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Classifying railway stations for strategic transport and land use planning: Context matters!

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ABSTRACT

The classification of railway stations is a potentially powerful tool for strategic transport and land use planning. Existing classifications rely strongly on the indicator "passenger frequency", which focuses on transport related issues, blending performance with preconditions at a given site. We argue that a classification system for strategic planning should focus on the demands and conditions of the site within which the railway station must function, i.e. system context. Here, we present such a classification system: a cluster analysis of the 1700 Swiss railway stations relying solely on context factors. The resulting classes vary primarily in density (of land use and transport services) and use (commuting, leisure time, tourism). Common geographic patterns and class-specific dynamics are discernable. These results indicate that classification based on the relevant demands and conditions given by context leads to clearly interpretable classes and supports multi-perspective strategic planning for railway stations. The systematic approach allows for a better understanding of the interrelations between railway stations and their context.

1. Introduction

Many efforts towards the sustainable development of transport and land use foster concentration strategies around nodes of public transport (cf. Haywood, 2005; Verhetsel and Vanelslander, 2010). Subsequently, public transport nodes – such as railway stations (hereafter, stations) – have become a key topic in urban planning (Calthorpe, 1993; Bruinsma et al., 2008; Peek and Louw, 2008). The operation and development of stations requires integration of multiple actors and interests (Bertolini and Spit, 1998; Wolff, 1999; Wucherpfennig, 2006). It is thus primarily the real estate or rail infrastructure companies (often a subdivision of regional or national rail transport companies) that are responsible for coordinating the development of these stations. Usually these companies operate a significant number of stations. Examples are: SBB Infrastructure in Switzerland operating over 700 stations (nearly half of all stations in Switzerland), DB Station&Service in Germany operating over 5400 stations, SNCF Gares & Connexions in France operating over 3000 stations, China Railway Network operating over 3900 stations. The characteristics and functioning of the stations within such a portfolio vary strongly (cf. Li and Cai, 2007; Reusser et al., 2008). An important question for the infrastructure companies – but also for all other effected and interested actors – is therefore: *What is the optimal station at a given site*? (cf. Ross, 2000; Connolly and Payne, 2004). In order to support a well-founded answer to this question, many rail infrastructure companies classify their stations.

Classifications of stations can contribute to strategic planning, the guidance of investments and ultimately the quality of stations in three ways: First and most important, classifications identify *comparable* stations with respect to certain questions. For the infrastructure companies this reduces management complexity by enabling the application of standards in operations and development, securing consistency of actions across large portfolios and geographic regions. Similarly, for the other actors, such as local spatial planning bodies, it enables the identification of sites and actors with comparable challenges or experiences. Second, classifications enable comparisons and performance assessments within the station classes, identifying successful benchmarks or highlighting needs for action. Third, classifications support the identification of general development potentials and necessary future adaptations of whole classes and within classes. These contributions of classifications require and support the definition of normative goals, and are thus highly interdependent (cf. Bosshard, 1997), i.e. the identification of development potentials relies on performance assessments, which, in turn, rely on the identification of comparable stations and the definition of the questions at hand.

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It is common practice for the station classifications of the rail infrastructure companies to primarily rely on the indicator "passenger frequency". SBB Infrastructure for instance classifies solely according to passenger frequencies (De Tommasi et al., 2004). DB Station&Service of Germany and Network Rail of the UK also apply systems substantially relying on passenger frequencies (DB Station and Service AG, 2009a,b; Green and Hall, 2009). This practice is understandable as passenger frequencies are generally easily accessible, straightforward in their meaning, and – if costs per passenger must be optimised – ultimately define the financial resources invested in a station.

In literature several other classification approaches are mentioned (cf. Bertolini and Spit, 1998; Ross, 2000; De Tommasi et al., 2004; Reusser et al., 2008). Although based upon broader indicators than just "passenger frequencies", these classifications are – to our best knowledge – not applied in practice. Two notable exceptions are described by Peek et al. (2006). Based upon the node-place model of Bertolini (1996, 1999), typologies describing the relationship of transport (network connectivity) and land use (intensity and diversity of uses in the catchment area) at stations have successfully been applied in The Netherlands: The Dutch administrations once used such a classification to coordinate national transport and spatial planning strategies in a reciprocal consistent manner, and the Dutch railways once used such a classification to coordinate the strategies within their business-units (passengers, station services, and real estate). Given the usefulness of such more comprehensive classification approaches, it is striking that there do not seem to be any station classifications originating from, e.g., governmental offices dealing with spatial development, although classification is a common tool in spatial development and also used to discuss interactions between spatial development and transport (cf. Verhetsel and Vanelslander, 2010).

1.1. Identifying comparable railway stations

If a classification is to support strategic transport and land use planning, we claim that the indicator "passenger frequency" reflects an insufficient theoretical basis and thus has practical shortcomings. Specifically, passenger frequencies insufficiently describe which stations are comparable with respect to their functioning. We assume that certain stations are not at all comparable, despite having similar passenger frequencies.

From our perspective a systemic view is necessary when the comparability of stations is discussed (cf. Wulfhorst, 2003). In analysing the functioning of stations, a distinction is necessary between comparable sites and comparable stations, i.e. one must distinguish between context and structures of a system. Theory defines *context* as encompassing all environmental constraints that are permanently relevant system or impact factors, while system *structures* refer to the system elements (material and organisational), their spatial and temporal relationships and partitioning (cf. Scholz and Tietje, 2002). *Functions* describe the intended processes of a system which serve specific outcomes (Checkland, 2001), i.e. what a system should do. Subsequently context refers to the demands and conditions under which a station functions (density of population in the catchment area, frequency of public transport services, etc.), while system structures refer to the design and operation of the stations (number or length of platforms, opening hours of ticket booths, etc.) and their interrelations with the context. As specified in Fig. 1, context influences system structures via two paths: First, context defines which functions are demanded or required at the stations (1a) and subsequently which structures are necessary to fulfil these functions (1b). Second, context defines the conditions for functioning (2), i.e. the situational opportunities and limitations to which the structures must be adapted.

