Doctoral Thesis

Sustainable positioning of railway stations
systematic analysis for knowledge integration

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SUSTAINABLE POSITIONING OF RAILWAY STATIONS:
SYSTEMIC ANALYSIS FOR KNOWLEDGE INTEGRATION

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presented by
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Sustainable Positioning of Railway Stations: Systemic Analysis for Knowledge Integration

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2011

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Summary

With both growing population and consumption patterns, Switzerland faces severe challenges regarding the development of its transport and land-use systems. Urban concentration strategies are proposed in order to slow both land consumption and the negative effects of mobility. Together, these effects have led to a new focus on the redevelopment of public transport nodes, especially railway stations.

The redevelopment of railway stations is demanding, involving both costly and complex technical infrastructures, as well as the incorporation of many different stakeholders. Successful redevelopment therefore requires integration of knowledge and coordination of actions. This thesis explores how passenger railway stations can be conceptualized and assessed with regard to the challenge of sustainable development, in order to foster integration of knowledge and coordination of actions. A systemic approach is taken, explicitly discerning and addressing the functions, contexts and structures of stations. Three publications form the main body of work:

1. Applying extensive qualitative research, the first paper identifies five generic functions of railway stations. These represent the goals and requirements typically imposed on stations by their stakeholders: linking catchment area and transport network, supporting transfer between modes of transport, facilitating commercial use of real estate, providing public space, and contributing to the identity of the surrounding area. Interrelations among the functions are described, including mostly synergies, but also including potential conflicts for space usage and customer attention or revenues, as well as the increasing system complexities with station size. We illustrate how the framework of functions can be used for fostering a common system understanding among the involved stakeholders, and for the structured derivation of assessment criteria.

2. Asking which stations are comparable in an assessment, the second paper explores the issue of station classification. Considering the multifunctional nature of stations, the common but one-dimensional classification criteria “passenger frequency” is dismissed. A novel quantitative and theory-guided classification approach for the contexts of railway stations is then proposed and examined using the 1700 Swiss railway stations. Using only the contextual factors that influence the functioning of stations, a cluster analysis reveals seven well interpretable classes. These differ according to land-use density, transportation supply, and the use of the station. Each class thus experiences different demands and conditions for functioning. This novel classification approach provides a unique basis from which to discuss questions of optimal system structures for specific contexts, thus supporting strategic and integrated station development.
3. Demonstrated by means of an examination of the railway stations of the S-Bahn Zürich, the third paper illustrates how railway stations can be meaningfully assessed with regard to the challenge of sustainable development. Using the six perceptors provided by the Sustainability Potential Analysis (SPA) (performance and efficiency, well-structuredness, interdependencies, buffer capacity, adaptive capacity, inter- and intra-generative equity), we assess whether the (built and procedural) structures of the stations can maintain performance and quality with regard to the functions demanded in their specific context. Both a quantitative approach for whole portfolios (screening tool) and a qualitative approach for the structured assessment of single cases (rapid assessment protocol) are presented.

The thesis illustrates that a key aspect of station redevelopment complexity arises from the multifunctional nature of stations. Sustainable development therefore requires the integration and coordination of many different actors with different knowledge types and decision-making cultures. The systemic conceptualization presented in this thesis—explicitly relating the functions, structures, and contexts of stations—has thereby proven itself capable of systematically linking the challenge of integration and coordination with the challenge of assessment with regard to sustainable development. The results further illustrate how assessments depend on earlier and support later, steps of the decision-making process, i.e., how integration of knowledge and coordination of actions are required at all redevelopment stages. Developed for the case of railway stations, the systemic approach seems capable of supporting the sustainable development of multifunctional infrastructures in general.
Zusammenfassung

Die Schweiz steht, aufgrund einer stark wachsenden Bevölkerung und deren zunehmendem Konsum, vor grossen Herausforderungen in der Verkehrs- und Raumentwicklung. Um negative Auswirkungen der Mobilität sowie des wachsenden Flächenverbrauchs zu minimieren, werden räumliche Konzentrationsstrategien vorgeschlagen. Sowohl das Wachstum wie auch die Konzentrationsstrategien führen zu einem verstärkten Fokus auf die Entwicklung der Knoten des öffentlichen Verkehrs, insbesondere der Bahnhöfe.

Die (Weiter-) Entwicklung von Bahnhöfen ist aufgrund von teuren und komplexen technischen Infrastrukturen sowie den zu berücksichtigenden Interessen verschiedener Stakeholder eine grosse Herausforderung. Um die dabei notwendige Integration des Wissens und Koordination der Handlungen der verschiedenen Akteure zu unterstützen, untersucht diese Arbeit, wie Bahnhöfe konzeptualisiert und in Bezug auf eine nachhaltige Entwicklung analysiert werden können. Entwickelt wird ein systemischer Ansatz, der explizit die Funktionen, Kontexte und Strukturen der Bahnhöfe behandelt. Drei wissenschaftliche Publikationen bilden den Hauptteil der Arbeit:


Kategorisierung bildet daher eine Grundlage zur Identifikation optimaler Systemstrukturen für einen bestimmten Kontext und unterstützt damit die strategische und integrale Entwicklung der Bahnhöfe.


Acknowledgements

No team, no thesis.

Learning takes place in feedback loops of action and reaction. Learning how to structure a problem—as was the case in this thesis—adds a second loop around the first. Additionally, the transdisciplinary nature of this project meant that requirements of both science and practice had to be integrated. The resulting tangle is commonly called an iterative process. This small word, “iterative”, by no means adequately describes the challenges I experienced in this learning process or the difficulties I had with it. I guess every PhD student wrestles with this problem—and certainly, these challenges are what make a PhD rewarding. For me, it was the team I was able to work with that made the difference. In the last five years I have had the incredible opportunity to meet, learn from and work with truly amazing people. Without them, this thesis would not have been possible.

I thank Roland Scholz for giving me the chance to research the fascinating topic of public transport nodes within the frame of regional sustainability transitions, for creating a most stimulating and challenging atmosphere in our research institute, and for having the grandeur to let me find my own way.

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Where in the world is one allowed to exchange ideas on a daily basis with physicists, mathematicians, engineers, environmental scientists, geographers, sociologists, and psychologists, on sustainability challenges ranging from energy, resources, and ecosystem services to regional transitions? I thank the whole NSSI team for providing a most stimulating and pleasurable working environment. It was great fun to work with you guys, and also to be immersed in coffee and politics during the breaks! Special thanks in that regard go to my roommates Andy Spörri, Fadri Gottschalk and Corinne Moser for lots of great feedback.
Some Remarks

This is a cumulative thesis composed of three peer-reviewed publications, an introduction and a conclusion section. The publications comprising the main body of the work were elaborated by a team of authors. Subsequently, the first person plural “we” is used as personal pronoun. In order to achieve a consistent style, I will therefore use the *pluralis auctoris* throughout the whole thesis—thus also in the introductory and concluding sections, which I authored by myself.

For the sake of consistency, we have adapted the numbering of the sections, figures and tables in the papers. Additionally, all references are concentrated in a single final section. Besides these changes, the contents of the three papers remain exactly as originally published—with the exception of the last paper—which is a preprint and will therefore be adapted during the upcoming peer review process. Please refer to the original publications when referencing these papers, and not to the post- or preprints published in this thesis.
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1 Introduction

Abstract

The urban concentration strategies proposed in order to mitigate the negative effects of the very high growth rates of the Swiss population and their expanding consumption patterns place a direct focus on nodes of public transport, especially railway stations. The redevelopment of railway stations, which are not only nodes of transport, but also important commercial and public urban areas, is a complex task requiring integration of knowledge and coordination of actions. Assessments are key in such complex redevelopment processes, as they guide decision-making on trade-offs. Assessments may therefore be both explicit, e.g., when deciding between alternatives, and implicit, forming problem identification and system description. Although there is a wide body of literature addressing the technical and planning questions of station redevelopment, only a few contributions address questions of station conceptualization that supports integration of knowledge and coordination of actions. Within a transdisciplinary process this thesis aspires to develop a conceptual model from which assessments can be derived, thus combining both integration of knowledge and decision-making (i.e. coordination of actions). Three peer-reviewed publications, forming the main contributions of this cumulative thesis, present the correspondingly developed systemic approach and its application to railway stations.
1.1 Background of the Thesis

The Swiss population more than doubled in the 20th century, growing from 3.3 million in 1900 to 7.2 million in the year 2000 (BfS, 2010c). Consumption patterns have also changed considerably. Average floor space per capita increased from 34 m² in 1980 to 44 m² in the year 2000 (BfS, 2010a). The daily distance travelled per capita has increased from 29 km in 1984 to 38 km in the year 2005 (BfS, 2010b). Due to the changes of the consumption patterns the transport and land-use systems thus require—compared to population growth—over proportional adaptations (Figure 1–1).

Population growth and costly consumption patterns have long been identified as having negative environmental effects. Considerable efforts were subsequently mobilized in order to reduce emissions and improve efficiencies. But recent high growth rates, paired with prospects of continued growth, expose new pressures for our transport and land-use systems (cf. ARE, 2006; BfS, 2010c). The Spatial Development Report of the Federal Office for Spatial Development 2005 described Swiss spatial development as unsustainable, requiring considerable efforts for a general change of direction (ARE, 2005). Swiss Federal Railways (SBB) explicitly questions whether their infrastructures and financial capacities can sustain the projected demand increases. In their annual report they conclude that “it is becoming
more and more clear that the state and its citizens cannot finance a limitless mobility” and ask “how much mobility is desirable?” (own translation, SBB, 2010, pp. 45-46). The sustainable development of our transport and land-use systems, which in the past has been successfully administered to fulfil our needs and requirements, is now a formidable challenge. The limited capacities of our societies to maintain the anthropogenic metabolism, as well as the limited capacities of our finite planet earth, have become real life issues (Scholz, 2011).

The challenge of the sustainable development of our transport and land-use systems is complicated by the fact that they are interdependent; they co-produce one another (Wegener & Fürst, 1999). They are additionally socio-technical systems: the requirements of both the intertwined technical systems (e.g., vehicle technologies, infrastructure networks, buildings and operations) and the social systems (i.e. reconciling decision-making, preferences and values at individual, organizational and societal levels) must be matched (Flüeler, 2006; Trist, 1981). Sectoral improvements alone, e.g., increasing transport capacities, will thus hardly suffice. Insights from sustainability science suggest that integration of knowledge and coordination of actions are generally necessary for transitions towards sustainable development (Clark & Dickson, 2003; McMichael, Butler & Folke, 2003). This is also the direction in which current transport and land-use development regulations are being adapted (cf. ARE, 2011). But integrating knowledge and coordinating actions is more easily said than done.

