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All aboard! Towards an assessment of sustainable development options of railway stations

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All aboard! Towards an assessment of sustainable development options of railway stations

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Abstract

Railway stations function not only as interchanges for both trains and other transport forms, but also, for example, as places of commerce, social interaction, and, potentially, as drivers of urban development. As such they are arguably important for urban form and sustainable development. Yet to be able to examine these claims, as well as to be able to make recommendations for the (re)development of existing railway stations, a method of assessment is required. Distinguishing railway stations in terms of node and place functions has been proposed. The former describes the connectedness of a railway station with other places of interest (e.g., the number of directions served, the frequency of services, parking capacity for cars and bicycles). The latter refers to the quantity and diversity of possible activities at the station (e.g., number of residents, number of workers, degree of functional mix). The present research aims to provide an assessment of all Swiss railway stations in terms of node and place function, as well as to enhance the original method, which is based on a limited number of indicators with no mention being given as to their relative weighting. Implications for sustainable development will be discussed, a central theme being that a balance between the node and place functions should be sought.

Keywords

Sustainability – Mobility – Accessibility – Railway Stations

1. Introduction[1]

The decentralisation of urban areas has continued unabated into the present century. The initial impetus from planning in the early eighteenth and nineteenth centuries may have reflected a concern for the human condition regarding overcrowding, unsafe conditions arising from increased automobile usage, and unsanitary conditions (Jackson, 2003; Ryan & McNally, 1995). Later impetus also came from the fact that decentralisation was an economically sound policy to follow insofar as land and construction costs in city centres vis-à-vis transport costs from more distant, non-central areas were much more expensive (Gordon & Richardson, 1997). Early decentralisation was heavily dependent on widespread railway and tramline construction but with the growth of affluence and car ownership after World War II the rate of decentralisation and suburbanisation greatly increased; decentralisation still could be defended on economic grounds and could now proceed independent of proximity to the rail and tram networks.

However, decentralisation dependent on the private automobile has brought with it a host of problems. Economic problems are related to the fact that growth is related to transporting goods further rather than producing more (e.g., Black, 2001; Böge, 1995; Whitelegg, 1997), Social problems include the growing public health (e.g., obesity) and social exclusion concerns when car ownership is assumed for activity participation, as well as the growth in car dependence not only among the general population but also among younger children, which may have long term ramifications (e.g., Larkin, 2003; Rajé, 2003; Schönfelder & Axhausen, 2003; Whitelegg, 2003). Finally, environmental problems are related to the fact that the car is the most land and resource intensive transportation mode and is responsible for a disproportionate amount of airborne emissions (e.g. Crawford, 2000; European Partners for the Environment, 1999; Pickrell, 1999; Vigar, 2002).

It should be apparent that such negative trends, intricately linked to urban and regional decentralisation in its present form, are not sustainable. This is argued to be the case irrespective of the exact definition of sustainability one adopts. As with any complex, multifaceted term, sustainability has no single accepted definition although most definitions tend to imply the need to conserve natural resources and include a reference to the welfare of both the present society and the society of the distant future; see Friedl and Steininger (2002) and Perman et al. (2003) for discussions of the main classes of definitions of sustainability

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developed in the literature. The issue of sustainability with respect to urban spatial development patterns and infrastructure implies a development form in which modes alternative to the private automobile are emphasised through an appropriate integration of land usage and transportation means. That is, relevant issues that need to be considered are mobility options and accessibility to services. This is one reason as to why the present paper focuses upon rail transport and railway stations, even though all alternatives to the automobile could be argued to be important.

Other reasons for the focus on rail include historical trends that have shown a general decline in patronage, despite the small gains of recent years, (e.g., Office of Rail Regulation, 2006) and/or decreasing modal split (e.g., World Bank, 2001) as well as the historical lack of coordination between urban planning and railway development and location (Haywood, 2005; Maillard, 1995). Indeed, Haywood (2005) even contends that such a lack of coordination and integration led to the location of stations towards the periphery of the urban areas they served, which placed railways in a disadvantageous position when private automobile ownership and usage gathered pace in the post-war period. Despite such a lack of coordination, rail transport remains the only mode with a significant amount of inter-modal trip chaining (Bertolini et al., 2005), something which emphasises its potential central and key role with respect to traffic infrastructure, urban planning, and sustainability. In fairness, this potential has not gone unnoticed by planners and planning authorities the world over. However, the focus has been on large, major stations such that there is “little evidence of such refocusing around suburban, ex-urban or new stations, even where significant rail investment has taken place” (Haywood, 2005, p.88). For these reasons, the present research focuses upon the sustainable positioning of smaller railways stations. Yet, the question remains as to which frameworks can and ought to be used to evaluate smaller railway stations with respect to sustainability and urban form. Several frameworks varying with respect to the focus placed on the railway station, on the one hand, and its nearby surroundings, on the other, have been proposed.