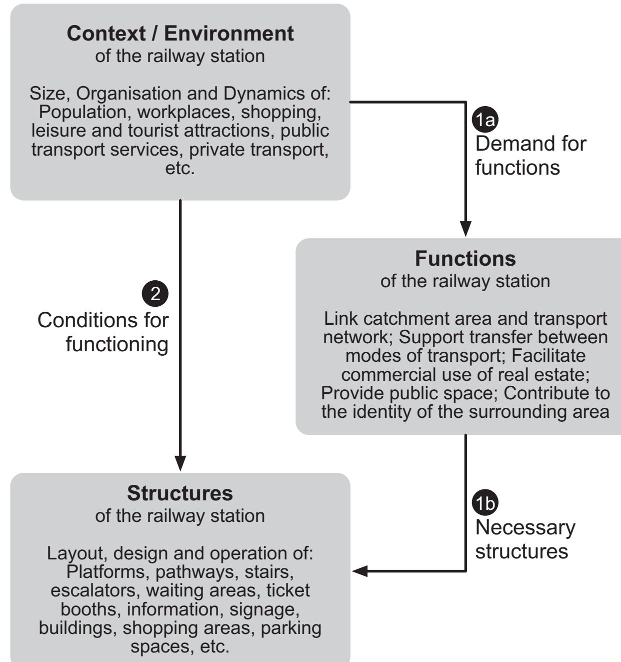

Fig. 1. Influence of system context on system structures.

Given the above, if a classification is to contribute to the development of an *optimal station at a given site*, it must enable comparisons of stations with comparable sites. Classifications should thus distinguish the relevant contextual circumstances, i.e. describe the demands and conditions given by the specific context within which a station is operated. The indicator "passenger frequency" sufficiently describes neither context nor system structures, but is more a result of diverse contextual factors and their interplay with the station quality itself. Additionally, as a second criticism, the indicator "passenger frequency" sets a focus on the transport functions of a station. But stations can fulfil multiple functions. Zemp et al. (in press) describe five functions stations may fulfil: F_1: link catchment area and transport network; F_2: support transfer between modes of transport; F_3: facilitate commercial use of real estate; F_4: provide public space; F_5: contribute to the identity of the surrounding area. At the very least, F_3–F_5 seem to be largely neglected by the indicator "passenger frequency". With integrated transport and land use planning becoming ever more important (cf. Curtis, 2008; Hickman and Hall, 2008) this omission is highly problematic. A classification based on passenger frequencies can therefore not be expected to represent the multiple actors and interests present at stations.

1.2. Exploring a classification based on contextual demands and conditions

In this paper we aim to contribute to the development of station classifications, especially the consideration of the multiple functions, actors and interests involved in station operation and development. We propose a systemic approach to the classification of stations that focuses on the comparability of the specific sites – i.e. the demands and the conditions within which the stations are operated, rather than the comparability of the stations themselves. Further, we explore the feasibility and usefulness of such a classification. To guide our analysis, we pose two research questions:

(i) Which contextual factors influence the functioning of railway stations?

(ii) Is a relevant classification of railway stations for strategic transport and land use planning based on contextual factors possible (and how do the resulting classes relate to a classification solely by passenger frequencies)?

We start with the 1700 passenger stations of Switzerland by way of example, thus omitting freight transport but still incorporating the multiple functions passenger stations can fulfil.

2. Methods and procedure

Multiple steps were followed to classify the Swiss stations according to contextual factors and interpret the results. First, relevant contextual factors were identified by means of expert interviews. The context factors were then translated into quantitative indicators and a cluster analysis was performed to achieve a minimal but coherent set of station classes. The classes resulting from the cluster analysis are described and interpreted by using the clustering indicators applied as well as by consulting additional data.

2.1. Identification of context factors

Context factors were identified by means of 28 face-to-face interviews with experts including operators of transport services, operators of rail infrastructures, real estate managers, business and retail, federal, cantonal and municipal administration, associations, consultants and academia. The interviews had a mean duration of 90 min, were conducted by a single interviewer and structured by means of a guide. The experts were asked to describe one function of stations close to their area of expertise along the following six systemic criteria: performance and efficiency, well-structuredness, interdependencies with other systems, buffer capacity and resilience, ability to accommodate, inter- and intra-generative equity (cf. Lang et al., 2007). These systemic criteria were developed to describe functionality potentials of systems and several of them refer to the interaction of system structure and context: The descriptions of "well-structuredness" revealed user-demands imposed upon stations. Descriptions of "interdependencies" indirectly revealed crucial resource flows and competition with other systems. Descriptions of "buffer capacity" revealed short-term, possibly recurring contextual stress factors for stations. Descriptions of "ability to accommodate" revealed long-term changes in context factors. Finally, descriptions of "inter- and intra-generative equity" revealed contextual equity demands made upon stations. As the interviews were also used to identify functions of stations they are described in further detail in Zemp et al. (in press). The interviews led to the identification of five functions of railway stations, each influenced by multiple context factors.

2.2. Cluster analysis

Where data were available, those context factors influencing at least three functions were quantified by means of indicators (Table 2). Data were obtained from the Swiss Federal Bureau of Statistics, the Swiss Federal Railways (SBB) or retrieved from an earlier study by Reusser et al. (2008), i.e. computed from the timetable of Swiss public transport. For some of the applied clustering algorithms missing data had to be imputed. This was partially achieved using multiple linear regressions and deleting resulting negative values, reducing the number of stations omitted by the clustering algorithms. Missing data were prevalent for smaller stations with insufficient data on passenger frequencies (I_5 only available for 60% of stations) or number of tourist visits for small municipalities (I_6 only available for 65% of stations). Otherwise, original data were available for over 92% of all stations for all other indicators. Data were log transformed (except for I_3, I_4 *and* I_5), and Z-scores computed to secure even weighting of the indicators. The sole ordinal indicator, I_4, was coded as 0 or 1. No consistent outliers could be identified (although the very large Zürich Main Station as well as the very small station of Wiesen were marginal).

Cluster analysis was applied to obtain classes of stations with minimal variance within classes and maximal variance between classes. Multiple cluster algorithms were applied in an exploratory phase of the data analysis, as advised e.g. by Webb (2005) and Everitt et al. (2001). Although similar patterns resulted, no stable solution could be identified. Often a high number of very small classes and few (2–6) large classes resulted, indicating strong variance between the stations. Since a result with multiple large and few small classes is assumed beneficial for strategic transport and land use planning, a clustering solution resulting from the Ward algorithm (Ward, 1963) (with Squared Euclidean distance measure) was chosen. The Ward algorithm is known to produce classes of similar size (Webb, 2005). A solution of seven classes was chosen, as further divisions of the classes did not improve their distinction.

