They are serviced by 0–43 trains per day (n_C), 0 meaning that no direct train connection is offered on a certain OD relation, with a mean value of 9.1 daily direct connections. The mode of only one train per day applies to 16% (2,434 OD relations) of the data. The number of connections with synchronized intervals (n_{SI}) ranges between 0 and 31 daily trains per OD relation with a mean of 6.2 and a mode of 0 (47%). The regularity of travel times (ρ_{RT}) covers values between 0 and 1, whereas the mode of 0 applies to 24% of the data and results from those OD relations with less than two direct train connections per day. The

Table 2 Sample description for 15,600 OD relations (1560 per timetable year)

	n_C (trains/day)	ρ_{RT} (–)	n_{SI} (trains/day)	s_D (km)	v_T (km/h)	t_I (min)
Minimum	0.0	0.000	0.0	2.1	10.6	2.0
Maximum	43.0	1.000	31.0	169.6	186.0	917.0
Median	8.0	0.969	4.0	59.9	60.0	60.0
Mean	9.1	0.736	6.2	63.5	61.0	81.4
SD	8.1	0.417	6.9	38.5	10.6	77.6
Mode	1.0	0.000	0.0	12.6	70.0	60.0

average travel speed (v_T) reaches 61 km/h. The maximum values of 186 km/h (n = 23) are not realistic for the analyzed region and are likely a mathematical result of short travel times between two stops combined with the assumption of a minimum dwell time of one minute. As well, we also cannot rule out errors in times given in the timetable. But these implausible speeds make up about 0.2% of the 141,111 journeys in total and thus do not appear of relevance.

The intervals (t_I) between two train connections on the same OD relation cover values from 2 to 917 min (Zagreb–Maribor in 1979/1980) with a median and mode of 60 min.

For a general overview over the different supply levels between the OD relations and their development over the years, a cluster analysis applying the k-means algorithm with the three parameters n_C, n_{SI}, and ρ_{RT} is conducted. Hereby, the squared Euclidian distance is used as the proximity measure and the initial cluster centers are determined using the k-means ++ algorithm with 100 iterations. Every cluster solution is recalculated 2000 times and the Calinszky-Harabasz criterion is applied to determine the optimal number of clusters (Backhaus et al. 2016; Calinski and Harabasz 1974).

For the parameters included into the cluster analysis, both the relatively high density of OD relations at the lower end of all three scales as well as the positive correlation between n_C and n_{SI} become clear in Fig. 3. However, divided into ten timetable years, it can be shown that this correlation is not constant over time. It rather increases from the 1970s ($R^2 = 0.71$) until the beginning of the 1990s ($R^2 = 0.94$), before it remains relatively constant between $R^2 = 0.94$ and 0.96 throughout the rest of the time series (see Table 3).

This already indicates the extended development of timetables with synchronized intervals during the first two decades of the period examined. While this correlation obviously leads to a train number-dependent aggregation of OD relations in the course of the cluster analysis, the regularity of the travel times may be interpreted only as a rather descriptive parameter—regularity is not characteristic for the clusters.