The assessment tool of the Swiss Association of Transportation Engineers (De Tommasi, 2004), for example, focuses on the station itself with little consideration of the surrounding areas. While the assessment tool is applicable to any transit interchange (i.e., interfaces where transfers are made between different modes of transportation), it is clear that railway-station transfers usually involve transfers to and from trains. In contrast, the node-place model proposed by Bertolini (1999) also includes the nearby station surroundings. The node-place model is based on the observation that railway stations not only provide access to the railway system (node) but are sometimes also destinations for trips, hosting a variety of services where direct contact with customers is necessary. Several indicators have been proposed for both the node (e.g., daily frequency of train services) and the place (e.g., number of residents in the close area of the station) function of the railway station. Finally, an even broader focus is adopted by transit-oriented development, which investigates railway stations, metro stations, tram stops and bus stations together with their surroundings. Transit-oriented developments are residential or commercial areas designed to maximise access to public transport, often incorporating features to encourage transit ridership (e.g., Jenks, 2005).

The present research utilises the node-place model with its focus on the railway station and nearby surrounding areas because, of the three frameworks presented, it is arguably best-suited to the aim of evaluating railway stations from the perspective of integrated land use and transportation. The reason for this is that the node function describes the transport activity and connectedness of the railway station to other places of interest (e.g., service frequency, the number of routes and directions served), whereas the place function describes the quantity and diversity of possible activities at the station (e.g., number of residents, number of workers, degree of functional mix). The node-place model can be depicted as shown in Figure 1. The y-axis corresponds to the transport activity of the railway station (node). Passengers that use the station provide a potential for physical human interaction (including commercial activities), the realisation of which corresponds to the activities of the railway station (place), drawn on the x-axis.

Bertolini (1999) suggests that a balance exists between node and place functions such that most railway stations tend to be found along the diagonal in Figure 1. Five regions can be identified in this figure. Firstly, in the centre, one can find the well-balanced railway stations. These are well balanced in terms of the node- and place-functions, as well as overall usage. Following this diagonal to the sections furthest from the origin, one finds the railway stations experiencing stress due to the fact that competition between modes of usage is very high and conflicts arise. These conflicts can take place along different dimensions: conflicts between a railway station's node and place function (e.g., commercial business may be hampered by the spatial requirements of transport-related infrastructure) and spatial conflicts during the construction phase (e.g., how much space should be allotted to mode interchanges, to commercial enterprise, and so on). Following the diagonal towards the origin, one finds railway stations that are too small to sustain themselves (e.g., they may require local authority or other assistance). They also are dependent upon larger railway stations in the system. Above the diagonal are railway stations where the potential for physical human interaction (commercial opportunities are by definition part of the physical human interaction) has not been realised to its full extent despite the presence of more than sufficient transport activities, whereas below the diagonal the converse is true.

The proposed balance between node and place provides a first criterion by which to assess sustainability with respect to urban spatial development patterns and infrastructure. The reasoning is quite simple when one considers that a railway station that is exemplary in travel activities but sub-standard in terms of urban activities represents a waste of potential. For example, in terms of the triple-bottom line often used to describe sustainability, i) individuals will need to travel more as they are unable to fulfil all their activities at this station, leading to greater environmental emissions, ii) the economic potential of the stations in terms of customer turnover goes unrealised, and iii) a lack of services reachable by public transport has the potential to exclude segments of society for whom the car is not an option. As such, the node-place distinction, as well as the requirement of a balance between the two functions, is important both as a means by which to evaluate sustainability and a means by which to make policy recommendations for the (re)development of any given railway station. The first aim of the present research, then, is to apply the node-place model to all Swiss railway stations.

Despite the benefits of the model there are some key limitations. Most notably, the set of indicators may be limited (or lacking) in its coverage of certain important aspects. Such data may be obtained from expert interviews or questionnaires. Moreover, the issue of the relative importance of the different indicators used to calculate the node- and place-index is not addressed in the work of Bertolini (1999). It is conceivable that some indicators[2] play a greater role and contribute more to the ability of a railway station to fulfil either the node or place function; that is, an assessment is required to examine if changes in the value of certain indicators affect scores on the node or place index more than changes in the values of other indicators. Indicator enhancement and assessment is the second aim of this study.

Jenks (2005, p. 23) has argued, from the perspective of transit-oriented development that "… further research be done to develop a typology and assign certain benefits to certain types of transit-oriented development". This statement is argued to also be relevant for the more specific case of railway stations insofar as an operationalized classification of railway stations is likely to be very useful. More specifically, the benefit of such a typology is that specific measures (e.g., the creation of additional housing space) may yield certain results or outcomes only for certain types of railway station and not others. Moreover, certain factors make sense only if they are discussed with respect to a certain type of railway station. For example, Crockett and Hounsell (2005) propose that convenience has to be judged in different ways for different types of railway station as a "one-size fits all" assessment for all national railways would be inappropriate. The Swiss Association of Transportation Engineers classifies railway stations according to three levels of importance: national, state or regional, and local (De Tommasi, 2004). However, a definition with respect to distinguishing between the different

[2] Note the distinction between index, which is used to refer to either the node or place function, and indicator, which is a single property (e.g. daily frequency of services) included in the evaluation of the two indices.