Concentration and densification strategies are heavily advocated as the new overarching development ideals. They should reduce further settlement expansions, favour walking and cycling over motorized transport, facilitate public transport, and generally shorten trips (Ackermann, 2007; Banister, 2008; Curtis, Renne & Bertolini, 2009; Haywood, 2005; Jenks, 2005). Nodes of public transport, especially railway stations, therefore become the textbook example of sustainable transport and land-use development challenges at the local level (Stauffacher, Scholz & Lezzi, 2005). Not only do railway stations constitute the interface of these two systems, they are also directly targeted by concentration strategies and require substantial adaptations to changing mobility patterns.

This thesis explores the issue of railway station redevelopment with regard to the challenge of sustainable development. We explicitly ask and focus on how stations can be conceptualized and assessed in order to support integration of knowledge and coordination of actions for sustainable development. We thereby take advantage of the fact that railway stations are a special form of socio-technical system: They occur in astonishing numbers, literally in the hundreds (VOEV, 2010). It is therefore possible to compare, conceptualize and standardize.
1.2 Redeveloping Railway Stations

For a better understanding of the case railway station, we take a look at the different perspectives from which stations can be described, which development challenges they currently face, and how stations are addressed in the scientific literature.

1.2.1 More than Transport Nodes

By means of private transport, e.g., by car, it is possible to travel more or less anytime from anywhere to anywhere. On the contrary, public transport is only available at specific times from a specific node to another specific node. Public transport is thus not only limited to certain lines and their schedules, but also, and maybe more characteristically, requires and defines nodes for boarding and disembarking vehicles. There are over 25 000 nodes of public transport in Switzerland, over 1700 of which are railway stations (VOEV, 2010).

Transport nodes that serve the boarding and disembarking of railways are called railway stations (from here on: stations). “Station” originates from the Latin stare, “to stand”, which was used to refer to “position”, especially the “position in life, status”. Today, “station” refers to “a place or a building where a specific activity or service is based” (Oxford Dictionaries, 2011). Examples are bus station, radar station, workstation, or research station. As such, the term railway station refers to both the (stopping) place and the (rail) transport services. Stations constitute the interfaces of both urban land-use systems and public transport systems. To understand stations requires an understanding of both of these systems.

1.2.1.1 Railway Stations Interconnect Different Modes of Transport

To take a stage of a journey by train requires a passenger to use at least two stations: one to board the train and one to leave the train. Over 1.2 million such stages are travelled in Switzerland every day (ARE & BfS, 2001). A return trip means using two stations, twice; transferring between trains along the way further increases the number of stations a passenger uses. As stations often connect multiple modes of public and private transport, even a passenger transferring from bicycle to bus may do so at a train station.

The distribution of passengers between stations is not random, i.e., it does not follow a Gaussian distribution, but rather follows a power law (cf. Li & Cai, 2007): There are a few (main-) stations with very high passenger frequencies and many stations with much lower passenger frequencies (Figure 1–2).
1.2.1.2 Railway Stations are Commercial Areas

The particularly high passenger concentrations at nodes of public transport create situations that are highly attractive for commercial purposes. This commercial potential is further supported by Swiss Labour Law, which allows longer opening hours for businesses in the evening and on Sundays at centres of public transport (ArG, 2007). SBB Real Estate, the real estate division of the largest Swiss railway company, which operates nearly half of all Swiss stations, is cultivating this potential with the brands RailCity for the largest stations, and Mehr Bahnhof for large stations. The nine RailCity stations (Basel, Bern, Geneva, Lausanne, Lucerne, St. Gallen, Winterthur, Zug, Zürich) achieve a total revenue of CHF 1.09 billion from commercial uses; the 32 Mehr Bahnhof stations generate a total revenue of CHF 0.37 billion (SBB, 2010). With a sales area of 16 700 m², and a total revenue of CHF 424 million, the ShopVille-RailCity shopping centre at the Zürich Main Station is the fourth-largest shopping centre in Switzerland (SBB, 2010). But not only the stations with the largest passenger frequencies are attractive to retailers; smaller stations may also bare commercial potential. The retail firms Valora AG and Migros demonstrate this with their respective brands, Avec and Migrolino, which are both applied to railway stations, as well as to petrol stations. Of course, this only describes the station premises, without counting the many commercial activities in the direct vicinity of the stations.

The commercial uses of the station premises—which may also include storage, offices, housing, advertising and promotions—can attract a significant number of additional
1.2.3 Railway Stations are Located in Cities

Most railways in Switzerland were built during the second half of the 19th Century (Treichler et al., 1996). Many cities were eager to be a part of this technical and social revolution in order to affirm their modern image and creative power (Wucherpfennig, 2006). To minimize costs, simplify planning, and reduce fire hazards, the railway lines were constructed over undeveloped land where possible, and the stations were often located at the cities’ periphery. As the Swiss population doubled during the 20th Century (BfS, 2010c), the corresponding over-proportional growth of the cities was often oriented towards and around their stations. Industrial parks were often situated on the rear side of a station. Many once-periphery stations are thus now centrally located. This means that within many city centres there now lies a structure with a length of often over 300 meters: a railway station with its platforms. The platforms, together with their afferent railway tracks, produce a distinctive spatial border. While fostering accessibility on a regional level, railway stations may therefore do the exact opposite on a local level, by constituting a barrier between proximate neighbourhoods.

1.2.4 Railway Station Redevelopment Concerns Multiple Stakeholders

This short introduction illustrates that many actors influence and have potential stakes in the redevelopment of a station. These include, among others, transport planners, rail and bus providers, real estate managers, small business owners, city and town planners, travellers, shopping customers and residents. They all introduce, actively or passively, their knowledge, demands, and values into station redevelopment. Supporting integrated decision-making and coordinating actions is thus a key requirement for station redevelopment that was already identified over 20 years ago (SBB & BRP, 1991).

1.2.2 Diverse Redevelopment Challenges

Large infrastructure networks develop in long waves (Grübler & Nakicenovic, 1991). The main development period of Swiss rail lines was during the second half of the 19th Century and the first decades of the 20th Century (Treichler et al., 1996). The number of stations in Switzerland has subsequently remained fairly constant. Building new stations is the exception. Even so, stations require much more attention than just routine maintenance. Just as with any other building, stations are constantly being adapted to the new requirements of users, technologies, laws, etc. (Brand, 1994). We therefore speak of redevelopment, rather than new development, to accomplish these adaptions.

An extreme example is the main station of Berne. It lies in a bend, squeezed between the historic centre of Berne—which itself lies on a peninsula of the river Aare—and a hill, the Grosse Schanze. Since its opening in 1860, the main station of Berne has been rebuilt...
multiple times, and a further major redevelopment step is in discussion (Huber, 2010). The main station of Berne exemplifies that the redevelopment of stations is about mastering a combination of interlinked challenges. Certain adaptations may be strongly related to local specificities such as, e.g., the geomorphology of Berne. But certain development challenges are more general. Those currently discussed in Switzerland are closely related to the overarching challenges of growth and limited (financial, spatial, and planning) resources:

Increasing frequencies: Future population increases (further growth until the middle of the century, BfS, 2010c), combined with increasing travel demand and changing travel patterns, are projected to result in increased passenger frequencies (ARE, 2006). Rising energy prices for private motorized transport, and a political preference for public transport, will lead to over-proportional growth in public transport systems, especially in the agglomerations. This comes on top of recent growth (cf. ZVV, 2008), and current developments partly surpass the projected trends (SBB, 2010). The required increases of station capacities (number and length of platforms, number or capacity of underpasses) are very expensive.

Increasingly, land-use densities and development focus on public transport nodes: Future population increases will lead to a densification of urban centres, possibly amplified by stricter implementation of spatial development laws (cf. ARE, 2011). After spatial development became heavily aligned with private transport during the second half of the 20th century (i.e., it accommodated the rise of the automobile), a new focus towards nodes of public transport evolved. The Canton of St. Gallen systematically assessed development potentials around stations (St. Gallen, 1996). The Canton of Berne locates strategic development areas at stations in order to foster integrated transport and land-use planning. The resulting density increases will generally increase the number of stakeholders involved in station redevelopment and reduce the number of development options or increase their costs, respectively.

Changing funding regimes: Swiss national and cantonal funding of public transport have a long development history, resulting in complex funding regimes. As it has not been possible to adapt these to the rapid demand increases (cf. SBB, 2010), a simpler funding regime is being developed (BAV, 2011). This will include higher costs for the users and a stronger focus on areas of priority. As a side note, there are strategic goals that the federal government defines for the SBB, e.g., demanding considerable contributions from the SBB Real Estate Division for the underfinanced pension fund of the SBB (GS-UVEK, 2010). A solution for the pension fund may relax the strain on the SBB Real Estate Division, possibly increasing development options at stations. Funding is very directly related to setting goals and responsibilities. Changes to the funding regime will most likely be reflected in new decision-making procedures.
1.2.3 Conceptualizing Stations

The diverse challenges of station redevelopment and the multiple perspectives from which these can be described have led to a large body of scientific literature. Most contributions have either a strong social (i.e., planning) or technical focus. An overview of the planning-related literature on stations is practically impossible. This may not only indicate the importance of stations, but also that a single solution is not possible—presumably because the complex processes have to be adapted to local regulations and policies. The technical literature describes a fundamental knowledge base without which station redevelopment is not possible, often illustrating the necessity for coordination and integrated decision-making. In the following, therefore, we concentrate on the relatively small body of literature where these two areas meet: the conceptualization of stations.