2.3. Description and comparison of classes

The first two principal components of the quantitative indicators applied in the clustering algorithm were interpreted, and appropriate proxies computed and used for a scatter plot of all stations and classes. The first principal component was found to be further divisible into two components frequently used to describe stations: node and place introduced by Bertolini as the node-place model (1996, 1999) and applied to Swiss stations by Reusser et al. (2008). Subsequently node and place proxies were also computed and a node-place model presented. Correlations of the applied metrics are provided (principal components, proxies and indicators).

The classes were further interpreted by comparison of passenger frequency distributions and geographic distributions. These two components were not directly included or represented by the quantitative indicators used for clustering, but used for comparisons with other classification approaches and to further understand similarities within classes. Finally, as the applied indicators only represent static components, indications for comparable development dynamics within classes were sought. Although passenger frequencies (as currently used for classifications) cannot represent any dynamics, this is an overly important issue in strategic planning (Peek et al., 2006). Subsequently, post hoc analysis of variance population and job dynamics within the catchment area were analysed (data for the other indicators was not available).

3. Results

3.1. Context factors of railway stations

Table 1 describes the context factors relevant for the functioning of stations as identified during the interviews. Included are factors describing location of transportation infrastructures, factors describing properties of the catchment area, and factors describing properties of the public transport services at the station.

Of the 14 context factors described in Table 1, seven (CF_2, CF_3, CF_6, CF_7, CF_{10}, CF_{11} and CF_{12}) could be quantified by means of indicators (Table 2). CF_1, CF_4, CF_5, CF_8, CF_9, CF_{13} and CF_{14} could not be quantified, although CF_1 and CF_4 are partly reflected by I_3, and CF_5 may be partly reflected by I_1 and I_2.

3.2. Description of classification results

Seven classes of stations were identified. Summary statistics for the indicators used and short descriptions of the classes are given

Table 1
Context factors for railway station functions. F1: link catchment area and transport network; F2: support transfer between modes of transport; F3: facilitate commercial use of real estate; F4: provide public space; F5: contribute to the identity of the surrounding area.

Context factor	Exemplary influences on functioning of railway station	Relevant for functions				
		F_1	F_2	F_3	F_4	F_5
Factors describing transportation infrastructure location						
CF_1 location of railway tracks	Location options for railway station	X				X
CF_2 centrality of railway station	Average distance to/from the railway station; egress mode distribution; barrier impacts to the urban area; security provision and perception at off-peak hours; attractiveness of railway station areas for commercial use; Public uses of station areas		X	X	X	X
Factors describing properties of the catchment area						
CF_3 size[a]	Passenger frequencies; demand for commercial uses of facility area	X	X	X	X	X
CF_4 concentration	Concentration favours short access distances and walkability; concentration favours provision of feeder services	X		X	X	X
CF_5 topography	Access to railway station; circumference of catchment area	X		X	X	X
CF_6 composition of goals/sources	Customer types distribution at the railway station; daily, weekly or seasonal passenger frequency distributions		X	X	X	X
CF_7 proximate urban density	Options for railway station design, layout and developments		X	X		X
CF_8 reputation of vicinity	Security provision and perception		X	X	X	
CF_9 cultural heritage and historical reference management	Local contributions to building maintenance costs; development options of railway station buildings		X	X		X
Factors describing properties of the public transportation services						
CF_{10} connection frequencies	Passenger frequencies; attractiveness of commercial areas; necessary infrastructure sizes	X	X	X	X	X
CF_{11} network density	Reachable goals/sources	X	X	X	X	
CF_{12} interconnection quality	Waiting time at the railway station; number of passengers changing vehicles/modes	X	X	X	X	X
CF_{13} reputation of public transport	Customer types distribution at railway station			X	X	X
CF_{14} relative attractiveness of private transport[b]	Passenger frequencies; customer types distribution at railway station	X	X	X	X	X

[a] Size of catchment area may be described by e.g. number of residents and workplaces, size of schools, size or attractiveness of shopping, leisure and tourist attractions, or relative regional importance.
[b] Relative attractiveness of private transport may be described by comparing e.g. travel duration, travel time variability and uncertainty (congestions), costs.

Table 2
Indicators for quantification of context factors.

Indicator name	Description	Related context factors[a]
I_1: jobs	Number of jobs within a 700 m radius	CF_3, CF_6, CF_7 (CF_5)
I_2: population	Number of residents within a 700 m radius	CF_3, CF_6, CF_7 (CF_5)
I_3: centrality	Average distance to jobs and residents within a 700 m radius	CF_2 (CF_1, CF_4)
I_4: regional centre	Main station of a regional centre	CF_3, CF_6, CF_{12}
I_5: frequency distribution	Passenger frequencies at weekends compared to weekdays	CF_6
I_6: tourism	Arriving tourists per 1000 residents of the municipality	CF_6
I_7: reachability	Number of reachable railway stations in 20 min	CF_{11}, CF_{12}
I_8: intercity trains	Number of departing intercity trains	CF_{10}
I_9: regional trains	Number of departing regional trains	CF_{10}
I_{10}: buses	Number of departing buses	CF_{10}

[a] For description of context factors see Table 1. Factors in brackets are only indirectly represented.

in Table 3, together with working names to simplify interpretation. The classes are further described using principal component analysis, and in addition passenger frequencies, geographic distribution and context dynamics.

3.2.1. Description of classes using principal components and node-place model

Principal component analysis was used to help describe and interpret the results. The Kaiser Criterion revealed three components with an eigenvalue over 1, while the Scree Plot suggested two components. The first two components could be clearly interpreted (cf. Table 4). The first component was interpreted as describing the "density" of transport and land use in the vicinity of the station. The second component was interpreted as describing the "use" of the station. Proxies were compiled for these first two components in order to simplify interpretation: *density* (Z-score of $I_1 + I_2 + I_7 + I_8 + I_9 + I_{10}$) for the first component and *use* (Z-score of $I_5 + I_6$) for the second component. Both proxies correlate well with the original components (cf. Table 5). The classes are presented in a scatter plot of these two proxies, called the density-use model (Fig. 2).

The proxy computed to represent the first principal component, "density", entails factors similar to those used for node-place models (cf. Bertolini, 1996, 1999; Reusser et al., 2008). *Node* thus describes the accessibility of an area, i.e. the potential for physical human interaction, while *place* describes the diversity of activities in an area, i.e. the degree of actual realisation of the potential for physical human interaction. Subsequently, the density proxy was also divided into node and place components: For the node factor – commonly quantified by describing the transport connections at a station – the indicators $I_7 \ldots I_{10}$ were totalled and Z-scores computed. For the place factor – commonly quantified by describing the spatial development at a station – the indicators I_1 and I_2 were totalled and Z-scores computed (Fig. 3).