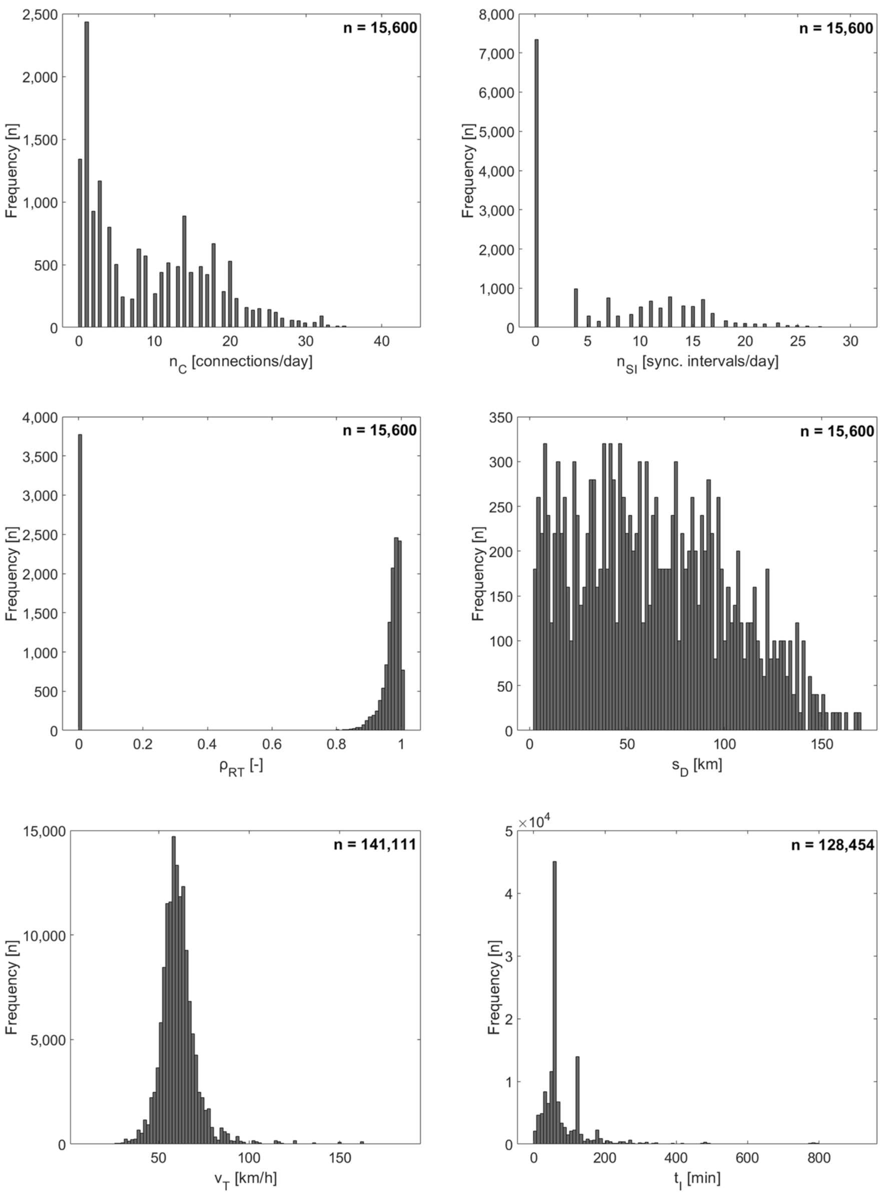


Fig. 2 Sample description for 15,600 OD relations: total train connections per day n_C (upper left), trains with synchronized intervals n_{SI} (upper right), regularity of travel times ρ_{RT} (mid left), distance s_D (mid right), travel speed v_T (lower left) and intervals between connections t_I (lower right)

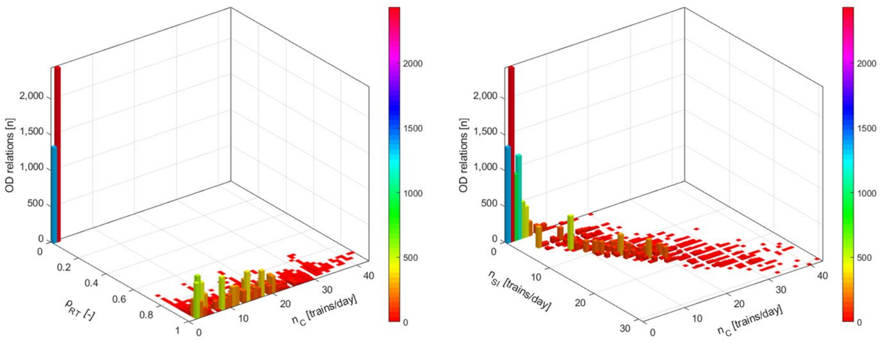


Fig. 3 Density of data points; n_C in relation to ρ_{RT} and OD relations n (left) and n_C in relation to n_{SI} and n (right)

3 Results

3.1 General results

In the course of the cluster analysis, the 15,600 OD relations are aggregated into six clusters with different supply levels of direct train connections (see Fig. 4 and Table 4). The diagonal cluster borders relating n_{SI} to n_C indicate the dependency of this cluster solution on the share of trains with synchronized intervals. Given the same number of daily connections, an OD relation is likely to be grouped into a higher supply level, the higher its number of n_{SI} is. In contrast, ρ_{RT} shows a relatively high dispersion across all clusters. However, looking at the median values, we can distinguish between a cluster with a rather low level (cluster 6 with ρ_{RT}=0.9578), two clusters with a medium level (cluster 2 and 3 with ρ_{RT}=0.9743 and 0.9745, respectively) and two clusters with a high level (cluster 4 and 5 with ρ_{RT}=0.9857 and 0.9831, respectively) of travel time regularity.

For an interpretation of the supply level of direct train connections based on the three input parameters n_C, n_{SI} and ρ_{RT}, the six clusters can be described as follows:

- Cluster 1 (purple) contains relations with zero or one daily connection, thus generally a transfer is needed to satisfy the transport demand.
- Cluster 2 (yellow) includes relations where a rather low daily supply of direct connections (min 2, max 10, mean 3.8) with basically not synchronized intervals is ensured. The regularity of travel times reaches an intermediate level (0.97). This cluster represents OD relations with a minimal offer of daily direct connections.
- Cluster 3 (blue) ensures a continuous basic offer throughout the day with a medium level of direct connections (min 5, max 20, mean 10.3), a relatively low share of trains with synchronized intervals (min 0, max 9, mean 6.0) and an intermediate level of travel time regularity (0.97).
- Cluster 4 (green) covers a medium supply level of total connections (min 11, max 21, mean 14.1) with a continuous offer of trains with synchronized

Table 3 Correlation between n_C and n_{SI} as well as between n_C and ρ_{RT} per timetable year