The main body of literature on station conceptualization is based on the transport land-use interaction feedback cycle, which illustrates the interrelation of the accessibility of a location and the location of activities (cf. Wegener & Fürst, 1999) (Figure 1–3): The more accessible a location, the higher the development pressure it experiences. The resulting land-use patterns influence activity patterns, and thus transport demand. Transport systems will be adapted according to transport demand, again influencing accessibility. The cycle thus illustrates why transport and land-use development must be coordinated. Elements of the transport land-use interaction feedback cycle may invoke the better-known question of how urban form influences transport behaviour (cf. Ewing & Cervero, 2001; Newman & Kenworthy, 1991). For this case, the effects of station quality on transport behaviour are discussed under the terms transfer cost (cf. Brons & Rietveld, 2009; Guo & Wilson, 2004; Guo & Wilson, 2011) and barrier-free design (cf. Hayashi, 2002; Woyciechowicz & Shliselberg, 2005). Integrative station redevelopment literature focuses more strongly on the influence of stations on urban development. Next to pure accessibility effects, it relies also on the fact that public transport services are concentrated at nodes, bundling the paths of many passengers, creating business opportunities, and developing a city or town centre (cf. Bowes & Ihlanfeldt, 2001; Debrezion, Pels & Rietveld, 2007b). This is also the field where conceptual models of stations have been developed.

Certainly the best known conceptual model of stations is the node-place model of Luca Bertolini (Bertolini, 1996, 1999; Peek, Bertolini & De Jonge, 2006). The node-place model compares urban development densities around stations with the (rail) transport services at the stations. This leads to the identification of stations with relatively underdeveloped urban densities. The model can be scaled according to the influence of the station and its transport services. The faster and further the provided transport connections, the larger the effect on accessibility, and thus on land use. While a local bus station will hardly influence its whole neighbourhood, a large national station with high-speed train services may well be compared to an airport. This may also explain the focus on large (international) stations with high-
speed services, which are said to be an important factor in the (economic) competition between regions (Bertolini & Spit, 1998).

![Figure 1–3. The transport land-use interaction feedback cycle (Wegener & Fürst, 1999).](image)

Less known, but also based on the transport land-use interaction feedback cycle, is the semiquantitative system dynamic model of stations and their contexts, developed by Gebhard Wulfforst (Wulfforst, 2003). Along with the land-use of station surroundings and the transport services at the station, Wulfforst includes variables describing the use of the station in his model. Issues such as safety, amenities, image, and the structural organization of the station can thus moderate the interactions of accessibility and land use.

Rudolf Juchelka introduced a pyramid of station functions (Juchelka, 2002). Stations are said to fulfil three functions in a hierarchical manner: an essential primary function of interconnecting multiple transport modes; secondary functions, such as providing commercial, leisure and cultural areas for medium-sized stations; and tertiary functions, such as providing an important city centre or centre of commerce for large stations. These functions describe both the station itself and its effects on the surrounding urban area. This concept can be found applied in practice, e.g., in order to structure current redevelopment efforts around the Badisch Bahnhof in Basel.

### 1.3 Research Framework

#### 1.3.1 Research Question

The challenge of station redevelopment, especially when framed within questions of sustainable development, is a challenge of integration of knowledge and coordination of actions. Integration of knowledge and coordination of actions can be supported by means of conceptual models illustrating systemic interrelations. Following the basic *modus operandi* of
Science, conceptual models decompose complex situations into simple elements and allow the discussion of their interrelations (Scholz, Spoerri & Lang, 2009). With regard to these challenges, the conceptual models available in the scientific literature describing stations are incomplete. Although readily applied and highly informative, the macro-view of the node-place model does not describe the actual station itself, but rather its two relevant contexts: transport services and land use. The system-dynamic implementation of Wulfhorst adds considerable complexity—possibly at the cost of practicality—but still lacks a more detailed description of station operation and redevelopment. Both models lack a direct link to the stakeholders who are actually developing the system. Finally, the station functions described by Juchelka include considerable ambiguity concerning their exact differentiation.

Infrastructure developments require decisions on trade-offs (Störmer et al., 2009). Making assessments and judging trade-offs are key steps in decision-making. They are explicitly addressed when an alternative must be chosen. Intuitive assessments further influence the early phases of problem identification and system description in the decision-making process (Scholz & Tietje, 2002). It may therefore be informative to link conceptual models of stations to questions of assessment. This would prominently link knowledge integration and decision-making (i.e., action). In light of the current development challenges focusing on stations, it is imperative that the integrative assessments be related to the question of sustainable development. We do not know of any literature that provides an integrative conceptual model of stations and links it to questions of sustainable development. This thesis, therefore, explores how stations can be conceptualized and assessed with regard to the challenge of sustainable development, in order to foster integration of knowledge and coordination of actions supporting sustainable development.

1.3.2 Research Approach

According to the challenges described above, we built our research approach on three pillars: the conceptualization of stations as built environments, systemic assessment, and decision-making for sustainable development. Besides the rational arguments introduced in the following, the choice of this approach is also biased by the author’s formal education in environmental sciences, and the institutional setting of the project in the Institute of Natural and Social Sciences, ETH Zurich, researching Human-Environment Systems (Scholz, 2011).

We conceptualize stations as built environments: Stations are not a given fact, but form part of the built environment intentionally developed by humankind in order to fulfil certain needs. Infrastructures are therefore also called auxiliary systems (cf. Lang et al., 2002) and, as such, are part of a Human-Environment System (Scholz, 2011). As the transport land-use interaction feedback cycle illustrates, the built environment, and changes to it, directly feeds back to human action (Spielmann, de Haan & Scholz, 2008).
We elaborate a systemic description: To motivate stakeholders to coordinate their actions and integrate their knowledge in decision-making processes requires that the stakeholders understand their interrelations. This calls for systemic descriptions, i.e., an elaboration of the system elements and their interrelations.

We investigate decision-making with regard to sustainable development: The constant adaptation of the built environment to changing requirements is achieved through complex decision-making processes. Sustainable development is generally accepted as the overarching normative development goal, in consideration of which, decisions regarding Human-Environment Systems should be made. We define sustainable development according to Laws et al. (2004) as encompassing three key concerns: the maintenance of a system within functional limits; an ethical relationship with the past and the future; and as a form of ongoing enquiry.

Combining these three pillars, the challenge of station redevelopment is thus a question of sustaining performance and quality within a specific context and with regard to the requirements imposed upon them. Lang et al. present the Sustainability Potential Analysis (SPA) method to support such a comprehensive and systemic assessment with regard to sustainable development (Lang, Binder, et al., 2007; Lang, Scholz, et al., 2007).

### 1.3.3 Transdisciplinary Project Organization

Station redevelopment can be described as a typical sustainability challenge, as it combines multiple complexities: the crossing of disciplinary boundaries and scales; a multitude of stakeholders with different world-views and values; different organizational and governmental levels; multiple, and potentially delayed, feedback loops, and thus high levels of uncertainty (cf. Kates et al., 2001). Such challenges are described as wicked (Rittel & Webber, 1973), messy (Ackoff, 1979), or ill-defined (Scholz & Tietje, 2002). To address such complex challenges requires the integration of knowledge from different scientific disciplines, knowledge from different areas of practice as well as knowledge from different stakeholders (Gibbons et al., 1994; Harris, 2002; Ravetz, 2000). Transdisciplinarity, a type of collaboration between science and society that supports mutual learning processes and integrates different knowledge types, is proposed as an adequate form of science for such challenges (Hirsch Hadorn et al., 2008; Scholz, 2000, 2011; Scholz, Mieg & Oswald, 2000). The knowledge of the relevant stakeholders is integrated in order to improve both decision-making capacities (with regard to problem identification, system description, and the development and assessment of alternatives), and the acceptance and implementation of decisions (due to their broad support) (Scholz, 2000; Walter et al., 2007).

For these reasons, the challenge of station conceptualisation and assessment with regard to sustainable development as presented in this thesis was addressed in a transdisciplinary project called Sustainable Positioning of Railway Stations (SPRS). Before the thesis presented
here commenced, the SPRS project had already run for a year and resulted in the elaboration of an adapted node-place model for all Swiss stations (Reusser et al., 2008). With the start of this thesis, the following project organization was adapted. The SPRS project was co-led by a scientist (Prof. Dr. R. W. Scholz; Natural and Social Science Interface, ETH Zurich) and a practitioner (Johannes Schaub; Bahnzugang, SBB Infrastruktur). A working group comprised of three scientists (a sociologist, an environmental scientist, and the author, also an environmental scientist) and two practitioners (both formally trained as geographers) carried out the main research. A stakeholder board with representatives of all stakeholder groups was developed during the project in order to adequately include the multiple perspectives of station redevelopment and obtain critical reflection on the intermediate results. Collaboration with the stakeholder board was adjusted according to the state of the research; thus, it included both full meetings as well as two-person discussions (cf. Stauffacher et al., 2008).

1.4 Contributions of the Thesis

This thesis addresses the question of conceptualising and assessing railway stations with regard to sustainable development. Three papers elaborate a systemic conceptualization of stations in order to assess them with regard to the concept of sustainable development. The functions, contexts and structures of stations are each addressed (Figure 1–4). The first two papers provide a structure for understanding stations. As such, they also set the stage for the assessment of railway stations as presented in the third paper.

1.4.1 Paper 1: “Generic Functions of Railway Stations—A Conceptual Basis for the Development of Common System Understanding and Assessment Criteria”.

The first paper presents five generic functions of stations and highlights the key complexity of station redevelopment: their multifunctionality. The term “function” refers to an end attributed to a system and the intended processes of a system, which serve specific outcomes (Checkland, 2001). We define functions as the goals and requirements imposed on a system by its stakeholders (adapted from Lang, Scholz, et al., 2007). Identifying the functions of a system is linked to identifying the stakeholders of the system. The functions of stations were therefore derived from extensive qualitative research: four focus groups (n = 38), 28 expert interviews, and two expert workshops.

The five generic functions identified are: linking a catchment area with a transport network, supporting transfers between modes of transport, facilitating commercial use of real estate, providing public space, and contributing to the identity of the surrounding area.
potential conflicts among these functions are identified. They concern the competition among multiple functions for space, for customer attention, or for revenues, as well as increasing system complexities with station size.

Explicitly identifying the functions of stations contributes to structuring problems and may thus foster a common understanding of the system among stakeholders. The concept of a function is solution-neutral (Pahl et al., 2007, p. 170); identifying a function says nothing about how the function is or should be fulfilled. This issue is addressed in the latter two papers. As such, the functions not only interrelate the many stakeholders of station redevelopment, but also provide an essential basis for the systematic derivation of assessment criteria.

1.4.2 Paper 2: “Classifying Railway Stations for Strategic Transport and Land-use Planning: Context Matters!”

There are over 1700 stations in Switzerland alone, and many more in other countries. It is therefore possible to learn through the comparison of cases: A challenge experienced at one station has most probably also been experienced—and addressed—at another station. Successful concepts may be applied to many other stations by means of standardizations,
guidelines, or corporate strategies. For this it is necessary to understand and identify which stations are comparable.