Both the density-use and the node-place models indicate that the classes may be differentiated primarily according to their density of context: number of jobs and residents in the catchment area, as well as number of transport connections. The first class includes those stations with the densest contexts, the last class those with the least dense context. This corresponds to a common pattern, usually referred to as "large" vs. "small" stations, and shows important influences on infrastructure sizes (e.g. number, length and width of platforms or number and width of underpasses).

The density-use model in Fig. 2 additionally shows differences in the use of the stations: use can vary from commuting-orientated (left side of Fig. 2) to tourism- or leisure-orientated (right side of Fig. 2). The stations in class 4 are thus frequented mainly on work-

Table 3
Summary statistics and class descriptions: *M* (SD) on clustering indicators[a].

Class	Indicator[b]									
	I_1	I_2	I_3	I_4[c]	I_5	I_6	I_7	I_8	I_9	I_{10}
C1 (*N* = 70)	1.71	1.29	−0.94	0.44	−0.44	0.36	1.97	1.72	1.64	0.45
	(0.47)	(0.28)	(0.44)		(0.62)	(0.22)	(0.72)	(1.50)	(0.79)	(1.36)
C2 (*N* = 151)	0.63	0.50	0.00	0.23	−0.10	0.25	0.26	1.77	0.12	1.05
	(0.61)	(0.68)	(0.85)		(0.63)	(0.72)	(0.76)	(0.67)	(0.91)	(0.65)
C3 (*N* = 448)	0.48	0.52	−0.36	0.05	−0.26	0.35	0.20	−0.44	0.29	0.31
	(0.57)	(0.51)	(0.66)		(0.68)	(0.42)	(0.74)	(0.31)	(0.74)	(0.96)
C4 (*N* = 274)	−0.30	−0.16	0.18	0.00	−0.24	−1.84	−0.04	−0.47	0.05	−0.37
	(0.72)	(0.71)	(0.92)		(0.70)	(0.00)	(0.65)	(0.28)	(0.61)	(0.78)
C5 (*N* = 310)	−0.88	−0.79	0.40	0.00	0.26	0.54	−0.25	−0.41	−0.35	−0.76
	(0.85)	(0.82)	(1.03)		(0.88)	(0.36)	(0.61)	(0.41)	(0.60)	(0.48)
C6 (*N* = 142)	−0.53	−0.77	0.08	0.02	1.43	0.69	−1.47	0.56	−1.29	−0.03
	(0.96)	(1.28)	(0.89)		(1.56)	(0.55)	(1.30)	(1.11)	(1.40)	(0.93)
C7 (*N* = 11)	−3.20	−4.07	5.46	0.00	1.91	0.60	−1.06	−0.20	−0.75	−0.81
	(0.00)	(0.00)	(0.00)		(1.59)	(0.89)	(0.93)	(0.56)	(0.98)	(0.66)
Total (*N* = 1406)[d]	−0.03	−0.03	0.01	0.07	0.05	−0.01	−0.03	0.01	−0.02	−0.01
	(1.03)	(1.03)	(1.03)		(1.01)	(1.00)	(1.03)	(1.01)	(1.01)	(1.00)

Class descriptions (working names of classes in quotes)

C1 "Largest and most central stations"
Railway stations with the densest contexts: highest number of jobs and residents in the catchment area and highest amount of transport services provided (especially highest reachability and number of regional train connections). Often regional centres and mostly centrally located stations. Some tourists but not many compared to commuters. Class centroids: Konolfingen, Neuchâtel, Weinfelden, La Chaux-de-Fonds

C2 "Large connectors"
Railway stations with above-average context density considering number of jobs and residents in the catchment area. Highest number of intercity train and bus connections, but only above average reachability and regional train connections. About a fifth of the cases are regional centres. Frequented by both residents and tourists. Class centroids: Degersheim, Maienfeld, Steckborn, Wittenbach.

C3 "Medium commuter feeders"
Railway stations with slightly above-average overall context density: similar amount of residents in the catchment area as C2, but with fewer jobs and practically without any intercity train connections. Above average reachability, number of regional train and bus connections. Very seldom regional centres, but often centrally located. Some tourists but not many compared to commuters. Class centroids: Dagmersellen, Les Plantaz, Nebikon, Courgenay

C4 "Small commuter feeders" railway stations with slightly below-average overall context density (concerning jobs and residents). Average reachability and number of regional train connections, but no intercity trains and only very few bus connections. Somewhat peripheral railway stations, which are never located at regional centres. Primarily frequented throughout the week (i.e. by commuters) and without any tourism in the municipality. Class centroids: Hettlingen, Villette VD, Birrwil, Brüttelen

C5 "Tiny touristy stations"
Railway stations with low overall context density. Only very few residents and even fewer jobs within the catchment area. Some regional trains but practically no intercity trains or buses. Rather peripheral stations, which are never located at regional centres. Frequented at weekends and above average tourism in the municipality. Class centroids: Enge im Simmental, Fontannaz-Seulaz, Weissenbach, Gluringen

C6 "Isolated tourism nodes"
A class with generally high standard deviations. Railway stations with generally low overall context density. Only very few residents and jobs. A unique combination of lowest reachability and number of regional trains, but with above average number of intercity train connections and average number of bus connections. May very seldom be regional centres and are partly peripherally located. Stations are used heavily at weekends with highest number of tourists visiting the municipality. Class centroids: Brusio, Campocologno, Herbriggen, Davos Wolfgang

C7 "Remote destinations"
A very small group of 11 railway stations. Distinguishing feature is extreme remoteness, i.e. no residents or jobs in the catchment area. Low reachability, number of regional trains and practically no intercity train connections. Only seldom with bus connections. They are also never regional centres. These stations have the highest weekend frequencies and are located in municipalities with high amounts of tourism. Class centroids: La Perche, Jor, Jaman, Alp Grüm

[a] Light grey cells indicate that class average is more than one SD below overall average (or, in the case of ordinal indicators, lower than the expected value), dark grey cells indicate that class average is more than one SD above overall average (or, in the case of ordinal indicators, higher than the expected value).
[b] For explanations of indicators see Table 2.
[c] Ordinal indicator.
[d] Mean ≠ 0 and/or standard deviation ≠ 1 because 301 cases with missing data were excluded from cluster analysis.

Table 4
Principal component loadings.