classes is not provided nor is the classification useful with respect to understanding the functionality of the railway station within the context of land use and spatial development. The present research attempts to provide a meaningful, operational classification of railway stations using the same variables argued to be important in terms of the node and place functions of a railway station. What is needed, then, is a method that is able to seek structure in a large data set of many variables that is not readily apparent. One such method is cluster analysis (see Aldenderfer & Blashfield, 1984, for a review and basic introduction), which is the generic term for any procedure that takes a data set containing information about a sample of entities (i.e., railway stations) and empirically forms groups of highly similar entities. Additionally, cluster analysis may be useful as an initial, preliminary validation of the node-place model. More specifically, if, as Bertolini (1999) hypothesises, there is a balance between each station's node and place functions, then all that remains to differ between stations size, which, in turn, should be vital in the final clustering solution. Furthermore, if there are a sufficient number of unbalanced stations, these should also be identified, thereby lending empirical support to the five areas outlined in Figure 1. Thus, the benefits of a cluster analysis are also practical, insofar as the identification of groups of dysfunctional railway stations is possible, with clear implications following for recommended actions (i.e., stations that are unsustained places require policies that improve their node function)

In summary, the present research aims:

- to provide an assessment of all Swiss railway stations in terms of node and place functions
- to enhance the method proposed by Bertolini, which is based on a limited number of indicators, and to assess the relative importance of such indicators:
    - which additional indicators, if any, ought to be taken into consideration? (extension of the model)
    - how important are these indicators to a railway station's ability to fulfil its node or place functions?
- to define an operationalized classification

2. Method

2.1 Description of data set

The data are taken from the Swiss Federal Railway’s (SBB) *railway-station database*, which includes all 1683 railway stations. Additional sources of information, used to complement and extend the data set, were the 2000 *Swiss census of the population* (Bundesamt für Statistik [BFS], 2000), the 2001 *Swiss census of enterprises* (BFS, 2001), and digital maps (Swisstopo, 2004; veloland, 2005).

Bertolini (1999, p. 202) proposed a set of fifteen indicators do evaluate the node and place functionality of a railway station. Eleven indicators (Table 1) were used from the database in this work. Differences in the set utilised in the present research to the set proposed by Bertolini are as follows. No complete data sets were available from the SBB railway-station database for the three indicators of passenger numbers, car parking capacity and bicycle parking capacity. Moreover, Bertolini used the number of workers per economic cluster, with the following four clusters being defined: retail/hotel and catering; education/health/culture; administration and services; industry and distribution, while the Swiss census of enterprises (BFS, 2001) did not allow the same distinction. Instead, only two indicators, the number of workers for the secondary and the tertiary sector, were available.

INSERT TABLE 1 ABOUT HERE

Seven indicators in addition to those proposed by Bertolini (1999) were also used for the analyses in the present research (Table 2). The rationale for the inclusion of these indicators is elaborated upon in a following section (enhancement of the model).

2.1.1 Missing values

Indicators with more than 30% missing values were excluded from the analyses (car and bike parking capacity information). A multiple imputation method using additive regression, bootstrapping and predictive mean matching was used to predict the remaining missing values (Little, 2004). This was only necessary for data about passenger numbers for 156 railway stations.

2.2 Analyses

2.2.1 Application of the node-place-model to Swiss railway stations

The node and place indicators —y_i and x_j, respectively— were used as defined in Table 1. All indicators except for bicycle access (y_7) and functional mix (x_4) were log-transformed in order to reduce the skewness of their univariate distribution. All indicators were also rescaled to have a minimum of 0 and a maximum of 1. The node index was defined as the sum of all node indicators; the place index analogously as the sum of all place indicators. Before plotting the node-place diagram, the two indices were z-transformed in order to obtain comparable scaling (i.e., distances on the node place diagram are shown in standard deviation units). Finally, a LOWESS smoother (Cleveland, 1985) with a span of s = 0.5 was applied in order to estimate the relationship between node and place index. The span determines the ratio of data points included in the calculation of the smoothing function. Convenient values for the span usually range from 0.5 to 0.8 (Cleveland, 1985).

2.2.2 Enhancement of the model

Two sources were used to extend the node-place model (Bertolini, 1999): an expert questionnaire and repertory grid interviews. The node-place model as initially defined by Bertolini (1999) was presented to five SBB professionals in the form of an expert questionnaire. They were asked to augment the set of indicators on the basis of their experience and expertise and to classify their suggestions as relevant for either the node or place function of a railway station. The knowledge elicitation method known as the repertory grid method (e.g. Fromm, 2004) was also utilised to extend the model. This method was used to find implicit concepts used for the description of railway stations. In brief, a total of eight experts, three from the Swiss Federal Institute of Technology (ETH) and five from the SBB, were asked to provide a list of ten small railway stations known from personal experience. These railway stations were then presented randomly in sets of three, with the interviewee being asked to distinguish one railway station from the other two, while at the same time describing the concept that underlies the difference between the one different railway station and the two similar stations (e.g., staffing). The interviewee was then asked to provide end-points for this concept (e.g., no staff present, staff present) before a new set of three railway stations was presented. This procedure was repeated until no new concepts could be identified. Finally, the interviewee was required to rate all 10 stations on each of the concepts s/he identified (i.e., not just the three stations used to elicit the concept); the elicitation of end-points aids this step of the repertory grid technique.