Building upon the multifunctionality of stations described in the first paper, the second paper asks which stations are actually comparable in an assessment. The most common approach to station classification, also applied in Switzerland, relies on passenger frequencies: Stations are classified according to the number of passengers frequenting the station. This classification directly influences, for example, the distribution of subsidies for station redevelopment. In this second paper we propose an alternative classification approach. We argue that stations have to fulfil their functions under very different contextual conditions, and that the quality of a station is a result of how its structures are adapted to these specific conditions. When a solution is carried over from one station to another, it concerns the structures of the station and their adaptation to its context. The key is therefore to identify stations with comparable contextual conditions, so that experiences of their structural adaptations can be exchanged. The one-dimensional indicator “passenger frequencies” is insufficient to represent contextual diversity.

We illustrate this approach by applying a cluster analysis to the key contextual factors influencing the functioning of stations. Seven contextual classes are identified. They differ not only according to the density of the context, but also according to the use of the station, which ranges from situations characterized by the regular transit use of experienced users to situations characterized by the recreational traffic of less experienced users. This novel classification approach provides a unique basis for discussing questions of optimal system structures for specific contexts, thus supporting strategic and integrated station development.

1.4.3 Paper 3: “Multi-perspective Assessment of Railway Stations with Regard to Sustainable Development: Focussing on Functional Potentials”.

Building upon the first two papers, this third contribution presents an approach to assessing railway stations with regard to sustainable development. In the first two papers, stations are conceptualized as systems that have to fulfil specific functions within a certain context. An assessment must therefore focus on the structures of a station and address their potential for fulfilling the demanded functions within this specific context. To derive assessment criteria we therefore rely on the Sustainability Potential Analysis, a systemic method, which introduces six criteria (performance and efficiency, well-structuredness, interdependencies, buffer capacity, adaptive capacity, inter- and intra-generative equity) for assessing the functional potentials of system structures with regard to their context. Both a qualitative and a quantitative implementation are presented:

1. The qualitative assessment protocol provides a complete assessment of a single station for each function with regard to all perceptors of the SPA.
2. The quantitative portfolio screening provides a rough overview of a portfolio of stations functioning in comparable contexts by means of a few key indicators of the assessment protocol.

The two assessment steps differ in their level of detail. The protocol provides a highly detailed guide for the structured assessment of a station. Here it is possible to include many qualitative indicators, such whether or not there is a “line of sight” supporting intuitive orientation. The protocol may either be applied to establish an overview of the quality of a station (e.g., at the beginning of a redevelopment process) or as a guide supporting the structured description of a station. For the screening, only a few key quantitative indicators of the protocol are applied in order to gain an overview of a large set of stations. Those stations with the highest and lowest potentials to contribute to the sustainable development of society are identified. Additionally, the screening can indicate whether station perception may vary significantly from one stakeholder group to another (in such a case one group may demand redevelopment, while the other may be content with the station and thus be reluctant to contribute to redevelopment processes). Together the two approaches support integration of knowledge and coordination of actions by providing a body of knowledge for station redevelopment, supporting the derivation of standards, and enabling the monitoring of developments.
Generic Functions of Railway Stations—A Conceptual Basis for the Development of Common System Understanding and Assessment Criteria


Abstract

The redevelopment of railway stations calls for the integration of many different objectives. Two crucial challenges thereby are the development of a common system understanding among the multiple stakeholders with potentially conflicting interests and the structured definition of comprehensive assessment criteria. Defining the functions of the system railway station, i.e. discussing what the system should do, can support solving these challenges. Based on a review of Swiss railway stations in a transdisciplinary research project applying four focus groups (n = 38), 28 expert interviews and two expert workshops, we present a structured framework of five generic functions of railway stations and their interdependencies. The five generic functions are: linking catchment area and transport network, supporting transfer between modes of transport, facilitating commercial use of real estate, providing public space, and contributing to the identity of the surrounding area. Potential conflicts between functions are identified. They concern the competition of multiple functions for space, for customer attention or for revenues as well as increasing system complexities with station size. We illustrate how the framework of functions can be used to foster a common system understanding and to develop assessment criteria. Although elaborated from a Swiss perspective the framework is perceived adaptable to railway stations of other countries.
2.1 Introduction

2.1.1 Multiple Stakeholders Focusing on Railway Station Redevelopment

Transport and land use influence one another considerably. With respect to sustainable development it is commonly agreed that a built environment resulting in fewer and shorter trips and more efficient modes of transport is to be favoured (cf. Banister, 2008). To maintain accessibility, many planning principles and strategies specifically supporting public transport, bicycling and walking have been developed, often emphasizing integrated transport and land use planning. Examples are transit-oriented development (Curtis, Renne & Bertolini, 2009; Jenks, 2005) and various concentration strategies (Holden, 2004; Meijers, 2005; Ritsema van Eck, Burghouwt & Dijst, 2005). A common factor among these principles and strategies is that they encourage concentrated development along public transport infrastructures or around nodes of public transport. Although concentrated development is not uncontested (Gordon & Richardson, 1997), nodes of public transport, especially railway stations, thereby become a centre of focus in planning (cf. Cascetta & Pagliara, 2008; Connolly & Payne, 2004; Hartz & Liechti, 1992; Haywood, 2005; Hine & Scott, 2000; Pels & Rietveld, 2007). The redevelopment of railway stations (ranging from orderly reinvestment to completely new construction within major brownfield developments or urban regeneration projects) therefore not only poses technical challenges (e.g. complex infrastructures, redevelopment under running conditions), but also significant social challenges. A multitude of stakeholders with divergent perspectives and interests are concerned (cf. Bertolini & Spit, 1998; Pretsch et al., 2007; Wucherpfennig, 2006).

Switzerland illustrates such redevelopment complexities for conditions with growing demand and often limited space. Passenger numbers on the Zürich S-Bahn System (suburban metro railway), for example, have doubled within the last 15 years (ZVV, 2009). Governmental agencies predict a growth of rail passenger transport numbers by 45% between 2000 and 2030 (ARE, 2006), and the Swiss Federal Railways (SBB) question whether their railway stations are adaptable to such growth rates (SBB, 2010). The surrounding urban areas are often of similar density. With an average population density of over 750 per km² the metropolitan areas of Switzerland encompass 55% of the Swiss population in 13% of its area (ARE, 2004a). Such context densities can put additional stress on the redevelopment process. A common example is the allocation of space in highly frequented stations. Real estate managers prefer to use some of this space for installing retail or advertisements, while transport managers prefer to keep areas free for optimized passenger circulation and orientation. The diverging requirements bear considerable conflict potential – and they must be addressed within each and every redevelopment case. In Switzerland there are over 1600
railway stations (Reusser et al., 2008). Tools supporting decision making, especially on trade-offs between diverging requirements of stakeholders, are thus highly valuable.

2.1.2 Conceptual Models Supporting Redevelopment Processes

Conceptual models can support decision making in complex redevelopment processes by helping to develop a common system understanding. This improves the interactions between the involved stakeholders in all redevelopment steps: e.g. problem identification, system analysis, development and assessment of options (Scholz & Tietje, 2002). A common system understanding is subsequently often described as key to a successful integrated planning process (Curtis, 2008b; Hatzopoulou & Miller, 2008; Stauffacher et al., 2008). Conceptual models are commonly applied for system analysis in redevelopment processes – either in very early phases of (intuitive) problem identification and structuring or later phases when specific redevelopment options are assessed and compared (c.f. Kölbl, Niegl & Knoflacher, 2008; Loorbach & Rotmans, 2006; te Brömmelstroet & Bertolini, 2008; Wiek & Walter, 2009). Accordingly, several conceptual models have been developed to support redevelopment processes at railway stations. Three are exemplarily summarized here:

- Bertolini’s node-place model describes railway stations from two perspectives: as nodes in the transport network, and as places in the urban system (Bertolini, 1996, 1999). Representing node and place values of stations in a two dimensional diagram depicts the relationship of transport (network connectivity) and land use (intensity and diversity of uses in the catchment area) of each station. Imbalances become visible. Bertolini assumes a trend towards balanced node and place functions. The model can thus be interpreted to identify potential future developments of the stations. The node-place model has been applied in a number of projects (cf. Peek, Bertolini & De Jonge, 2006). Reusser et al. (2008) applied an adaptation of the model for a comparison of over 1600 Swiss railway stations.

- Juchelka (2002) describes three functions of railway stations from the perspective of urban development potentials: All railway stations are described as having an essential primary function of interconnecting multiple transport modes. On this basis, additional synergistic functions are seen as possible depending on the size of the station: secondary functions, such as commercial, leisure and cultural areas for medium-sized stations, and tertiary functions, such as an important city center or center of commerce for large stations. Within a railway station redevelopment project these functions can be seen as drivers for the development of the surrounding urban area. The stakeholders to be consulted in a redevelopment process must therefore be selected according to the function in focus.

- Wulfhorst (2003) applies methods of system dynamic modeling to the case of railway stations. Using 24 variables, the interactions between land use in station...
surroundings, use of station buildings, transport interconnection quality, and rail transport demand are described. Once the model is calibrated to a specific case, potential redevelopment scenarios can be implemented. Subsequently, an estimation of impacts and development of key measurement indices (such as land use development in station surroundings, valorization of station buildings, and improvements in interconnection quality) is possible for each redevelopment scenario.

These models have successfully contributed to complex redevelopment processes at railway stations by describing the system railway station, its interrelations, historic developments, dynamics, and potential redevelopment options, (Juchelka, 2002; Peek, Bertolini & De Jonge, 2006; Pretsch et al., 2007). What the presented models consider less is the identification and description of trade-offs in redevelopment processes. Herefore an understanding of the (diverging) requirements of the stakeholders is necessary. These may be identified by explicitly addressing what a railway station is and to what ends it serves, i.e. an explicit definition on the normative reference upon which the redevelopment process is based.