Year	1975/76	1979/80	1985/86	1989/90	1992/93	2000/01	2002/03	2004/05	2009/10	2015/16
R^2 (n_C, n_{SI})	0.718	0.665	0.893	0.901	0.944	0.962	0.952	0.951	0.960	0.945
R^2 (n_C, ρ_{RT})	0.494	0.360	0.518	0.598	0.739	0.839	0.816	0.566	0.578	0.598

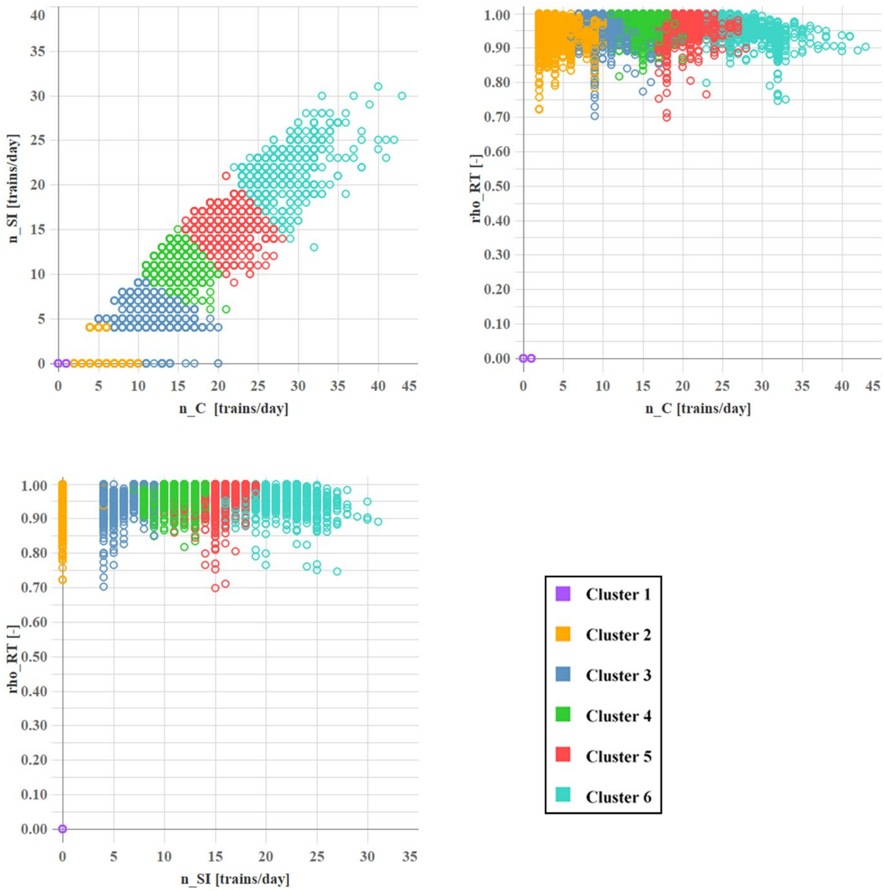


Fig. 4 Clusters in three variable relations, n = 15,600 OD relations

intervals throughout the day (min 6, max 15, mean 11.5). This also leads to a relatively high regularity of travel times (0.98).

- Cluster 5 (red) aggregates OD relations with a high supply level of daily train connections (min 16, max 28, mean 19.7), combined with a high number of trains with synchronized intervals (min 9, max 21, mean 15.5) and a high level of travel time regularity (0.98).
- Cluster 6 (cyan) represents the OD relations with the highest frequency of trains (min 22, max 43, mean 28.0) and a high number of connections with synchronized intervals (min 13, max 31, mean 21.6), while the regularity of travel times only reaches a relatively low level (0.95), which is mostly due to a mixture of long- and short-distance trains with significantly differing travel times servicing the same OD relation.

Table 4 Cluster characteristics

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
OD relations						
n	3775	3909	2239	2714	2255	708
Share [%]	24.2	25.1	14.4	17.4	14.5	4.5
n_C						
Minimum	0.0	2.0	5.0	11.0	16.0	22.0
Cluster center	0.6	3.8	10.3	14.1	19.7	28.0
Median	1.0	3.0	9.0	14.0	20.0	27.0
Maximum	1.0	10.0	20.0	21.0	28.0	43.0
n_{SI}						
Minimum	0.0	0.0	0.0	6.0	9.0	13.0
Cluster center	0.0	0.4	6.0	11.5	15.5	21.6
Median	0.0	0.0	7.0	11.0	16.0	22.0
Maximum	0.0	4.0	9.0	15.0	21.0	31.0
ρ_{RT}						
Minimum	0.0000	0.7200	0.7017	0.8182	0.6971	0.7469
Cluster center	0.0000	0.9666	0.9702	0.9796	0.9747	0.9521
Median	0.0000	0.9743	0.9745	0.9857	0.9831	0.9578
Maximum	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000