The indicators presented in Table 2 resulted from the use of expert questionnaires and the repertory grid technique. However, concepts from the repertory grid method were only included if described by at least two experts. Also, only indicators for which data was available from either the SBB railway-station database or the Swiss censuses of the population (BFS, 2000) and of enterprises (BFS, 2001) were included in the present research; Table 2 also presents the indicators that were excluded for these reasons as well as the indicators suggested by experts that were already included in the node-place model. As seen in Table 2, a total of seven new indicators were obtained by means of the expert questionnaires and the repertory grid method. These indicators were also log-transformed except for the indicators assessing station staffing (y_{10}), and the extent of commercial services (x_7). These seven indicators were then rescaled to have a minimum of 0 and a maximum of 1.

INSERT TABLE 2 ABOUT HERE

2.2.3 Indicator importance

Implicitly, a weight of 1 is assigned to all indicators in this and previous work using the node-place model. Yet, the relative importance of the utilised indicators to a railway station's ability to fulfil its node or place functions should be assessed in order to understand which indicators have a greater impact than others on railway stations' node and place scores.

One way to assess the relative importance of the utilised indicators is by manipulating the weights and observing the resulting change in scores on node and place indices. This was done by increasing the weight of each individual indicator from 1 to 2, 3.5 and 5, while holding the remaining indicators constant. Node and place scores were recalculated permitting an examination of the potential impacts of the weight of a certain indicator on these scores.

2.2.4 Cluster Analysis

The two-step clustering procedure available in the software package SPSS 12.0 and onwards was used on the indicator set $x_{1\ldots7}$ and $y_{1\ldots11}$. Two-step cluster analysis is ideally suited for very large data sets and data sets that are comprised of categorical and continuous data, as is the case with the present data set. The procedure is a two-step procedure because in a first step preclusters are formed that are, in the second step, used to define the distance matrix that is the input to a standard hierarchical clustering procedure (see Norušis, 2003, for a basic introduction). Two preclusters are combined on the basis of the log-likelihood criterion, with preclusters being combined if they lead to the largest log-likelihood. The number of clusters formed this way can either be pre-specified by the researcher or determined on the basis of the Bayesian Information Criterion (BIC). Finally, it is also possible to create a separate cluster for cases/preclusters that do not fit well with any other preclusters.

The present research applied two-step clustering to the extended variable set $y_{1...11}$ and $x_{1...7}$. The distance matrix was calculated using the maximum likelihood method. The number of clusters was selected on the basis of the BIC. Stations were excluded if the corresponding cluster size was less than 25% of the maximal cluster size. Importance of variables for cluster formation was tested using Bonferroni-adjusted t-tests for continuous data (all indicators except y_{10}) and Bonferroni-adjusted Chi-square tests for categorical data (y_{10}). The observed distribution of cases within each cluster was compared to the expected distribution based on all cases in the data set.

3. Results

Figure 2 illustrates the results of i) analyses applying the original formulation of the node-place model to Swiss railway stations, ii) analyses applying the extended node-place model to Swiss railway stations and, finally, iii) the cluster analysis. These will be described in greater detail in the appropriate sections below.

INSERT FIGURE 2 ABOUT HERE

3.1 Application of the model

Swiss railway stations exhibited, consistent with expectations, a general balance between node and place indices despite certain exceptions (see Figure 2, upper panel). The stations most distant to the LOWESS smoother and a few large stations (i.e., those with a high node and place index) are labelled. A striking feature is the group of 47 railway stations in the bottom left corner of the figure. These are stations for which two of the three indicators comprising the degree of functional mix (x_4) — residents (x_1), workers in the secondary sector (x_2) and workers in the tertiary sector (x_3) — are 0 (e.g., railway stations specifically serving industrial plants or areas). Nevertheless, these stations do not disturb further analyses.

The general balance between node and place index, as well as the ability to identify systematically differing stations, suggests that the method is useful for improving the understanding of railway stations, as claimed by Bertolini (1999). For example, one such station is Zurich International Airport, which has an above average node index score but a below average place index score, which can possibly be explained by the huge spatial requirements of an airport, which make other uses (e.g., residential, industrial) common to the surrounding areas of stations with similar node scores more difficult. Finally, the non-linear trend captured by the LOWESS smoother indicates that the place function is more pronounced at larger railway stations compared to smaller ones. While the LOWESS smoother with a span of 0.5 smoother was a reasonable fit, there is evidence of considerable fanning out in the data as stations increase in their fulfilment of the node function; yet another reason to examine whether or not an enhanced model may yield a better description of Swiss railway stations.

3.2 Enhancement of the model

As previously indicated, use of expert interviews and the repertory grid technique led to the inclusion of four additional indicators for the node index and three for the place index (see Table 2). These indicators were used to recalculate the node and place index scores for each railway station. Stations were then plotted using these new scores (see Figure 2, lower panel).

As before, Swiss railway stations exhibited a general balance between node and place indices for the larger stations, although certain exceptions remained. The most distant stations from the estimated LOWESS smoother with span of 0.5, as well as a few large stations are labelled. For example, Zürich Selnau is such a distant station with a high place index and, relative to other stations, a low node index. This station is situated close to the centre of Zürich and used to be the final station of the line to the top of Uetliberg, a well-known location for leisure activities in the vicinity of Zürich. In 1990 the station was relocated with the opening of the Zürich metropolitan rail network and is now located underground beneath the Sihl River. There is no good link to other public transport (tram and bus), as the nearest bus and tram stops are both located at different places several hundred metres from the railway station. Also as before, a non-linear trend was captured by the LOWESS smoother indicating that the place function is more pronounced at larger railway stations and less pronounced at smaller stations.