Indicator	Components		
	1, "Density"	2, "Use"	3
I_1: jobs	.845	.110	.209
I_2: population	.764	−.114	.008
I_3: centrality	−.381	.247	.220
I_4: regional centre	.512	.365	−.520
I_5: frequency distribution	−.220	.676	.313
I_6: tourism	−.266	.722	.247
I_7: reachability	.796	−.164	.372
I_8: intercity trains	.718	.381	−.073
I_9: regional trains	.767	−.065	.435
I_{10}: buses	.508	.294	−.544
Total variance explained	.382	.146	.115

days and lie in municipalities with little tourism. These are typical smaller commuter or transit stations. The stations of class 6 (and similarly in class 7) have above-average passenger frequencies on weekends and are situated in municipalities with considerable tourism. Diversity in use is more pronounced for smaller stations (low density stations). Small stations vary from heavily commuter-orientated to heavily tourism- or leisure-orientated, while the use of larger stations is generally more uniform.

The general differences in context densities visible in the density-use model are specified by the node and place components in the node-place model (Fig. 3). For example, the average context density reduction from classes 2–3 is mainly due to a reduction of the node component (i.e. fewer transport connections), while the average context density reduction from classes 3–4 is mainly due

Table 5
Correlations of principal components, proxies, passenger frequency and ward clustering solution.

	Principal components[a]		Proxies				Passenger frequency	Clustering solution
	1, "Density"	2, "Use"	Density	Use	Node	Place		
1, "Density"	1.000	.014	.818**	−.152**	.800**	.653**	.715**	−.642**
2, "Use"		1.000	−.089**	.725**	.033	−.232**	.143**	.228**
Density			1.000	−.190**	.925**	.861**	.821**	−.773**
Use				1.000	−.114**	−.251**	−.079*	.290**
Node					1.000	.604**	.768**	−.715**
Place						1.000	.690**	−.671**
Passenger frequency							1.000	−.598**
Clustering solution								1.000

[a] For explanations of principal components see Table 4.
[*] Pearson correlation is significant at the 0.05 level (2-tailed).
[**] Pearson correlation is significant at the 0.01 level (2-tailed).

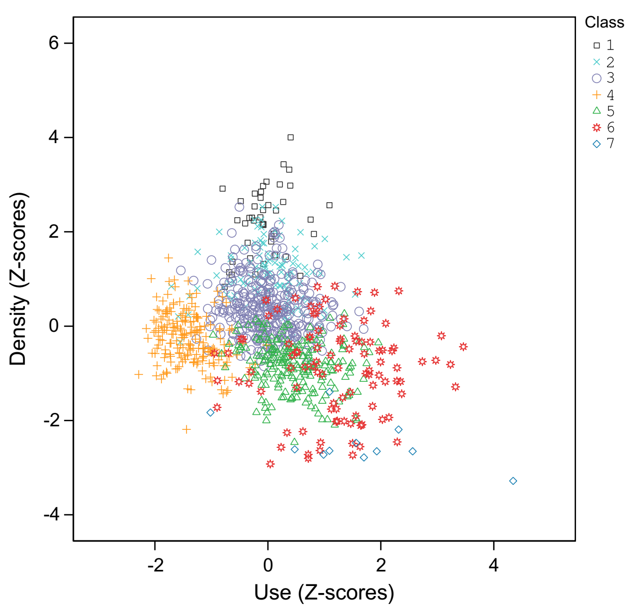

Fig. 2. Density-use model of Swiss railway stations ($N = 1000$; random selection).

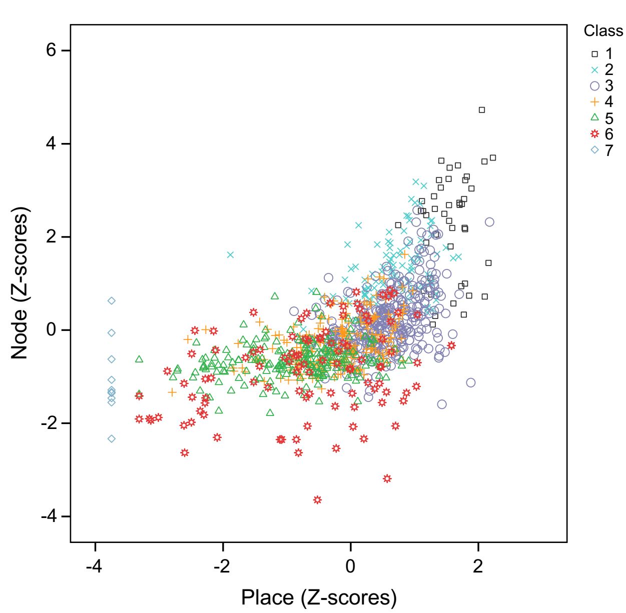

Fig. 3. Node-place model of Swiss railway stations ($N = 1000$; random selection).

to a reduction of the place component (i.e. fewer jobs and residents in the catchment area).

3.2.2. Similarities in passenger frequencies, geographic distributions and context dynamics

Indicators for passenger frequencies, geographic location or dynamics of context were not included in the cluster analysis. These factors were analysed for further understanding of the classes. The indicator "passenger frequencies" does correlate with the classification developed (Table 5), but passenger frequencies of the single classes overlap significantly (Fig. 4). The classes show geographic distribution patterns (map available as Supplementary material from the journal homepage): The stations of class 1 are the main stations of the largest cities and their directly neighbouring urban stations, as well as some larger regional centres. These stations are located in the lowland areas of Switzerland (Swiss Plateau). The stations of class 2 are often regional centres, partly located in alpine regions, as well as directly neighbouring stations of larger cities. The stations of classes 3 and 4 are located almost exclusively in the lowland areas of Switzerland, with the stations of class 3 situated more in the inner agglomeration areas, and the stations of class 4 situated more in the outer agglomeration areas. The stations of class 5 are more widely distributed, but often

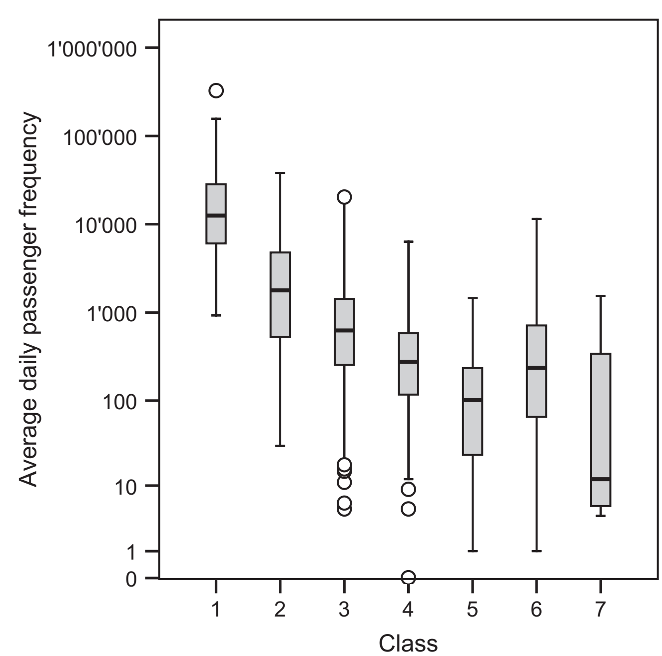

Fig. 4. Box plots of passenger frequencies. C1: $n = 55$; C2: $n = 125$; C3: $n = 305$; C4: $n = 200$; C5: $n = 159$; C6: $n = 92$; C7: $n = 7$.