From a systemic view, this means that the functions of the railway station must be defined. In using the word function we refer to an end attributed to a system. Functions describe the intended processes of a system which serve specific outcomes (Checkland, 2001). In conceptual design, a function is a “solution-neutral relationship between inputs and outputs” of a system (Pahl et al., 2007, p. 170). A clear differentiation must be made between a function of a system and the structures implemented to fulfill the function. Put in simple words, a function describes “What a system should do”, while structure refers to the system elements, their spatial and temporal relationships and partitioning (Scholz & Tietje, 2002). Examples for structures are length and number of platforms or opening hours of ticket booths. We define functions as the goals and requirements imposed on a system by its stakeholders (adapted from Lang, Scholz, et al., 2007). As suggested by the node place model (Bertolini, 1996, 1999), railway stations serve both transport and land use functions. Juchelka (2002) explicitly names three functions, such as “interconnecting multiple transport modes”. Wulfhorst (2003) shows that such functions can not be dealt with in an isolated manner, but are highly interrelated.

Identifying the functions of a system is intrinsically linked to the identification of the stakeholders of the system, as a reference to their goals and requirements is made. With the term stakeholders, we mean not only organized groups and their relation to organizations (as in the classic definition of Freeman, 1984, p. 46), but more broadly “any group of people, organized or unorganized, who share a common interest or stake in a particular issue or system” (Grimble & Wellard, 1997, p. 175). Subsequently, both experts (e.g. regulators, operators, planners, scientists; often described as professionals) and users (e.g. customers, local residents; often described as laypeople) are considered stakeholders. As a system such as a railway station has multiple stakeholders, which have different goals and requirements, it is
again to be expected that multiple functions exist simultaneously and might conflict with each other.

The reference system and the normative assumptions inherent in conceptual models strongly influence the outcomes of the corresponding system analysis (Lélé & Norgaard, 1996). Defining the functions of railway stations can therefore not only support the development of a common system understanding, but also serve as a basis for the structured derivation of assessment criteria. Such criteria could be used for the analysis and comparison of real sites or potential redevelopment options by indicating how well a (given or planned) railway station fulfills its functions. Applied to a large portfolio of railway stations, such assessments would help to identify critical situations and focus limited redevelopment resources.

2.1.3 Research Questions

Defining the functions of a system is an explicitly normative step, which needs to be broadly based: the goals and requirements of a diversity of stakeholders need to be elicited and translated into functions. Although not each railway station can be expected to fulfill exactly the same functions, a set of generic functions – potentially fulfilled by many railway stations – should be identifiable. The three models described above provide valuable contributions to the identification of functions of railway stations. Nonetheless, we think the functions described still do not provide a sufficient framework for the elaboration of a common system understanding or the definition of comprehensive assessment criteria to guide the redevelopment of railway stations. More specifically, the basis on which the functions were derived (which stakeholders contributed to their definition), whether additional functions are possible and how they relate to each other is still at least partly unclear. This is not surprising, as the models were developed for other purposes. In this paper we therefore develop a structured set of generic functions of railway stations in order to form a basis for both the development of a common system understanding and the elaboration of criteria for the comprehensive assessment of the quality of railway stations. Two research questions guide this process:

1. What are generic functions of passenger railway stations from a multi-stakeholder perspective?

2. How are these functions interrelated?

We take the Swiss railway stations as an example and starting point and make two restrictions when speaking of railway stations. Firstly, the study focuses on passenger railway stations and omits freight transport. Secondly, technical operations are not considered (e.g. guiding or servicing trains, providing operational safety, and facility management of the station premises) as their organization may be largely separated from the premises of railway stations.
2.2 Methods and Procedure

The identification of generic functions of railway stations required the integration of all stakeholder perspectives. We therefore consulted both users (local residents and transport system users) and experts (operators, planners, regulators, etc.); users were consulted by means of focus groups, while experts were consulted using guided face-to-face interviews. In a synthesis and review process, initial results were discussed with experts in a workshop and refined to a final set of functions. Interactions of the functions were assessed in an impact matrix. To secure the practical applicability of the results to all 1600 railway stations of Switzerland, the project was co-organized together with experts of the Swiss Federal Railways (SBB). The project was organized in a transdisciplinary manner (cf. Scholz et al., 2006; Stauffacher et al., 2008). This means that it included a process of mutual exchange between university and stakeholders from outside academia, in particular the planners from SBB.

2.2.1 Focus Groups

As mentioned, to assess functions of railway stations from the perspective of users, focus groups were conducted (a qualitative explorative study method, cf. Bloor et al., 2001; Krueger, 1998). For a large and a small agglomeration in Switzerland (Zurich and Lucerne), residents were randomly selected from four predefined small to medium-sized municipalities with direct services to the inner city. For each city two groups were formed, consisting of nine or ten participants (Table 2–1). The first group consisted of low users, i.e. people who use the train less than once per month on average (but do have experience of using the train) and are therefore assumed to have low experiential knowledge. The second group consisted of heavy users, i.e. people who use the train at least four times per week either for commuting and/or for leisure activities and are therefore assumed to have high experiential knowledge.

The discussions lasted 2½ hours each and were led by two professional moderators of the Zurich LINK Institute. Access to the railway station from the place of residence/work (and vice-versa), signposting and orientation, importance of the railway station for the municipality, the surroundings of the railway station, as well as diverse emotional aspects were discussed. The topics were covered both for the smaller railway stations of the participants’ home communities, and also for the larger stations of Zurich and Lucerne (destinations of commuting or leisure activity for many of the participants). Discussions were videotaped and transcribed verbatim. Based on statements from the participants, an initial set of preliminary functions was compiled.

1 The municipalities were predefined to ensure variation in their size, as well as to be able to visit the sites and put the statements made in the focus groups into context.
Table 2–1. Participants in the focus groups.

<table>
<thead>
<tr>
<th>Participants \ Group</th>
<th>Zurich 1</th>
<th>Zurich 2</th>
<th>Lucerne 1</th>
<th>Lucerne 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Travel behavior</td>
<td>Low Users</td>
<td>Heavy Users</td>
<td>Low Users</td>
<td>Heavy Users</td>
</tr>
<tr>
<td>Sex (women; men)</td>
<td>5; 5</td>
<td>3; 7</td>
<td>3; 6</td>
<td>4; 5</td>
</tr>
<tr>
<td>Age (min.; av.; max.)</td>
<td>24; 51; 68</td>
<td>21; 36; 57</td>
<td>34; 49; 70</td>
<td>21; 38; 60</td>
</tr>
<tr>
<td>Origin</td>
<td>Effretikon; Affoltern a. A.; Männedorf; Oberglatt</td>
<td>Sarnen; Küsnacht a. R.; Wolhusen; Eschenbach</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2.2 Expert Interviews

To assess functions of railway stations from the perspective of experts, face-to-face expert interviews were conducted (Hesse-Biber & Leavy, 2005; Mieg & Näf, 2006). A total of 28 experts were interviewed (Table 2–2), with a mean interview duration of 90 minutes (min. 50, max. 150 minutes). The interviews were structured by using a guide, conducted by a single interviewer and recorded. The interviews consisted of three parts: (1) description of the expert’s area of business and expertise; (2) elicitation of goals and requirements concerning railway stations; (3) description of one of the functions mentioned in part two (nearest to the expert’s expertise) along the six systemic perceptors of the Sustainability Potential Analysis (performance and efficiency, well-structuredness, interdependencies with other systems, buffer capacity and resilience, ability to accommodate, inter- and intra-generative equity, cf. Lang, Scholz, et al., 2007) to gather insight into systemic properties and possible assessment criteria. The interviews were closed by eliciting the experts’ career and asking for suggestions for additional stakeholders (snowball process). Results of the interview were sent to the expert for review.

Each interviewed expert represented a stakeholder group related to one or more of the functions. The first interview partners were chosen according to the preliminary functions derived from the focus groups. Additional experts were included as new functions and stakeholder groups were identified in the interviews. The interviews were continued until no new functions or stakeholder groups were mentioned and at least one expert had been interviewed for each relevant stakeholder group (as listed in Table 2–2).

2.2.3 Synthesis and Review

We applied an iterative process of synthesis and review to elaborate a final set of generic functions potentially fulfilled by many railway stations. The results of the focus groups and expert interviews were adapted for consistency in level of detail and wording to converge to a structured set of a minimal number of clearly differentiated functions (cf. Scholz, Spoerri & Lang, 2009; Shaw et al., 2004). We found no major contradictions between different stakeholders; most presented converging or even overlapping views. Thus, we were able to
construct a hierarchy of functions and subfunctions. We use the term subfunction to describe goals and requirements at a more detailed level, which, together with others, fulfill one (more generic) function.

In a workshop, a first set of seven functions was presented to an extended group of 17 experts (primarily interview partners). With the help of their comments, an adapted final set of five functions was developed (two functions merged twice). The experts further weighted the functions to discuss different perspectives of stakeholders, and used the functions directly to describe and discuss specific railway stations and their redevelopment potentials. The functions were additionally applied in a later workshop with 14 experts that dealt with the categorization of railway stations. This time, the experts welcomed the framework as supporting the common understanding of the multi-faceted character of railway stations.

Table 2–2. Interviewed experts.

<table>
<thead>
<tr>
<th>Stakeholder group</th>
<th>Interviews</th>
<th>Institutions (sections: original names in German)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operators of transport services</td>
<td>5</td>
<td>SBB Passenger Traffic (Regionalverkehr; Fernverkehr); Regionalverkehr Bern-Solothurn RBS</td>
</tr>
<tr>
<td>Operators of rail infrastructures</td>
<td>7</td>
<td>SBB Infrastructure (Trassenmanagement; Qualität; Projekt Management; Programm Management; Zugang zur Bahn; Denkmalschutz)</td>
</tr>
<tr>
<td>Real estate managers</td>
<td>4</td>
<td>SBB Real Estate (Bewirtschaftung; Portfoliomanagement; Business Development; Marketing)</td>
</tr>
<tr>
<td>Business &amp; retail</td>
<td>1</td>
<td>Valora Retail</td>
</tr>
<tr>
<td>Federal administration</td>
<td>2</td>
<td>Federal Office of Transport FOT; Federal Office for Spatial Development ARE</td>
</tr>
<tr>
<td>Cantonal administration</td>
<td>1</td>
<td>Zürcher Verkehrsverband ZVV</td>
</tr>
<tr>
<td>Municipal administration</td>
<td>3</td>
<td>Risch Rotkreuz (Planning Department); Burgdorf (Planning Department); Eschenbach-Luzern (Mayor’s Office)</td>
</tr>
<tr>
<td>Associations</td>
<td>2</td>
<td>Swiss Association of Public Transport VÖV UTP; Pedestrian Mobility Switzerland</td>
</tr>
<tr>
<td>Consultants for urban planning</td>
<td>2</td>
<td>Archipel; INURA Zurich Institute</td>
</tr>
<tr>
<td>Science</td>
<td>1</td>
<td>ETH Zurich Network City and Landscape NSL</td>
</tr>
</tbody>
</table>

2.2.4 Assessment of Interactions

We analysed function interactions using an impact matrix (cf. Gausemeier, Fink & Schlake, 1996; Scholz & Tietje, 2002; Wiek, Lang & Siegrist, 2008). Based on the expert interviews (their descriptions of potential interactions of subfunctions) an initial impact matrix was compiled on the level of the subfunctions. Assuming satisfactorily provided subfunctions, the impact matrix designates whether more or less of one subfunction may have an impact on another subfunction. Three impact qualities were used: 1: positive impact; 0: no impact; -1: negative impact. When the impact quality was perceived to be dependent on the size or type
of the railway station, a range was indicated. Impacts to or from context were not included at this stage, as we are only interested in interactions between the functions themselves.