The enhanced model appears to achieve a better fit to Swiss data insofar as the fanning out of stations that are above average in node and place scores is no longer present and there is no longer a small distinct cluster of 47 stations with low node and place scores (cf. upper and lower panels, Figure 2).

3.3 Indicator importance

Given the use of z-transformed scores for describing railway stations' node and place indices, then the mean of each individual index is zero. Therefore, changing the weights of individual indicators implies that the mean shift in node and place scores for the data set is also zero. It follows, then, that the standard deviation of the shift can be interpreted as the effect of different indicator weightings on railway-station scores for the node and place indices. Even with a weight of 5, all standard deviations are less than 0.5. Assuming a normal distribution, this implies that approximately 60% of all stations vary less than 1 unit in Figure 2. As such, it is argued that the assignment of weights is not of high priority and has little influence on the node and place index scores of a railway station.

Nevertheless, some insights may be gained by a closer examination of those indicators with greater influences on node and place scores. For illustrative purposes, the four indicators influencing node and place indices by more than 0.4 when they are assigned a weight of 5 (see Table 3) are discussed.

INSERT TABLE 3 ABOUT HERE

Beginning with the node index, the influence of the weight on a station's score is largest for staffing (y_{10}) and motorway access (y_6). Interestingly, the first indicator was included as part of the enhanced model. While the fact that the ability of a railway station to fulfil its node function is related to staffing may come as no surprise, the importance of motorway access is less than entirely clear. It is likely that access and egress factors are also important to the node function of a railway station. With respect to the place function of railway stations, there appear to be two indicators whose scores are most influenced by changing weightings: station location with respect to the town (x_6) and the availability of commercial services (x_7) Understandably, the more commercial services a railway station has, the better its place score (presumably as there are more reasons for an individual to conduct his or her activities there). As for station location, the distance from a town centre has a strong impact on a railway station's place score presumably because of the reduced accessibility of relatively distant stations.

3.4 Cluster Analysis

Figure 2 shows the resulting cluster assignment of the two-step cluster analysis. The analysis was run several times with railway stations being randomly (and differently) ordered with each new run. This is consistent with the recommendation of Norušis (2003), who notes that the final solution may be dependent on the order of cases in a data file. In the present research, the various runs yielded either a 2- or 5-cluster solution. The two clusters in the top right of the lower panel in Figure 2 (i.e., the large and very large stations) formed one cluster in the 2-cluster solution; the remaining three clusters formed the other cluster. In addition to this commensurability between the 2- and 5-cluster solutions, and arguably more importantly, the assignment of stations was extremely consistent within each cluster solution (i.e., across runs). For these reasons, and to avoid excessive data reduction, the 5-cluster solution was selected, which also yielded two outliers, Zurich Main Station and Lucerne, both of which are very large railway stations.

In the 5-cluster solution, two clusters (C1 and C2) are comprised of very small and small railway stations with very low scores on both the place and node index. Two clusters (C4 and C5) consist of large and very large stations. Finally, one cluster (C3) lies between the other four clusters but is positioned below the LOWESS estimator (i.e., it generally consists of the railway stations with a low node index relative to the place index). It is the case, however, that the low node index is mainly due to low values being obtained on indicators concerning other forms of public transportation (y_4 and y_5), while indicators specific to train services (y_1, y_2 and y_3) are high. This information, together with general cluster descriptions and station examples, is provided in Table 4.

INSERT TABLE 4 ABOUT HERE

Also shown in Table 4 are the indicators for each cluster that are significantly different ($p < .05$) from the overall distribution suggesting that such indicators are important in distinguishing a certain cluster from others. For example, C4 tends to be near average on most indicators, reflecting its composition of medium-size stations. C5 is above average for indicators bar one, reflecting the fact that it is composed of the large to very large railway stations. The peculiarity of C3 is revealed in that it outperforms or is equivalent to C4 on many place indicators and in that it is above average on many node indicators for which C4 is below average (and vice versa). These patterns (including those for C1 and C2) are presented in Table 4, together with a general cluster description and some examples of stations from each cluster.

Finally, with respect to the hypothesis, some support is obtained insofar as the overall node and place scores tend to monotonically increase from C1 through C5. Additionally, increasing (equal or larger value) values are obtained for all indicators except for bus routes (y_4) and service frequency (y_5), type of trains (y_9), station staffing (y_{10}), and extent of commercial services (x_7) as one progresses from C1 to C2 to C4 to C5; on these indicators C2 also underperforms relative to C1. As already apparent from Figure 2 and as alluded to above, C3 deviates from the general pattern exhibited by other clusters. Nevertheless, this further demonstrates the utility of the node-place model in that the model is able to highlight groups of stations that may need extra attention with respect to node or place functionality or that deviate systematically from other stations.