Table 6
Resident and job dynamics in the catchment area per class.

Class[a]	Resident dynamics[b] (% change from 1990 to 2000)			Job dynamics[b] (% change from 1995 to 2005)		
	n	Mean	SD	n	Mean	SD
1	100%	−3.828	7.277	100%	−0.849	12.392
2	99.3%	4.666	18.013	99.3%	1.578	47.806
3	100%	4.278	13.487	100%	0.845	24.019
4	98.5%	8.377	19.756	94.2%	−2.207	36.021
5	93.5	7.294	30.771	76.5	−8.420	30.997
6	81.8	1.030	14.762	82.5	−13.982	25.128

[a] Data for class 7 not given as $n = 0$ for residents and jobs in the catchment area.
[b] Cases with $n < 20$ excluded.

Table 7
Difference in mean dynamics[a] of residents and jobs between classes.

		Class					
		1	2	3	4	5	6
Class	1		2.43	1.69	1.36	7.57	13.13
	2	8.49		0.73	3.78	10.00*	15.56**
	3	8.11*	0.39		3.05	9.27**	14.83**
	4	12.21**	3.71	4.10		6.21	11.78*
	5	11.12**	2.63	3.02	1.08		5.56
	6	4.86	3.64	3.25	7.35*	6.26	

[a] Grey cells represent differences in dynamics of residents, white cells represent differences in dynamics of jobs. Computed according to Table 6.
* Pearson correlation significant at the 0.05 level (2-tailed).
** Pearson correlation significant at the 0.01 level (2-tailed).

located in rural areas of alpine regions and the Jura Mountains. The stations of class 6 are located practically exclusively in the alpine regions of Switzerland. The eleven stations of class 7 are all very remotely located, but show no regular geographic pattern.

Some class-specific dynamics of residents and jobs in the catchment area can be identified in the post hoc analysis of variance, although variance within classes is generally high and overall effects are small (classification effect for resident dynamics $r = 0.16$, and for job dynamics $r = 0.15$), explaining slightly more than 2% of overall variance (Table 6). Resident dynamics within the 700 m perimeters of the stations for 1990–2000 reveal a mean decrease for class 1 and increases for the other classes. The decrease of residents in class 1 is significant compared to classes 3–5, whereby the increase in class 4 is again significantly larger compared to class 6 (Table 7). Job dynamics within the 700 m perimeters of the stations for 1995–2005 reveal only small increases in classes 2 and 3, and to some extent large decreases for all other classes. The large average decreases observed in classes 5 and 6 are significant compared to increases in classes 2 and 3. The decrease in class 6 is even significantly larger than the decrease in class 4.

4. Discussion

In a preliminary survey of the results we conclude, first, that there are many context factors that influence the functioning of stations (Table 1), and, second, that the classes resulting from the quantification and clustering of these factors are well interpretable (Table 3). In contrast to existing classifications, we find stations that perform equally with respect to passenger frequency but are located in a different context and thus experience different demands and conditions for functioning (Fig. 4).

In the following, we discuss the significance of the results in three subsections. Following our research questions we first discuss our systemic approach to identifying comparable stations, before a second subsection substantiates potential contributions to strategic planning using the newly defined classes. A last subsection addresses methodological improvements.

4.1. Identifying comparable railway stations based on contextual requirements

A variety of context factors were identified, representing both transport and land use related issues (Table 1). The context factors vary depending on the function investigated. As some functions have a micro- and others a macro-perspective, the delineation between system context and system structures depends on the function assessed. The location/centrality of, as well as the access to, a station are, for example, system structures from the perspective of F_1, but context factors from the perspectives of F_2, F_3 and F_4. Our approach allows the context factors, which are generally comparable to those applied by Bertolini (1996, 1999) and Reusser et al. (2008), to be related to specific functions of stations. Newly identified context factors, such as security of station vicinity or reputation of transport services, seem to be especially important for the secondary or "latent" (Merton, 1967) functions of stations: commercial and public uses of the station premises (F_3, F_4). Although not all context factors could be quantified by means of indicators, a fair representation of all station functions was possible.

The resulting classes are well interpretable and indicate that some common patterns exist with regard to the relevant context of Swiss stations. The principal component analysis newly highlighted the *use* of stations as an important factor in addition to the already well-known factor *density* (i.e. node and place). The classes with smaller stations (C4, C5, C6), for example, overlap and are not well differentiated within the node-place model (cf. Fig. 3), but are considerably differentiated in the density-use model due to different use characteristics (cf. Fig. 2). Such differences in use will partly reflect differences in the actors and interests involved in the development of the station. As node and place are interlinked by the land-use transport feedback cycle (Wegener and Fürst, 1999), balancing tendencies are assumed (Bertolini, 1999). Similarly, an averaging force can be assumed for density and use: the larger the station, the more averaged its use – hence extreme positions can be assumed to be stable for small stations in the density-use model. A concordant distribution is visible in Fig. 2. The third principal component (cf. Table 4) could not be satisfactorily interpreted and relies on indicators, which are either ordinal (I_4 "Regional centre") or rely on sketchy data (the indicator I_{10} "Buses" lacks tram connections which are important in some large Swiss cities). This component may indicate the "regional importance" of a site. Surprisingly, the indicator I_3 "Centrality" – often described by the experts as heavily influencing the functioning of stations – is not reflected in the principal components.