2.3 Results

2.3.1 Five Functions of Railway Stations

A set of five generic functions of railway stations was developed, with several subfunctions grouped under each function in a hierarchical manner (Table 2–3). The functions are structured according to subject (transport or land use) and spatial scale (macro to micro). In the following sections, the five functions Fₜₙ and their subfunctions Fₙᵢ are introduced together with sample assessment criteria, as mentioned by the experts (performance criteria are presented). Also, examples of positive interactions as mentioned by the experts are given for each function.

Table 2–3. Functions of railway stations and related subfunctions.

<table>
<thead>
<tr>
<th>Function</th>
<th>Subfunction</th>
<th>Subject</th>
<th>Spatial Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>F₁ Link catchment area and transport network</td>
<td>F₁,₁ Localize public transport demand</td>
<td>Transport</td>
<td>Macro</td>
</tr>
<tr>
<td></td>
<td>F₁,₂ Provide public transport supply</td>
<td>Transport</td>
<td>Micro</td>
</tr>
<tr>
<td>F₂ Support transfer between modes of transport</td>
<td>F₂,₁ Secure access, loading and standing of vehicles</td>
<td>Transport</td>
<td>Micro</td>
</tr>
<tr>
<td></td>
<td>F₂,₂ Support locomotion</td>
<td>Transport</td>
<td>Micro</td>
</tr>
<tr>
<td></td>
<td>F₂,₃ Secure spatial orientation</td>
<td>Transport</td>
<td>Micro</td>
</tr>
<tr>
<td></td>
<td>F₂,₄ Support waiting</td>
<td>Transport</td>
<td>Micro</td>
</tr>
<tr>
<td></td>
<td>F₂,₅ Inform on transport services</td>
<td>Transport</td>
<td>Micro</td>
</tr>
<tr>
<td></td>
<td>F₂,₆ Provide ticketing</td>
<td>Transport</td>
<td>Micro</td>
</tr>
<tr>
<td>F₃ Facilitate commercial use of real estate</td>
<td>F₃,₁ Operate business and retail area</td>
<td>Land use</td>
<td>Micro</td>
</tr>
<tr>
<td></td>
<td>F₃,₂ Operate advertising and promotion area</td>
<td>Land use</td>
<td>Micro</td>
</tr>
<tr>
<td></td>
<td>F₃,₃ Convey corporate image</td>
<td>Land use</td>
<td>Micro</td>
</tr>
<tr>
<td>F₄ Provide public space</td>
<td>F₄,₁ Provide public space</td>
<td>Land use</td>
<td>Micro</td>
</tr>
<tr>
<td></td>
<td>F₄,₂ Simplify meeting of users</td>
<td>Land use</td>
<td>Micro</td>
</tr>
<tr>
<td>F₅ Contribute to the identity of the surrounding area</td>
<td>F₅,₁ Structure area</td>
<td>Land use</td>
<td>Meso</td>
</tr>
<tr>
<td></td>
<td>F₅,₂ Provide spatial orientation</td>
<td>Land use</td>
<td>Meso</td>
</tr>
<tr>
<td></td>
<td>F₅,₃ Serve as cultural heritage and historical reference</td>
<td>Land use</td>
<td>Meso</td>
</tr>
</tbody>
</table>

2.3.1.1 Linking Catchment Area and Transport Network (F₁)

Railway stations are links between transport networks providing a transport supply and catchment areas comprising a certain transport demand. From the perspective of the rail
transport network (and partly also from other transport networks such as light rail or bus services), a railway station must localize public transport demand \( (F_{1,1}) \), i.e. define a catchment area. The size of the catchment area is thereby dependent on the accessibility of the railway station premises. From the perspective of the catchment area, the railway station must provide public transport supply \( (F_{1,2}) \), whereby rail is the most important, but may be complemented by other modes of public transport.

Performance criteria mentioned were for instance: transport demand potential of the catchment area \( (F_{1,1}) \) (i.e. number of residents, workplaces, shopping, tourist and leisure attractions accessible), and quality of the transport services \( (F_{1,2}) \) (i.e. average travel times by rail to nearest centers relative to other modes of transport). Interactions mentioned for the function linking catchment area and transport network \( (F_i) \) were, for example, positive influences on the facilitation of commercial uses of the station building \( (F_3) \) and the contribution to the identity of the surrounding area \( (F_5) \).

2.3.1.2 Supporting Transfer Between Modes of Transport \( (F_2) \)

Within the premises of the railway station, passengers change between modes of transport (or between vehicles of the same mode) by foot. To support these transfers, the railway stations must secure access, loading and standing of vehicles \( (F_{2,1}) \) for vehicles of all modes to stop or be parked, support locomotion between transport services \( (F_{2,2}) \), secure spatial orientation between transport services \( (F_{2,3}) \), support waiting of passengers for connections \( (F_{2,4}) \), inform on transport services \( (F_{2,5}) \), as well as provide ticketing (and further transport related services such as lost-and-found services) \( (F_{2,6}) \) according to the needs of the passengers.

Performance criteria mentioned were for instance: bicycle parking capacities \( (F_{2,1}) \); locomotion effort \( (F_{2,2}) \) (i.e. distances, number of stairs, transfer time needed); cognitive effort and successful orientation rate \( (F_{2,3}) \); security, cleanliness and subjective well being \( (F_{2,4}) \); information quality and effective information rate \( (F_{2,5}) \); sales volumes \( (F_{2,6}) \). Interactions mentioned were for example positive influences on linking catchment area and transport network \( (F_i) \) and on the provision of public space \( (F_4) \).

2.3.1.3 Facilitating Commercial Use of Real Estate \( (F_3) \)

Railway stations are attractive locations for commercial purposes. Shopping, business and leisure opportunities are demanded by and may be provided for both passengers and local residents. Station operators can therefore generate additional revenues when operating a business and retail area \( (F_{3,1}) \) or when operating an advertising and promotion area \( (F_{3,2}) \) on the station premises. Additionally, successful station operation, design and architecture may be used to convey a corporate image \( (F_{3,3}) \) of either the transport operators, the station proprietors or the surrounding residential area.
Performance criteria mentioned were for instance: business volumes of retail areas and attractiveness of retail offering for transport passengers ($F_{3,1}$); business volumes of advertising areas ($F_{3,2}$); added value ($F_{3,3}$). Interactions mentioned for the function facilitating commercial use of real estate ($F_i$) with other functions were, for example, positive influences on the support for waiting ($F_{2,4}$) and the provision of public space ($F_4$).

2.3.1.4 Providing Public Space ($F_4$)

Railway stations usually provide public space ($F_{4,1}$). This space may serve as room for multiple social activities and public events such as fairs, markets, or exhibitions. Additionally, in order to simplify meeting of users ($F_{4,2}$), there may be specific dedicated meeting points (used by both passengers and residents).

Performance criteria mentioned were for instance: square footage, freedom of access and use density ($F_{4,1}$); distinctiveness and degree of familiarity ($F_{4,2}$). Interactions mentioned were for example positive influences on facilitating commercial use of the real estate ($F_i$) and on contributing to the identity of the surrounding area ($F_5$).

2.3.1.5 Contributing to the identity of the surrounding area ($F_5$)

Railway stations contribute to the face, amenities and identity of their surrounding areas by means of three interwoven subfunctions: The station building as well as the connecting railway tracks create borders and boundaries contributing to the temporal and spatial structure of the surrounding area (structure area, $F_{5,1}$). The resulting structures, together with possible signage (“to the station”), provide spatial orientation ($F_{5,2}$). The station building and its architecture may additionally serve as a cultural heritage and historical reference ($F_{5,3}$).

Performance criteria mentioned were for instance: level of separation and barrier building ($F_{5,1}$) (i.e. distance between over- and underpasses, strength of visibility barrier); visibility and distinctiveness ($F_{5,2}$); architectural quality and level of heritage-protection ($F_{5,3}$). Interactions mentioned were for example positive influences on the provision of public space ($F_4$).

2.3.2 Interactions of Functions

Interactions between functions, omitting interactions with context, are depicted on a system graph (Figure 2–1). Interactions described on the level of subfunctions in an impact matrix were integrated to the level of functions. Of the 87 interactions between subfunctions mentioned (of 194 possible), 68 were positive and none were purely negative; 20 interactions indicate a range along which effects are dependent on the station size and thus may be negative.
Examples of positive interactions are given in the descriptions of the functions (Section 2.3.1). In the following the most frequently mentioned potentially negative interactions describing necessary trade-offs between functions are summarized:

Transfer becomes more difficult with increasing station size: providing access to public transport ($F_{1,2}$) in large railway stations may have negative effects on supporting locomotion between transport services ($F_{2,2}$) and securing spatial orientation between transport services ($F_{2,3}$) due to the increasing complexity of the infrastructures.

Conflict between transport, commercial and public use of the station premises: securing access, loading and standing of vehicles ($F_{2,1}$), supporting locomotion between transport services ($F_{2,2}$), operating business and retail areas ($F_{3,1}$), providing public space ($F_{4,1}$) and simplifying meeting of users ($F_{4,2}$) may compete for surface area in the station premises. This becomes especially visible in large stations at peak hours and is due to both limited space and pressure for revenues.