In general, a trend from a lower to a higher level of supply can be identified along the time series (see Fig. 5). Simultaneously, the OD relations are divided into those with a planning priority of a direct train connection and those requiring at least one transfer. From the timetable year 2000/2001 until 2015/2016, around half of the OD relations can be assigned to the clusters 4, 5 or 6, representing those with the highest level of supply. In the 1970s, however, around 50% of the relations are only serviced with a “minimal offer” (Cluster 2), while another 30% meet the criteria of a “daily basic offer” (Cluster 3). In the 1980s, the number of OD relations falling into Cluster 2 halved, mainly in favor of an increasing level of supply and a higher regularity of travel times (Clusters 4 and 5). As the data for the timetable year 1992/1993 shows, the beginning of the 1990s mark a clear reduction of the overall supply level, which can be noted in a more than doubled number of OD relations in Cluster 1 as well as in the decrease of the share of Cluster 4, representing a medium supply level, while those with a basic train service (Cluster 3) more than doubled. Until the timetable years 2000/2001 and 2002/2003, the share of OD relations without direct train connections increases to around 43%. Apart from that, the train service on half of the OD relations is developed to a significantly higher level of supply, which is represented by Clusters 4, 5 and 6 with 19%, 23% and 7%, respectively. This overall picture changes only insignificantly in the following timetable years. However, the timetable of 2004/2005 shows a reduction of OD relations without direct trains (from a share of 42 to 24%), while the number of OD relations with a minimal supply (Cluster 2) increases.

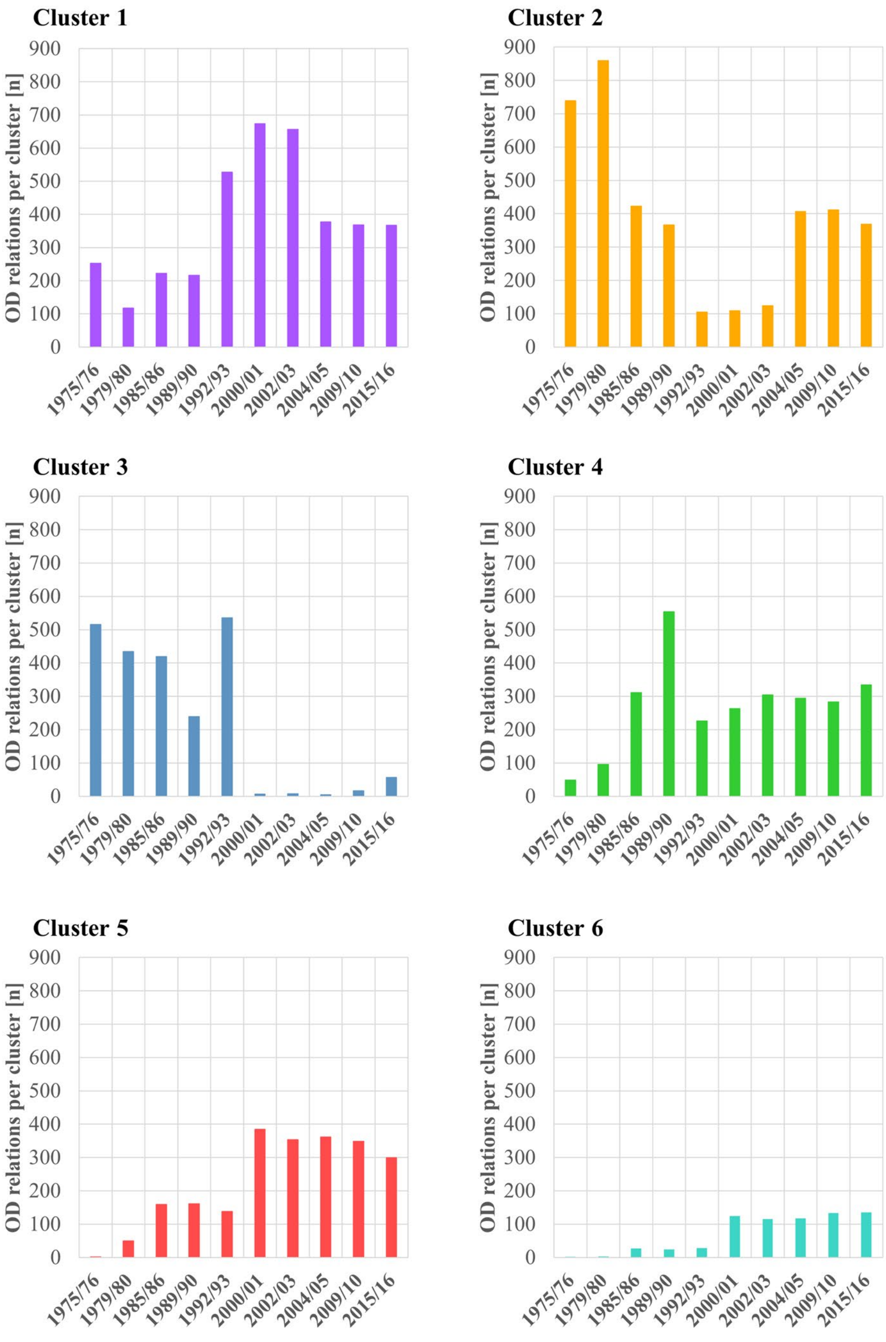


Fig. 5 Number of OD relations per cluster along the timetable years

From this general scrutiny of all three lines over the total period of inquiry we exemplify the detailed analysis by zooming in Slovenia's most important line.