Being able to differentiate both *density* (i.e. node and place) and *use* in a classification must be considered an improvement compared to classifications relying on passenger frequencies. Each of the components density and use illustrate functional demands and conditions for station design and operation. With increasing *density* of context stations will generally require, for example, more, longer and wider platforms, i.e. they must be larger. But adjusting station structures becomes increasingly complex within the ever-denser urban areas. Changes in *use* influence station design and operation in a more complex manner. Changes in use influence not only weekly, but also daily and seasonal ridership patterns, as well as the customer type composition at the station (cf. Dallen, 2007; Chen et al., 2009). A commuter-oriented context results in predictable passenger peaks in the morning and evening hours. The majority of customers are familiar with the station facilities and experienced in using public transport, and therefore require minimal support or information, but pose high demands on reliability and efficiency: e.g. punctuality, short walking distances and waiting times (Brons and Rietveld, 2009). Operating commercial services at such stations requires attracting additional customer groups during the less-frequented midday hours. At the other extreme, stations in a tourism- or leisure-oriented context experience larger and less readily predictable weekly or seasonal variances in ridership patterns. The customers are less familiar with the specific station facilities, possibly even inexperienced in using public transport, carrying baggage and travelling in larger groups (e.g. families) (Dallen, 2007). They pose demands on ease of use, i.e. require orientation, information and ticketing support as well as agreeable waiting areas (Thompson and Schofield, 2007). The high seasonal variances in passenger frequencies may make it very difficult to operate commercial services at such stations.

Patterns are also visible for factors not included in the cluster analysis. The geographic distribution patterns suggest that relevant context of stations is coupled to larger geographic situations. We identified stereotypical situations often used for land use classifications, such as whether a station lies in a "major city", "agglomeration" or "rural area", or even whether a station is located in the lowland, pre-alpine or alpine regions of Switzerland (cf. Diener et al., 2005). Such distributions are commonly indicated in intuitive classifications such as that given by Ross (2000), who distinguishes between city centre, urban, suburban and rural stations. In recent research, Chen et al. (2009) also found geographic ridership patterns in the New York subway system, and Verhetsel and Vanelslander (2010) found geographic commuting patterns in Belgium. Both studies conclude that transport-related assessments or policies should be spatially differentiated. Similarly, patterns are also visible in the population and job dynamics of the catchment areas. The fact that the presented classification approach is able to reproduce previously known geographic distribution patterns and development dynamics is a key result and must be considered a major improvement compared to classifications relying on passenger frequencies.

As mentioned in the introduction, in literature two classifications are described that are based on a broad set of indicators and applied in practice (cf. Peek et al., 2006). Both examples were derived from the node-place model of Bertolini (1996, 1999), thus systematically integrating transport and land use perspectives to identify conditions for development. Our approach is partly similar: We also integrate perspectives – by addressing the multiple functions of stations. Further, we also do not classify the stations themselves, but rather the contexts within which the stations must function. That the *node* and *place* factors are reproduced (albeit complemented by the factor *use*) is a clear indication of these similarities. Unique to our study is the systemic approach, explicitly distinguishing functions, structures and contexts of stations (Fig. 1). Identifying contextual requirements for the functioning of stations allows for a systematic derivation of classification criteria and leads to well interpretable classes.

4.2. Contributions to strategic planning

As stated in the introduction, classifications of stations based on similarity of context support strategic planning by (i) identifying stations with comparable contextual circumstances, (ii) supporting performance assessments and (iii) allowing for descriptions of development potentials and future adaptations by class. These three contributions are elucidated in the following.

Once a class of stations with similar context is identified, the system structures of these stations can be compared. Knowing the relevant context factors permits the identification of the general and unique characteristics of the cases, and thus allows for better exchange and interpretation of experiences and development solutions. The data collected, for instance, allows for the identification of all "medium commuter feeders" (C3), which are located at the outskirts of the settlement area and have bus connections. Classifications allow for the identification of exemplary cases, description of prototypes or development of stereotypes, each usable for comparison, learning and general simplification of communication (Kunda, 1999; Meadows and Wright, 2008). General class names (e.g. large connectors, isolated tourism nodes) exemplify this effect. Here, care must be taken when comparing the given class working names and class centroids in Table 3: e.g. when asked to give an example of the class "largest and most central stations" (C1) one will think of *the* largest station, Zürich Main Station, and not of the *average* large station as given by the centroids. In contrast to a classification based on passenger frequencies, not only the largest or smallest stations, but also intermediate sizes may be used as such exemplary cases. This would support a more diverse but still intuitive guidance for analysis and design purposes among, e.g., planners and operators (Balz and Schrijnen, 2009).

Identifying stations with similar context improves performance assessments. The question of optimal system structures for a specific context (as well as their adaptation to the context) can be addressed and explored in a systematic manner (cf. Bossel, 1999, 2000). This is often described as interaction of local and global scales or hierarchies, and leads to discussions of compatibility or harmony of a system and its context (cf. Miller, 1978; AAG GCLP, 2003). This approach therefore fosters the identification of the relevant context factors (cf. Bruinsma et al., 2008), as well as the necessary adaptations of the structures to context. Performance assessments permit the definition of benchmarks within classes and the description of comparative development potentials for the remaining stations. An analysis of current performance or efficiency is a logical first step. Additionally, a comparison of historic performance, as well as recent or planned projects is possible. This is also where we perceive the indicator "passenger frequency" as highly useful: when comparing stations with similar contextual conditions, the number of passengers must be assumed a key indicator for successful station design and operation.

Context changes continuously, requiring continuous or step-wise adaptation of the station structures. As also suggested by Levinson (2008) and Chen et al. (2009), we assume that such dynamics are at least partly similar within a context class and different between classes. This is supported by the analysed dynamics of population and jobs in the catchment areas of the stations (cf. Tables 6 and 7). The largest stations (C1) have experienced a reduction in the number of residents in the catchment area, while all other classes, especially the small commuter feeders and tiny touristic stations (C4, C5) have experienced significant growths. The smaller stations with more tourism (C5, C6) have experienced massive reductions in the number of jobs in their catchment areas within the last 10 years, while the larger commuting stations (C2, C3) have experienced small growths. Context changes can thus be monitored or predicted per class, and the necessary development strategies worked out accordingly (cf. Scholz and Stauffacher, 2007). If the relevant context factors are well known, it may be rewarding for the station operators to consider how they can (if only minimally) influence these factors, or make the communities at the station sites aware of their influence on the station.