Figure 2–1. Possible interactions between functions of railway stations. Notes: Solid arrows depict positive impacts, dashed arrows depict negative impacts. Self-impacts are omitted (i.e. impacts between subfunctions of one function). Each arrow comprises several impacts with potentially different effect mechanisms and strengths. The proportion of potential impacts is indicated by the thickness of the arrows (i.e. arrows do not show impact strength).

Overdemands on visual/cognitive capacity of users: securing spatial orientation between transport services ($F_{2,3}$), informing on transport services ($F_{2,5}$) and the operation of advertising and promotion areas ($F_{3,2}$) compete for the attention of users. The combined
visual/cognitive demands may overstrain the capacities of users, especially those with limited experiential knowledge.

### 2.3.3 Lessons Learnt from Expert Workshops

The functions were introduced, discussed and applied in two workshops concerned with the assessment of railway stations for sustainable development. A presentation of all results from these workshops exceeds the scope of this paper. Nonetheless we would like to briefly accentuate three lessons learnt: Firstly, the experts – although from different stakeholder groups – all agreed on the set of functions presented (i.e. accepted all and did not suggest additional functions). Secondly, the experts showed differences when weighting the importance of the functions. Although the weightings converged towards a characteristic importance of the functions, differences between stakeholder groups and station types could be clearly identified. Thirdly, the experts declared that the functions support them in understanding and describing railway stations and the relations between stakeholders. This also became obvious when the experts discussed trade-offs between functions.

### 2.4. Discussion

A set of five generic functions ($F_1, \ldots, F_5$) of railway stations was identified and jointly agreed upon, providing a functional conceptualization of the system railway station. For reasons of clarity we will refer to these five functions as a framework, and to the work of Bertolini (1996, 1999), Juchelka (2002) and Wulfhorst (2003) as models. For a clarification of the developed framework we firstly compare the functions with the railway station models presented in the introduction. We then discuss the insights that can be drawn from the interactions of the functions, especially when considering the stakeholders involved. Finally, we discuss potential applications of the framework in railway station redevelopment processes as well as the sufficiency of the framework as a basis for the definition of assessment criteria.

#### 2.4.1 Comparison with Existing Models

Each of the three models presented in the introduction mentions functions of railway stations. These can be directly related to the systemic functions presented in this paper (Table 2–4). Although Wulfhorst (2003) does speak of functions of railway stations, he further uses “pivotal fields of action” to define assessment criteria for railway station development projects; since the latter are closer to our understanding, we use these for the comparison. The comparison shows that all functions mentioned by Bertolini (1996, 1999), Juchelka (2002) and Wulfhorst (2003) were identified. Additionally, we describe 16 subfunctions, which allow for a further differentiation and description of the functions.
Comparing our results with the existing models, we identify three key issues, which we now discuss.

Our framework is structured in two dimensions. First, the functions may be differentiated according to subject as either transport or land use related. $F_1$ and $F_2$ are transport related, while $F_3$, $F_4$, and $F_5$ are land use related. This differentiation is also applied by each of the existing models. Second, our functions may be differentiated according to spatial scale, ranging from micro to macro perspectives. The functions $F_2$, $F_3$, and $F_4$ take a micro perspective: the utilization of the station premises. Function $F_1$ takes a macro perspective: transport and land use functions of the station for its catchment area and transport network. In between these two, function $F_5$ takes a “meso” perspective, describing land use functions of the station for its directly surrounding urban area. The node-place model of Bertolini (1996, 1999) focuses on the macro-perspective (although place may include some indicators of station premises use density), while the models of Juchelka (2002) and Wulfhorst (2003) include, and partly blend, several spatial scales.

Our framework focuses on railway stations themselves. The greatest differences between the existing models and our framework can therefore be seen in the definition of function $F_5$. Here we describe the railway stations’ contribution to the identity of the surrounding area, deliberately not including the topic urban development. We argue that urban development is better described as a function of the whole “rail transport system” (consisting of railway lines, railway stations and transport services). Function $F_5$ is restricted to functions a railway station fulfils independently of the rail network. Our framework therefore only includes a small, but clearly specified, component of the larger topic urban development. Similarly, Wulfhorst (2003) identifies the quality of the rail transport services provided as a stronger impact factor for urban development than the quality of the railway station itself.

The experts interviewed and involved in the workshops frequently described the transport related functions $F_1$ and $F_2$ as the defining, basic or primary functions of railway stations. By this they implicate that not all functions are of even importance or weighting, and that such a weighting can change from station to station. Similarly, Juchelka (2002) speaks of a hierarchy of functions, describing the primary function as a precondition for any subsequent functions. We support this view to a certain extent and argue that it is difficult to speak of a “railway station” without the functions $F_1$ and $F_2$. On the other hand, Juchelka (2002) additionally claims a sequential evolution of functions: small stations do not fulfil tertiary functions and secondary or tertiary functions are only possible once primary functions are fulfilled. This contrasts with our framework, which does not suggest a sequential order of the functions. We claim that the functions can be found in a diversity of combinations, dependent on the size and context of the station, yet as stated above, with $F_1$ and $F_2$ playing a crucial role.
Table 2–4. Comparison of models: whether and how the models of Bertolini (1996, 1999), Juchelka (2002) and Wulfhorst (2003) include the functions described in this paper.

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<tr>
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<tbody>
<tr>
<td>F1 Link catchment area and transport network</td>
<td>F1,1 Place</td>
<td>Incl. in urban development</td>
<td></td>
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<tr>
<td>F1,2 Node</td>
<td></td>
<td></td>
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<tr>
<td>F2 Support transfer between modes of transport</td>
<td>F2,1 Primary function: interconnecting multiple transport modes</td>
<td>Transport interconnections</td>
<td></td>
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<td>F2,2</td>
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<td>F2,3</td>
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<td>F2,4</td>
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<td>F2,5</td>
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<tr>
<td>F2,6</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>F3 Facilitate commercial use of real estate</td>
<td>F3,1 Can be included in place</td>
<td>Secondary function: commercial, leisure and cultural area</td>
<td>Use of station building</td>
</tr>
<tr>
<td>F3,2</td>
<td></td>
<td>Tertiary function: city center or center of commerce</td>
<td></td>
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<tr>
<td>F3,3</td>
<td></td>
<td></td>
<td>Included in urban development</td>
</tr>
<tr>
<td>F4 Provide public space</td>
<td>F4,1</td>
<td></td>
<td></td>
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<tr>
<td>F4,2</td>
<td></td>
<td></td>
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<tr>
<td>F5 Contribute to the identity of the surrounding area</td>
<td>F5,1</td>
<td></td>
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<tr>
<td>F5,2</td>
<td></td>
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<td>F5,3</td>
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2.4.2 Interactions of Functions

The results concerning the interactions of functions must be understood as indications or general tendencies. The actual interactions at any specified railway station are dependent on its specific structures and context. Nonetheless, multiple potential interactions were identified. The system graph (Figure 2–1) indicates that the majority of the interactions between functions are positive. This means that great potential for synergies exists, but at the same time that there may be critical dependencies between functions. The negative impacts identified are dependent on station size and describe potential conflicts: competition of multiple functions for space, for customer attention or for revenues as well as increasing system complexities with station size.

The interactions influence the relations of the stakeholders (e.g. providers, users) and thus also potential redevelopment options. Examples of potentially problematic stakeholder relations are: same function provided by multiple stakeholders with diverging goals (e.g. F2 jointly provided by the operators of transport services, operators of station infrastructures and the municipal administration); same function used by multiple stakeholders with diverging needs (e.g. F4 used by both transport system users and local residents); dependencies between functions possibly leading to dependencies between providers (e.g. retailers interested in passengers having spare time between connections); generally

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2 Due to a mistake of Elsevier Publishing Services this table was printed with incorrect shading. The version presented here is correct and was published in an erratum.
conflicting functions where decisions on trade-offs are necessary (e.g. providers of $F_2$, $F_3$ and $F_4$ which need to agree on the use of the available space and distribution of costs). Hence, the framework can support the structuring of potential conflicts in a redevelopment process.

Again here, it is worth comparing our insights with existing models, as Bertolini (1996, 1999) and Wulfhorst (2003) both discuss interactions between functions. Applying a system dynamic model, the interactions between system variables are most fully elaborated by Wulfhorst (2003). Still, our results are consistent with his work. Bertolini (1996, 1999) distinguishes different ideal-typical situations in the node-place graph (dependency, accessibility, stress, unsustained node/place). Here our framework can provide further and more detailed insights. Yet in contrast to Bertolini’s node-place model, the functions alone do not directly show redevelopment potentials.

Knowledge of existing or potential interactions between functions may support the design of the redevelopment process as well as the understanding of redevelopment options. Different solutions on how to handle conflicts or trade-offs between functions may be found depending on their relative importance. Because the functions are derived from “goals and requirements” of stakeholders, the interactions can be traced back to the respective stakeholders. We think the ability to show such interactions with a direct link to stakeholders is an important capability of the framework.

2.4.3 Representativeness and Applicability of the Framework

For the framework to provide a sufficient (cf. Scholz & Tietje, 2002) basis to foster the development of a common system understanding or for the definition of assessment criteria, the functions must represent the characteristic goals and requirements imposed on a railway station. We therefore discuss whether essential functions may be missing (i.e. if all stakeholder groups are represented), whether the functions are applicable to any railway station (i.e. applicable in screening tools), and whether they are stable or subject to future changes (i.e. if the goals and requirements of stakeholders change).

Additional or different functions to those identified might emerge if some of the “goals and requirements” of certain stakeholders were not included, i.e. the selection of stakeholders and subsequent elicitation of functions are both critical. The identification of the functions was an iterative process of i) eliciting the goals and requirements of a stakeholder group, and ii) identifying further stakeholders of these functions, who again may mention new goals and requirements. Likewise, with respect both to stakeholders and functions a step-wise refinement was possible. In the end, two facts suggest that we have accumulated a sufficient set of functions. Firstly, all functions described by Bertolini (1996, 1999), Juchelka (2002) and Wulfhorst (2003) were identified. Secondly, the methodological triangulation applied in this study (focus groups and expert interviews) revealed largely overlapping results, both within and between methods. Different stakeholder groups mostly mentioned similar functions.
This certainly indicates that the set of functions developed is considered to be useful and adequate for all participating experts. Nevertheless, the goals and requirements that are ultimately imposed on a system, and especially the importance of each function, is of course dependent on the specific case and its context\(^3\) (e.g. urban density, transport network quality). Additional functions are possible, and not each station must fulfill all of the mentioned functions.