3.2 The OD relation Ljubljana–Maribor

The rail line between Ljubljana and Maribor has a length of 155.6 km and connects the capital of Slovenia with its second-largest city. In the course of the time series, the three input parameters to the cluster analysis—n_C, n_{SI}, and ρ_{RT}—do not follow a constant tendency of development. In the direction of Maribor (see Fig. 6), the number of daily train connections increased from nine to twelve in the 1970s, while the number of trains with synchronized intervals remained nearly constant around four to five in the same period. In the 1980s and the beginning of the 1990s, in addition to a further expansion of daily train connections, the train schedule was also developed with the priority of ensuring synchronized intervals. Thus, in the timetable of 1992/1993, 14 out of 16 direct trains meet this criterion. However, until the turn of the millennium, the train supply was reduced to the level of the 1980s again. Except for a short-term increase in 2004/2005, the service level remained nearly unchanged at 13 daily connections—six of them with synchronized intervals—until the end of the time series.

The regularity of the travel time can be described as relatively low on this OD relation along the time series, which is a result of different train types with a different number of stops between the two cities. While the highest regularity was reached in 1989/1990 ($\rho_{RT}=0.947$) and results of travel times between 130 and 175 min, the lowest value of $\rho_{RT}=0.899$ in the timetable of 2002/2003 is a consequence of travel times between 105 and 165 min. Overall, the increasing level of supply during the first part of the time series was accompanied by an alignment of travel times and a corresponding increase of their regularity, while the reduction of train numbers from the middle of the time series reflects the increasing mixture of trains with a widening spread of travel speeds between the two cities. Although train numbers remained nearly unchanged between 2009/2010 and 2015/2016, the slight alignment of travel times (from 108 to 171 min in 2009/2010 to 110–159 min in 2015/2016) led to an increase of ρ_{RT} on this connection.

In the opposite direction of travel (see Fig. 7), a similar development can be observed. Beginning with five trains per day in 1975/1976, the supply was increased

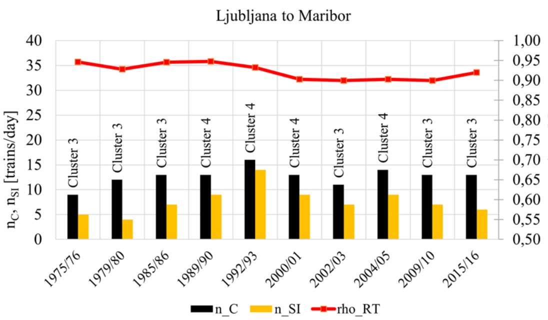


Fig. 6 Development of the cluster parameters on direct train connections from Ljubljana to Maribor

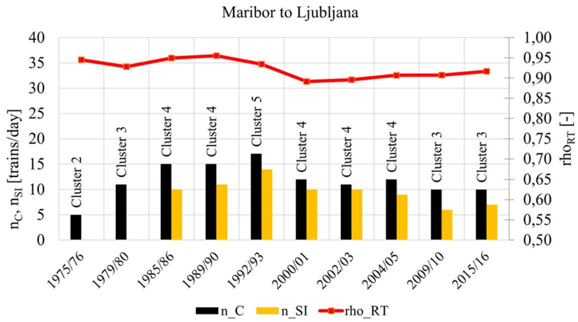


Fig. 7 Development of the cluster parameters on direct train connections from Maribor to Ljubljana

up to 17 daily direct connections until 1992/1993. In addition, the increasing emphasis on a train schedule with synchronized intervals can be identified in the 1980s and 1990s, before the reduction of supply becomes evident in the timetable of 2000/2001. In the same year, the lowest regularity of travel times is reached due to the increased spread of journey times between 105 and 173 min. At the end of the time series, a further reduction of train numbers to ten per day was accompanied by a decrease to six connections per day with synchronized intervals.

The initial increase in train numbers without the focus on synchronized intervals in the 1970s came along with an increase in the range of travel speeds (see Fig. 8). In contrast, the priority of synchronized timetables reduced the median of the travel speeds by 5 km/h in the 1980s. In the timetable of 1992/1993, the year with the maximum number of trains and the highest share of trains with synchronized intervals, the median travel speeds increased by 11–14 km/h to a total of 67 km/h and 64 km/h, respectively. In the further course of the time series, a progressive increase in travel speeds becomes apparent in both directions, reaching a median of 86 km/h in the timetable years of 2000/2001 and 2002/2003. While the slowest connection with 57 km/h remained on the speed level of the 1970s, half of the trips reached a range between 86 and 89 km/h.