4.3. Methods enhancement and practical application

This study applied exploratory data analysis methods (cluster analysis, principal component analysis), which are useful for formulating, but not for testing hypotheses (Tukey, 1977). The results show how density (divisible into node and place components) and use may be important factors for classifying stations, with indications that the regional importance or centrality of the station may also play a role. These findings are supported by the few classifications available in the literature. Differentiating general functional types of stations, Ross (2000) also distinguishes not only between the predominant type of interchange (rail-to-rail, bus-to-rail, rail-to-sea, road–rail, park-and-ride) but also according to location (city centre, suburban, rural) and adjacency (airport, sport stadium, commercial development area). What is currently missing in our study (or only partly represented by I_7, reachability) is the location of the station within the larger rail network. Passengers always pass through at least two stations on their journeys. The functions demanded at a single station are therefore probably interdependent with the functions fulfilled by the stations in the surrounding network.

The classes presented in this paper are primarily considered a "proof of concept". In addressing all context factors relevant for the functioning of the stations, the resulting classes try to address all actors and interests. But it is exactly this diversity of perspectives that may reduce the classes' applicability to station management or strategic land use and transport planning. This raises the question of appropriate approaches to practical classifications. Here we can only highlight the importance of clearly defining the question at hand. If a classification is e.g. used to develop standards concerning station integration in the community (as e.g. proposed by Green and Hall (2009)) it is essential that the classification is based on indicators reflecting the relevant issues at hand. But still, every classification will have certain flaws and conclusions will always have to be scrutinised in situ. If a classification is to be achieved by statistical cluster analysis as presented in this paper, the researcher must take several decisions (e.g. chosen variables, normalisation of data, weighting of indicators, distance measure, cluster algorithm, number of classes). Because the important indicator "centrality" did not contribute to clustering, we feel that the weighting of the indicators (e.g. in accordance with the number of functions they influence) may be the most interesting path to pursue for future classifications relying on statistical cluster analysis. But alternative methods such as manual classification or defining specific acquisition criteria per class are also conceivable. According to Fig. 1, a two-step procedure may be fruitful: first the identification of classes with similar function-patterns, and then in a second step a further division according to the relevant contextual conditions. Independent of the classification method, the continuous changes and developments of context will eventually require adaptations of the classification, either resulting in new classes or reallocation of single stations.

A classification system for everyday practice must not only fulfil requirements of scientific soundness but also of practical relevance. Having discussed potential contributions of the classification system to strategic planning in Section 4.2, we would like to mention some of the potential barriers related to developing and operating a new classification system. These may also partly explain why current classifications heavily rely on the indicator "passenger frequency": (i) Passenger frequencies are straightforward. A single indicator is far easier to interpret than the multi-criteria approach presented in this paper – although correctly assessing passenger frequencies is very complex[1] (in this sense, we present a complex method using simple data, while the current system is a simple method using complex data). (ii) Many rail infrastructure companies receive subsidies to sustain their infrastructures. This means that adopting and adapting a classification system influencing investment decisions (e.g. by defining minimum standards per class) requires political approval – a process presumably favouring straightforward methods. (iii) The indicator "passenger frequencies" represents the "daily bread" of public transport. Passenger frequencies are the basis for modal share calculations and thus represent a key goal of every public transport company – and station operators do partly need a "transport-orientated mindset". Switching to other indicators means losing this link. (iv) The classes derived upon passenger frequencies are "not far off". Passenger frequencies correlate well with density of context, a key distinction of the classes we extracted (Table 5). Classifications based on "passenger frequencies" therefore indirectly represent certain contextual requirements. (v) Last but not least, it may well be that the potentials of classification for strategic planning have not yet been fully recognised. This would lead to reduced requirements and expectations currently placed upon classifications. These arguments also show, that ultimately concrete applications are necessary to prove how well the presented classification system can actually support strategic planning in the context of everyday practice (Straatemeier et al., 2010). The fact that the presented classification was elaborated within a transdisciplinary research project, enabling mutual learning between science and practice (cf. Scholz, 2000; Hirsch Hadorn et al., 2006; Stauffacher et al., 2008) should support later applications, but cannot replace them.

5. Conclusions

This study started with the observation that the classification of stations is a potentially powerful tool for the many actors involved or interested in the strategic planning of stations. We have argued that the potentials of this tool are currently sub-optimally utilised due to classifications strongly relying on an inadequate indicator: passenger frequencies. We argue for a systemic approach, i.e. that a classification of stations must focus on system context, as context defines and influences the demands and conditions within which a station must fulfil its many functions. The indicator "passenger frequency" not only blends system-structural and contextual elements, but also has a focus restricted to the transport-related functions of stations.

As proof of concept we present a classification of Swiss railway stations relying exclusively on contextual indicators. First, using exploratory data analysis methods, we have shown how a classification may be achieved. The resulting classes are well interpretable and able to reproduce geographic patterns often used in land use classifications. Second, we have shown how the new classification can contribute to strategic planning of railway stations: Exemplary cases can be defined, optimal system structures for a specific context identified, and development strategies per class worked out.

Although the paper has focused on the influence of system context on system structures, effects working in the other direction are also better understood. The structures of a station influence the functions it can fulfil – a common topic in e.g. ecology, where stability and reactions to disturbances are dealt with. Spatial planning and transport policy then discuss where which functions should be fulfilled, and railway stations generally form part of the context of other systems. The systematic description of these interrelations also illustrates why the interests of so many actors must be integrated in railway station operation and development.

Current classifications are often used to define station standards. New standards could also include issues such as the integration of the station in its surrounding community. But for such topics the current classifications do not rely on adequate indicators. This paper gives an example in which manner the current classifications may be further developed.

[1] Correctly assessing passenger frequencies of stations is highly complex. In Switzerland these numbers are assessed by the railway companies themselves and thus confidential. The numbers used in this study originate from the Swiss Federal Railways (SBB). The SBB model passenger numbers for most Swiss stations based on data originating from passenger census in trains (acquired five times a year for each train), automatic passenger count systems in the doors of newer regional trains, and estimations from train conductors. Model results may thereby vary significantly from in situ observations – especially effects of short trips are assumed to be underestimated (Personal communication, Katrin Richter, 25 June, 2010). Further, data concerning shopping customers are not systematically collected, although this customer group can constitute a significant fraction of the users of stations with many shops (Stauffacher et al., 2005).

To conclude, we do understand why "passenger frequencies" are currently used to classify stations. But – as we have hopefully convincingly shown – "passenger frequencies" reflect an insufficient theoretical basis and thus have practical shortcomings. There is no such thing as a "typical 1000 passengers per day railway station". The current classification approaches present a lost opportunity for the development of stations (perhaps even for transport nodes in general), and should concern not only the companies operating large portfolios of stations, but also the many affected communities with stations situated in their urban core.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jtrangeo.2010.08.008.

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