4. Discussion

The motivation for this work originated from a desire to assess the sustainable development options of railway stations. To this end, the node-place model originally proposed by Bertolini (1999) was utilised. Application of this model to Swiss data showed a general balance between the node and place functions, as put forward by Bertolini (1999). Deviation from the balance could be used to identify which stations were prime candidates for a given policy recommendation. Additionally, the relationship between node and place was found to be non-linear such that the place function was more pronounced at larger railway stations than smaller ones. In contrast to Bertolini (1999) who hypothesizes that stations deviating from the middle diagonal in Figure 1 are either unsustained nodes or unsustained places, our empirical findings indicate that stations not situated on the nonlinear LOWESS smoother are unsustained. The interpretation of the non-linearity is that a minimal node functionality is required for the place function to become of importance. It was also revealed that supplementing the scores with additional indicators obtained from experts captured the relationships between node and place better insofar as the spread of data was reduced.

A preliminary examination of the relative importance of each individual indicator to the node or place score of a railway stations revealed that the assignment of weights is not of high priority. Indicator weights have little influence on the final node or place score of a station (i.e., an approximation in which all indicators are equally weighted is reasonable from modelling viewpoint). Nevertheless, from a practical and planning point of view, when not all indicators are able to be influenced or desirable to influence, then those indicators whose weighting plays a greater role in a station’s node or place score to a greater extent (for better or worse) should be targeted. In the present data set, these indicators were staffing, motorway access, station location with respect to the town centre, and the availability of commercial services.

Finally, a cluster analysis with a five-cluster solution yielded an interpretable solution. Partial support was obtained for the hypothesis that if the node and place functions were in balance then size would be crucial to the final clustering solution; this was the case for four of the five clusters. The cluster that was the exception to the rule has interesting implications with respect to land-use and traffic planning. This cluster was comprised of stations underperforming in their node functions relative to the place functions and this underperformance could be attributed to poor bus and tram connections. Interestingly, this severely limits a station in its ability to enable inter-modal trip chaining, a feature known to be of great importance for rail transport and which usually sets it apart from other modes (Bertolini, 1999).

As previously mentioned, there are a variety of classes of definition of sustainability. The present paper proposed a definition specifically related to the node and place model. Based on the proposition that node and place functions ought to be in balance, stations that perform well in one aspect but poorly in another are not sustainable in their present form. This imbalance represents a waste of potential with ultimate negative impacts with respect to the economic, social and environmental aspects of sustainability. With respect to the sustainability of a railway station, Bertolini (1999) goes even further suggesting that the long-term, future development of stations that lack balance in their node and place functions will follow a path whereby the unbalanced station will move towards the area of balance (i.e., the diagonal in Figure 1). However, how this re-balancing occurs is a question for planners and developers. Using Cluster 3 as a case in point, doing nothing may ultimately lead to a deterioration of these stations' place functions such that the stations shift towards Cluster 2 (see Figure 2, lower panel). Alternatively, improving bus and tram services might see a balance being achieved through an improvement in these stations' node scores such that these station shift towards Cluster 4.

Of course, which developmental path should or ought to be followed is beyond the scope of this paper. What the present research has shown is how the node-place model may be a useful means by which to evaluate railway stations. Based on the evaluation the problem space can be defined in which recommendations for railway stations have to be placed. Therefore, it is a tool for planning processes allowing the derivation of recommendations for further development. More specifically, the method enables the identification of whether the place or node functions of any given railway station should be improved. Based on the set of indicators, statements are possible concerning which services to enhance. The selection of specific development options, however, are issues related to values and preferences and, as such, ideal for public participation during the decision process. Realizing the transition process according to transdisciplinary methods provides a high learning potential for both the public and research community. In sum, the present research is a first step in improving the understanding and evaluation of railway stations. Such an understanding permits an increase in their contribution to sustainable urban form both in terms of the activities (place) and travel options (node) they make available to people.

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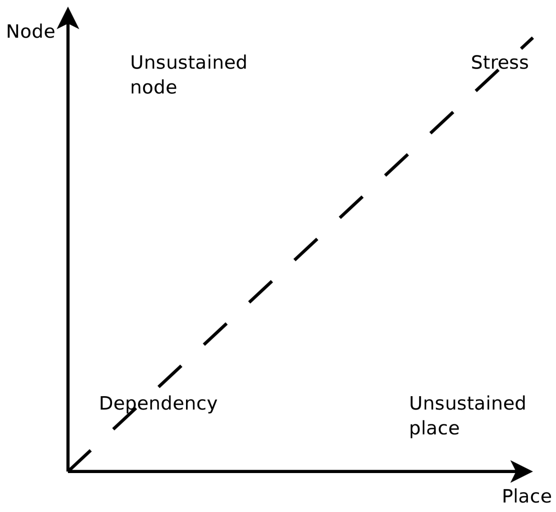
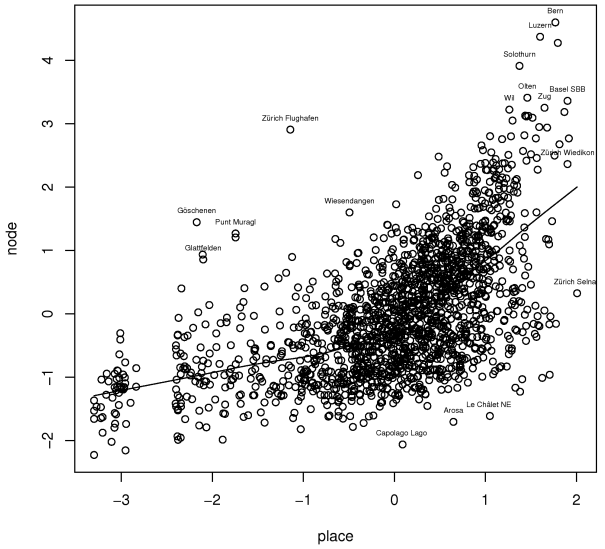
Figure 1 Node-place model