With the subsequent reduction of direct train connections between Ljubljana and Maribor, the median of the travel speed was reduced by 10–15 km/h, while the

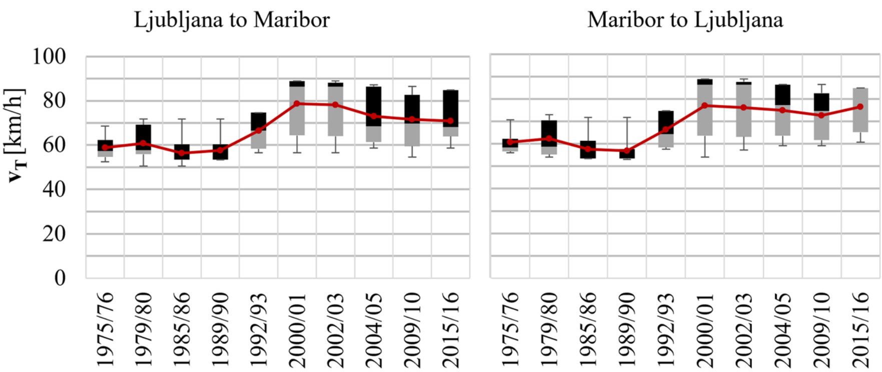


Fig. 8 Development of travel speed of direct train connections (v_T) between Ljubljana and Maribor

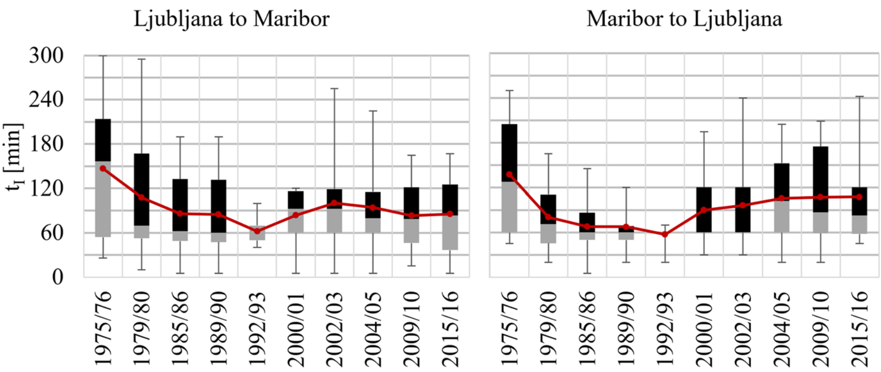


Fig. 9 Development of intervals of direct train connections (t_I) between Ljubljana and Maribor

maximum speeds remained almost constant. This indicates that especially trains with higher speeds and short travel times were affected by the reduction of the daily rail supply.

The development of the train intervals (see Fig. 9) of the direct connections between Ljubljana and Maribor reflects the general development of passenger services outlined above. The continuous increase in train numbers from 1975/1976 to 1992/1993 is inevitably accompanied by a reduction in train intervals. While a median of 70 min is already reached in the timetable of 1979/1980, which is further reduced to 60 min in the 1980s, the supply extension also leads to a reduced spread of the intervals. Accordingly, the maximum time between two trains—depending on the direction of travel—decreases from 300/250 min in 1975/1976 to 100/70 min in 1992/1993, respectively.

The subsequent reduction of the number of trains, becoming apparent in 2000/2001, had a different effect on the intervals depending on the direction of travel. While the median of the intervals to Maribor immediately increased to 90 min, this parameter could be held constant at 60 min in the direction of Ljubljana until the timetable of 2002/2003. This is a consequence of the higher number of trains with synchronized intervals (see Fig. 7). In the course of the further changes in supply during the following timetable years, the intervals in both directions increased to a median of 90 min, whereby less than two hours could be ensured between two connections in 75% of the cases in 2015/2016.

In addition to the previous findings, Fig. 10 shows the development of the service times of the train connections for both directions along the time series. Each bar represents a direct connection and its position and length on the horizontal axis indicates its planned departure and arrival time in the course of the day.

The diagrams point out that the service-level increase between the timetables of 1975/1976 and 1992/1993 goes in line with a linearization of the course of departure times. This is a result of an equalization of train intervals and an indicator for the introduction of an interval timetable with constant time frames between subsequent trains, as can be observed in the year 1992/1993 on both directions. At the same time, it becomes clear that although the departure times have an hourly schedule,