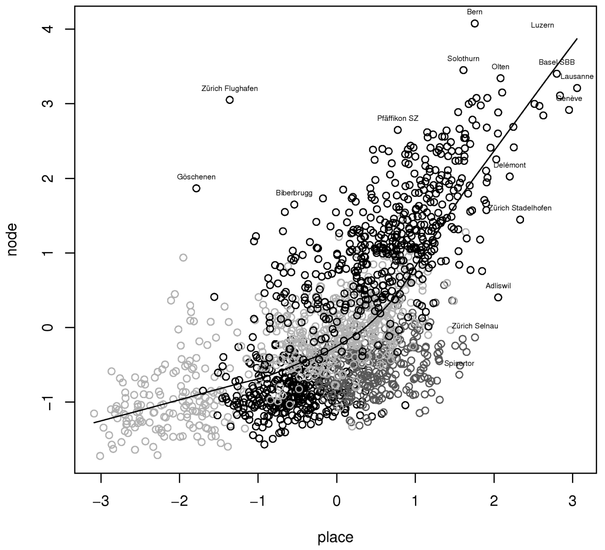
Source: after Bertolini, 1999, p. 202

Figure 2 Node-place model for Swiss railway stations with LOWESS smoother (s = 0.5) indicating general trend in data.

Feldfunktion geändert



s=0.5



s=0.5

N = 1683 Swiss railway stations. Upper panel = initial model; Lower panel = extended model

Formatiert: Englisch (Großbritannien)

Feldfunktion geändert

Table 1 Indicators used to calculate node and place indices (Indicators used as proposed by Bertolini (1999) unless otherwise indicated).

Description	Calculation of indicators
Node index	
directions served by train	y_1 = number of endstations reachable by train
frequency of train services	y_2 = number of trains departing from the station on Thursday, Oct. 20th 2005
number of stations within 20 minutes of travel	y_3 = number of stations reachable within 20 minutes[1] when leaving with any train from the station on Oct. 20th 2005, also including stations reachable with connecting trains.
number of directions other public transport (bus and tram)	y_4 = number of endstations reachable by bus and tram
daily frequency other public transport	y_5 = number of buses and trams departing from the station on Oct. 20th 2005
distance from the closest motorway access	y_6 = distance to next highway exit
car parking capacity	no data available
bicycle access	y_7 = bike path length within 2 km around the railway station
bicycle parking capacity	no data available
Place index	
population	x_1 = number of residents within 700 m
the number of workers per economic sector[2]	x_2 = number of full time position equivalent workers within 700 m of the railway station in the secondary sector
	x_3 = number of full time position equivalent workers within 700 m of the railway station in the tertiary sector
degree of functional mix	$x_4 = 1 - \frac{\left(\frac{a-b}{d}\right) + \left(\frac{a-c}{d}\right)}{2}$ with $a = max(x_1, x_2, x_3)$, $b = min(x_1, x_2, x_3)$, $c = mean(x_1, x_2, x_3)$, $d = \sum(x_1, x_2, x_3)$

[1] Bertolini (1999) calculated stations reachable within 45 minutes. In order to reduce computational effort, 20 minutes were used in this work instead.

[2] While Bertolini (1999) distinguished four economic clusters (retail/hotel and catering, education/health/culture, administration and services, industry and distribution), the corresponding data was not available from the Swiss census of enterprises. Distinction between the secondary and tertiary sector was used instead

Feldfunktion geändert

Table 2 Indicators for node and place model suggested from expert questionnaires and the repertory grid method. Both included and excluded indicators are reported.

Description	Calculation of indicators
Node index	
passenger frequency	y_8 = number of passengers
type of train services	$y_9 = \dfrac{\text{no long distance services}}{\text{no regional services}}$
staffing	y_{10} = present / not present
direction of commuters	no data available
Place index	
conference rooms and educational facilities	x_5 = number of full time position equivalent workers withing 700 m of the railway station in educational facilities
distance to town center	x_6 = 1/distance from the town center
commercial services	x_7 = presence of grocery stores + presence of restaurants + presence of a pharmacy + presence of a flower shop
urbanity of the town	no data available
Excluded concepts	Reason for exclusion
quality of intermodal change	no clear operationalization available
composition of station users	no data available
age and history of the railway station	no operationalization with respect to importance
type of railway station (e.g. terminus vs. through station, overpass vs. underpass)	no operationalization with respect to importance
ticket availability	data not sufficient
arrangement of the station surrounding	no operationalization with respect to importance

size	included already with several of the indicators, e.g. x_1, x_2, x_4, x_5, x_9
number of service providers operatiting at the station	no data available

Feldfunktion geändert

Table 3 Effect of indicator weighting on node or place scores holding other indicators constant