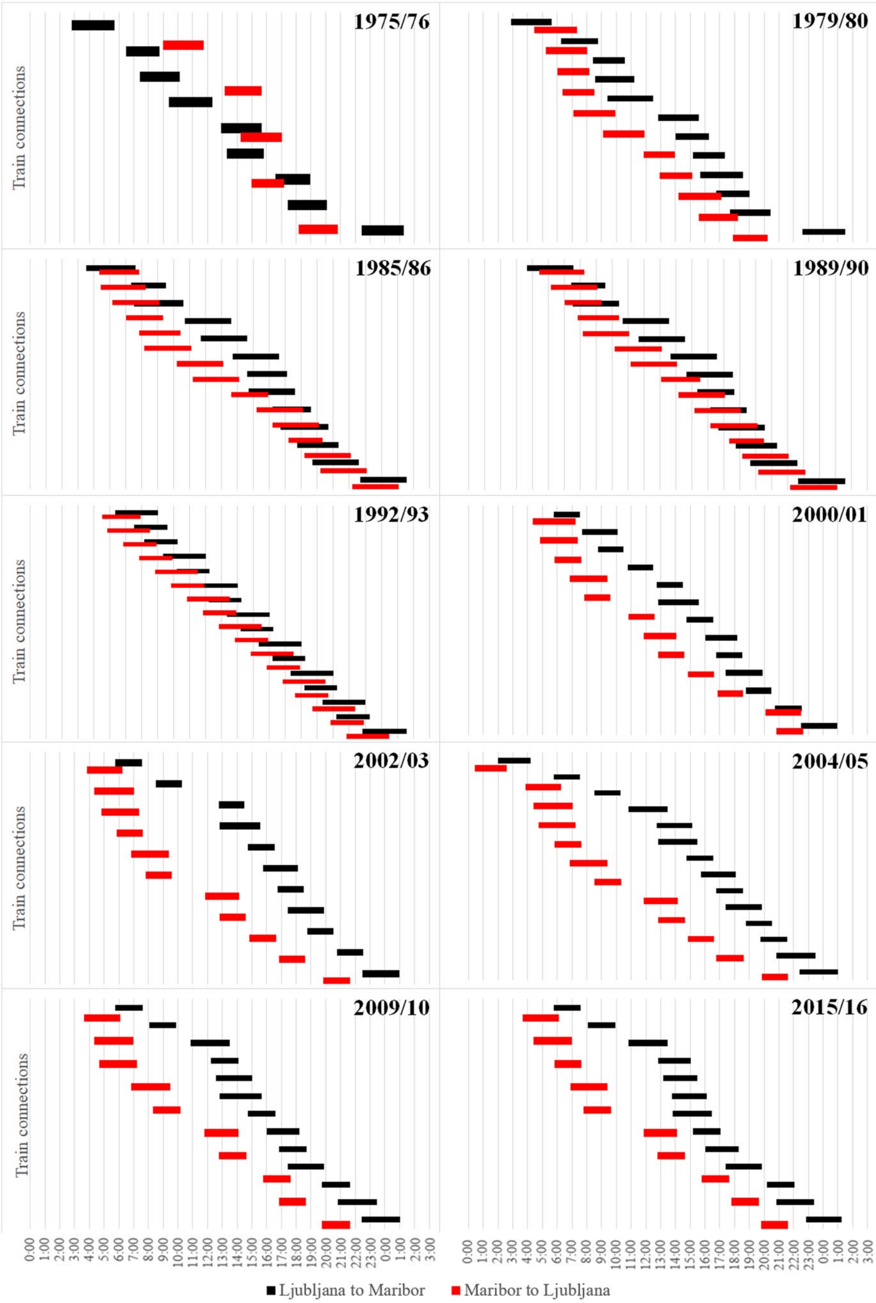


Fig. 10 Development of the service times of direct train connections between Ljubljana and Maribor

the journeys are of a different duration. Thus, an hourly interval timetable comes with hourly alternating travel times of 125 min and 160 min. Therefore, departure time intervals of 50/70 min to Ljubljana and 60 min to Maribor result in arrival time intervals of only 15–25 min, respectively. While on the one hand this schedule provides a very constant hourly train supply, on the other hand it also implies hourly alternating transport qualities, which are reflected in the relatively low level of travel time regularity already discussed above.

As a result of the subsequent reduction in train numbers from the timetable year 2000/2001 onwards, the timetable design turns away from the priority of an interval timetable in favor of a daytime-dependent increase in train densities. This is also reflected by the reduction of n_{SI} in Figs. 6 and 7. In the direction of Ljubljana, the highest supply densities are reached on departures before 8 am. These are followed by a service interruption until around noon, before the remaining five trains are allocated to the afternoon and evening of the day. In contrast, only one to two daily trains are scheduled before 8 am in the direction of Maribor. Starting at about midday, a service with regular intervals can be observed. However, towards the end of the time series, this shifts to a higher train density of departures in the early afternoon.

Overall, the findings of Fig. 10 confirm the results that have been already obtained. Between Ljubljana and Maribor, the first two decades of the time series were dedicated to an increase of train numbers with the planning priority of a supply-oriented interval timetable. With the year 2000/2001 at the latest, this focus shifted towards a schedule with higher dependency on the daytime as well as on the direction of travel: higher train frequencies to Ljubljana in the morning and to Maribor in the afternoon.

4 Discussion

The transformation of the late twentieth century brought yet another chapter to the many historic changes of the railway system of Slovenia (Černe 1993)—this time less within the geography of networks than within the geography of services and users' travel behavior. In general, an overall increase of the quality of the rail service supply is identifiable, with the largest improvements taking place in the decades from the 1970s to 1990s. During the time series, the inter-city connection between Ljubljana and Maribor was initially expanded to a regular and supply-oriented interval timetable (year 1992/1993 in Fig. 10). From the year 2000/2001 onwards a reduction in numbers of trains renewed a tendency towards a demand-oriented service. This trend is clearly visible along the timeline in Fig. 10, where from year 2000/2001 on clearly an asymmetric spreading of services is observable. Figures 6 and 7 also demarcate this change in terms of reduced numbers of trains as well as the share of synchronized interval connections from year 2000/2001 on, in comparison to year 1992/1993.

The cluster analysis reveals that the increase of services went hand in hand with a priority for close-to-interval timetable design and an increase in travel time reliability. Services thus went from being describable as "whole-day base offer" to "dense and close-to-interval with constant haulage quality" on the western and northern section and to "whole-day close-to-interval" style on the eastern section.

The year 2000/2001 is also remarkable from two additional perspectives. First, on a general budgetary level, for the year 2001 a limited peak of investments into the rail sector is documented by federal sources. These investments still amounted just to 11.4% of the national transport infrastructure budget, surpassed before that with 12.6% in 1994 and after that with 14.0% in 2008. Unfortunately, the projects that these funds were invested in, are not publicly available.

Second, it needs to be noted that the year 2000 also marks the introduction of Fiat tilting trains as Intercity Slovenia (ICS) product, running between Ljubljana and Maribor.

As no timetable data is available within the timespan 1992/1993 to 2000/2001, an informed interpretation on this break in trend is difficult to achieve. Slovenia still had to join the European Union in 2004 and their public service procurement regulations were enacted 2007 and later; we may speculate that this change in service supply characteristics did not emanate from long-term oriented service planning and procurement but that the societal changes also led to changes in transport policies and service provision, albeit with some years of time lag. With the disintegration of Yugoslavia and the reduction of travel needs over now new national borders followed the time-lagging abolition of international long-distance connections. This development was likely also driven by the transition from a socialist to a market economy-based transport policy and the accompanying massive investments into motorway construction.

The current Slovenian transport strategy (Vrcko et al. 2017, p.193) does include a list of railway-related objectives in terms of infrastructure, safety and efficient operations. The railway objectives do not—in contrast to the road objectives—provide any statements in terms of the provided levels of service and how to improve them. The experiences of other countries with highly developed passenger railway services, e.g. Switzerland (Durrer et al. 1986; Meiner 1991; Smoliner et al. 2018; Stohler et al. 2012; Weigand 2012), show the repeatedly identified needs of providing a service objective plan first to follow suit with appropriate infrastructure for further improvement of services.

From a methodological perspective, the cluster analysis based on three indicators has shown to be suitable to reduce the overall complexity in the data and to make it easier to distinguish between OD relations with different levels of supply and their development over time. Since the travel time reliability indicator is based on a fixed OD matrix, it can also be regarded as travel speed reliability. As this indicator is based on the Gini coefficient, it is able to compare relations with very different band widths of service frequencies. However, for a detailed picture regarding the development of the train supply on a specific OD relation, the analysis of absolute travel speeds, intervals as well as the service times has shown to add further insights to the cluster information.

We thus claim that the five aims set in the beginning, have been achieved. We developed a method for timetable analysis that shows to be flexible enough to cope with timetable changes over this 40-year time period. While not taking interchange into account, the characteristics of direct connections and their change over the course of the inquiry period have been pointed out. We applied these parameters to a selected line for the given time series. With the help of cluster analysis we could also characterize the timetable supply from a customer perspective, for example with timelines of interval distributions and service time diagrams.

5 Conclusion

During the time series, the inter-city connection between Ljubljana and Maribor was initially expanded to a regular and supply-oriented interval timetable, before a slight reduction in train numbers renewed a tendency towards a demand-oriented service from the year 2000/2001 onwards. Our analysis follows a passenger perspective and focuses on direct train connections along every origin–destination relation within the area of interest. The timetable offer is characterized by a multivariate analysis with two levels of detail. Our coefficient of travel time regularity and the criterion on connections within a synchronized interval have shown to be suitable to analyze and meaningfully depict the timetable data of four decades. Thus, in addition to traditional parameters such as supplied seat kilometers per trip kilometer or occupancy rate, the method at hand highlights its potential for use in (long-term) monitoring the service quality performance of passenger rail timetables.

As indicated previously, massive construction programs for motorways were conducted after the societal transition. Research questions of the future need to look into the appraisal of changes across modes, e.g. by integrating these massive investments into motorway construction and their detrimental impact on public transport's share among modes.

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Data availability The scanned timetable data that were used for analysis in this study are available from the corresponding author upon request.

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