Indicator	Weighting 2 SD	3.5 SD	5 SD
Node			
y_1 – train directions	.08	.17	.24
y_2 – train frequencies	.06	.15	.22
y_3 – 20 min. stations	.08	.19	.29
y_4 – bus directions	.11	.22	.31
y_5 – bus frequencies	.12	.24	.32
y_6 – motorway	.12	.28	.41
y_7 – bicycle access	.11	.20	.38
y_8 – no. passengers	.10	.21	.24
y_9 – type of trains	.08	.20	.30
y_{10} – staffing	.19	.35	.43
Place			
x_1 – residents	.06	.12	.17
x_2 – sec. sector	.08	.17	.22
x_3 – tert. sector	.07	.13	.18
x_4 – functional mix	.08	.18	.24
x_5 – education	.10	.20	.26
x_6 – distance town	.15	.34	.48

x_7 – commercial services	.13	.29	.42

Feldfunktion geändert

Table 4 Cluster descriptions and summary statistics; M (SD) on node and place indicators†

Cluster	Node and place indicators (see Tables 1 and 2 for descriptions)																
	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}*	x_1	x_2	x_3	x_4	x_5	x_6	x_7
C1 (N = 160)	.18 (.08)	.47 (.08)	.42 (.12)	.09 (.15)	.08 (.15)	.29 (.12)	.08 (.10)	.11 (.13)	.29 (.08)	.09	.31 (.13)	.05 (.10)	.15 (.12)	.41 (.28)	.01 (.04)	.36 (.17)	.03 (.08)
C2 (N = 324)	.22 (.09)	.52 (.05)	.48 (.08)	.03 (.08)	.03 (.08)	.34 (.12)	.13 (.13)	.26 (.14)	.26 (.04)	.00	.57 (.08)	.37 (.13)	.36 (.09)	.83 (.07)	.15 (14)	.48 (.17)	.02 (.08)
C3 (N = 309)	.26 (.11)	.58 (.07)	.55 (.09)	.03 (.08)	.03 (.08)	.49 (.13)	.16 (.16)	.39 (.15)	.22 (.05)	.00	.75 (.07)	.60 (.13)	.60 (.11)	.92 (.04)	.50 (.16)	.41 (.13)	.02 (.08)
C4 (N = 414)	.24 (.10)	.52 (.10)	.48 (.09)	.38 (.10)	.44 (.12)	.39 (.14)	.15 (.13)	.38 (.14)	.27 (.10)	.00	.66 (.09)	.51 (.14)	.48 (.11)	.89 (.06)	.33 (.20)	.48 (.15)	.03 (.10)
C5 (N = 474)	.36 (.16)	.61 (.10)	.52 (.12)	.40 (.22)	.43 (.25)	.40 (.17)	.17 (.15)	.51 (.17)	.30 (.15)	1.00	.72 (.11)	.60 (.15)	.59 (.14)	.92 (.05)	.48 (.21)	.52 (.17)	.14 (.20)
All stations (N = 1681)#	.27 (.13)	.55 (.10)	.50 (.11)	.23 (.23)	.25 (.25)	.39 (.15)	.15 (.14)	.37 (.19)	.27 (.11)	.29	.64 (.16)	.48 (.21)	.48 (.18)	.85 (.18)	.34 (.24)	.47 (.17)	.06 (.14)

Cluster descriptions

C1	Smallest stations, furthest from the town centre, higher than expected ratio of long-distance to regional trains (and more buses/trams than C2), some are staffed. The stations are close to important leisure activities such as skiing or hiking (both for residents and tourists) Examples: Jungfraujoch; Uetliberg; Davos Monstein
C2	Small stations, very few bus/tram connections and not many long-distance rail services. All stations are unstaffed. These stations serves small villages, many of which are also not too distant from leisure centres. Examples: Davos Wolfgang; Moos; Alpnachstad
C3	Mid-size stations in populated areas with many residents and employment opportunities in different sectors, but further away from the town centre and with poor bus/tram connections but good motorway access. Many stations are in medium-size towns or are part of the outer areas of a large conurbation. Examples: Geneve-Sécheron; Zürich Wipkingen; Giubiasco
C4	Medium-size, unstaffed stations in populated areas with not so many train services and direction but more bus/tram services. These stations do not have so many commercial services given their size, but this may be due to their proximity to larger urbanised areas (hence the importance of urban public transport such as trams and buses). Examples: Lugano Paradiso; Chur Stadt; Zürich Wiedikon
C5	Large to very large stations with ample train, bus and tram services, centrally located in populated areas with many employment opportunities in various sectors.

Feldfunktion geändert

Table 4 Cluster descriptions and summary statistics; M (SD) on node and place indicators†

	These are main stations of large cities and stations of large towns, often on key routes between major cities, as well as urban satellites of larger cities. Examples: Lausanne; Lenzburg; Thun; Zurich Oerlikon.

Notes:

† Cells shaded light grey are significantly lower than the average of all stations (or, in the case of categorical variables, lower than the expected value); cells shaded dark grey are significantly higher than the average of all stations (or, in the case of categorical variables, higher than the expected value); cells tat are not shaded do not differ from the average for all stations.

* Categorical variable

Two outliers were excluded from the final cluster solution.