For the functions to be generic they must be applicable to railway stations of all types and sizes. Our study focused on Swiss railway stations used for passenger transport. Throughout the study, a diversity of station types and sizes were considered (small and large, rural and urban, transit- and tourist-oriented). No contradictions or differences according to the set of functions were identified. Similarly, in the expert workshops the functions were described as applicable to many different railway stations. What does change considerably with the size and type of the railway station is (besides the relative importance of the functions and their specific interactions, as discussed in Sections 2.4.1 and 2.4.2), the dimensions of infrastructures and the organization of operations. The latter two represent the structures of the system. The structures implemented to fulfill the functions are diverse and adapted to the specific contextual situations (e.g. size of the station, spatial or financial restrictions). One example is the commercial use of the station premises \((F_3)\), which may be a shopping mall in a large railway station and a vending machine in a small railway station. Subsequently, even if the same function is provided by different structures one can use the derived criteria for comparative analysis. For example, the experts suggested “business volumes of retail areas” as a performance criterion for the commercial use of the station premises (cf. Section 2.3.1.3). This analysis criterion is usable – given data availability – to compare such diverse stations as small subway stations and large international hubs. It is this differentiation between more generic functions and case-wise adapted structures which lets us assume that the identified functions may be applied in a wide variety of contexts\(^4\). Although the functions were developed from the perspective of Swiss railway stations, where the modal split of rail is more than twice the EU-27 average (EC DG TREN, 2008), they may thus even be applicable – after critical appraisal – in other countries. In this sense, a rural railway station in Germany may have to provide the same functions as a high-speed railway station in Japan, albeit in a different manner.

\(^3\) Which goals and requirements stakeholders impose on a system is partly dependent on the specific context. The definition of the functions of a system therefore represents a duality of system and context, as described by Fisher, Turner, & Morling (2009) for the case of ecosystem services.

\(^4\) The difference between function and structure may even help describe what constitutes a railway station – i.e. what the differences and similarities are to other transport nodes such as bus stops, airports and harbors. These differences may have more to do with the characteristic structures and performance of the functions, and less with the functions actually provided. Consequently, some lessons may be learned from comparing assessment approaches and redevelopment processes of nodes from different transport modes.
The functions identified can be considered rather stable. This is important, as a rapidly changing framework would be unsuited as e.g. a guide for the elaboration of assessment criteria for sustainable development. Nonetheless, functions will alter according to fundamental changes in the goals and requirements of the stakeholders. The handling of freight – formerly an important function of many passenger railway stations in Switzerland and now largely concentrated in specialized stations – is an example for such a fundamental change. If crucial functions (i.e. the transport related functions $F_1$ and $F_2$) drop away the system can no longer be considered a “railway station”. But such dramatic changes are interesting, as they allow a focused investigation of the non-transport related functions and may provide insights for station redevelopment. The former railway station building of Hombrechtikon is such an example (Figure 2–2): Rail services on the corresponding Uerikon-Bauma-Bahn were closed down in 1948 and tracks were quickly dismantled, but the station building in Hombrechtikon still exists (Aeschimann & Wenger, 1984). It is well identifiable as such, among others because of the familiar Swiss station clock. The renovated building is now under heritage protection and accommodates a small restaurant and schooling rooms of a nonprofit making women’s association. It borders upon an important meeting place of the community, together with a church and the town hall, and the adjacent street names remember the railway line (Bahnweg, Bahnhöfliplatz). Thus, although the transport related functions ($F_1$, $F_2$) have dropped away, the former station building still partly fulfils the remaining three functions commercial use ($F_3$), public use ($F_4$) and identity ($F_5$). The example of Hombrechtikon thus illustrates both that the non-transport related functions can be of high importance to the local community, as well as how flexible the concept of systemic functions is. Of course, with such derelict stations it is necessary to define anew which functions they can still fulfil (and in what manner). Here fore the methodology presented in this paper may be a starting point.

Figure 2–2. The old railway station building of Hombrechtikon. Although the transport related functions have dropped away with the closing of the railway line, the building still partly fulfils functions common for railway stations (Foto: U. Schudel).
We conclude that the functions presented are sufficiently generic with respect to stakeholder representation and station applicability. Also, the functions can be considered rather stable – contrary to the more case-specific structures. From this perspective, we perceive the functions as a sufficient basis to foster the development of a common system understanding or for the definition of assessment criteria of railway stations.

2.4.4 Outlook: Application of the Functions

In the following we briefly illustrate how the framework can support the development of a common system understanding in a redevelopment process and how the framework can be used to derive assessment criteria for railway stations in a structured manner.

2.4.4.1 Fostering Common System Understanding

Our multi-stakeholder approach, applied within a transdisciplinary setting, was designed to identify and include the perspectives of a multitude of stakeholders. The introduction and discussion of the functions in two workshops indicated how the framework is capable of fostering the development of a common system understanding. This is in general due to the fact that the stakeholders can use the framework as a basis to find a common language to describe their perspectives and requirements. But the framework can also serve concrete applications in the redevelopment process: First, the important early project phase of initial (often intuitive and vague) problem identification and structuring is supported by explicitly addressing each function. Second, the framework may support the identification of stakeholders, thus ensuring that all stakes have the chance to be represented in the redevelopment process (each function may be related to specific stakeholder groups, and vice versa). Third, the framework may help stakeholders involved in a process to identify and understand potential conflicts, e.g. by discussing the interrelations of the functions, their relative importance and solutions to trade-offs.

2.4.4.2 Deriving Assessment Criteria

The framework can be used to derive assessment criteria indicating how well a given railway station fulfils its functions. This can be done in a structured and traceable manner. In the results section we give examples of criteria to measure the performance of a railway station (or its redevelopment options). Naturally, assessment criteria related to performance alone do not reflect a sufficiently broad system description in terms of sustainable development – often a main motivation for integrated planning in the first place. Therefore additional assessment criteria addressing relevant systemic characteristics with respect to the current and future functionality of the system are necessary (cf. Laws et al., 2004). For defining these criteria the Sustainability Potential Analysis (SPA) developed by Lang et al. (Lang, Binder, et al., 2007; 2007) is a promising approach. The SPA comprises six systemic characteristics for which criteria are to be defined: performance and efficiency, well-structuredness, interdependencies with other systems, buffer capacity and resilience, ability to accommodate,
as well as inter- and intra-generative equity of the system. The defined criteria can be used to conduct a multi-criteria assessment. In so doing the diverging perspectives of the stakeholders may be integrated by weighting the assessment criteria as in other stakeholder based multi-criteria analyses (cf. Scholz & Tietje, 2002). We assume that the ability of the framework to support a common system understanding will positively influence the derived assessment results with regard to their quality, acceptance and application.

The distinction of functions and structures was appreciated by the experts, allowing for a focus on structural design and addressing questions of multifunctionality or adaptability. Obviously, comparing stations functioning under similar conditions but with different structures will be of special interest, as this allows for the identification of optimal structures (Zemp et al., 2011a). The functions therefore do not allow for the direct derivation of planning guidelines, but foster a learning process within which such guidelines can be developed.

### 2.5 Conclusions

The motivation for this work originated from the desire to improve the multi-perspective description and assessment of railway stations in a planning process striving to support sustainable development. To this end a systemic framework of five generic functions of railway stations was developed and the interrelations between the functions described. We differentiate between functions, which are presumed to be similar for all railway stations, and structures, which are case-specific. The framework can therefore describe a diversity of situations, from small rural to large urban railway stations, and - although elaborated on the basis of Swiss railway stations - may even be adaptable to other countries.

The value of the results are nicely illustrated by a statement of the head architect of the SBB at the final discussion of the functions: “We finally gained a common pair of glasses” (Johannes Schaub, personal communication, October 9, 2009). Essentially, the elaborated set of generic functions of railway stations provides a basis from which two key contributions for the redevelopment of railway stations can be derived: First, they provide a basis for the stakeholders to find a common language. This enables them to better describe and understand their perspectives, requirements and interrelations. The fostered common system understanding is a prerequisite for any integrated redevelopment process, reducing ignorance and supporting deliberate decision making concerning trade-offs between conflicting functions. Second, generic assessment criteria can be derived in a structured and traceable manner by asking “how” the functions should be fulfilled (i.e. effective, adaptable, fair, etc.). The subsequently possible comparisons of railway stations may support the development of planning guidelines and allocation of limited redevelopment resources.
The multi-stakeholder approach applied in the study was not only a central methodological necessity for developing the functions, but also provided a constant critical review of the achieved results. During the process we experienced, how the framework supports interaction and communication among stakeholders. Steps for the comparative assessment of railway stations have also commenced. Accordingly, much of what has been learned during the study has already diffused into the daily practice of the involved practitioners.

Acknowledgements

The authors would like to thank: all experts for their contributions to the expert interviews and the workshops; the participants of the focus groups; the project partners from the Swiss Federal Railways (SBB): Johannes Schaub, Marionna Lutz and Beat Hürzeler for their support in many phases of the work; Maya Wolfensberger Malo; Thomas Köllner, Rainer Gabriel, Dominik Reusser and Ulrich Weidmann for their comments on earlier versions of the text; Heather Murray for editorial support. This work was conducted within a broader study entitled “Sustainable positioning of railway stations” funded by the SBB.
3 Classifying Railway Stations for Strategic Transport and Land Use Planning: Context Matters!


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 discernible. 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.
3.1 Introduction

Many efforts towards the sustainable development of transport and land use foster concentration strategies around nodes of public transport (cf. Haywood, 2005; Verhetsel & Vanelfslander, 2009). Subsequently, public transport nodes – such as railway stations (hereafter, stations) – have become a key topic in urban planning (Bruinsma et al., 2008; Calthorpe, 1993; Peek & Louw, 2008a). The operation and development of stations requires integration of multiple actors and interests (Bertolini & 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 & 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. Connolly & Payne, 2004; Ross, 2000). 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.

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, Oetterli & Müller, 2004).
DB Station&Service of Germany and Network Rail of the UK also apply systems substantially relying on passenger frequencies (DB Station&Service AG, 2009a, 2009b; Green & 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 & Spit, 1998; De Tommasi, Oetterli & Müller, 2004; Reusser et al., 2008; Ross, 2000). 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 & Vanelslander, 2009).

3.1.1 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 & 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 Figure 3–1, 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.

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. (2011b) describe five functions stations may fulfil: 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. At the very least, F3 - F5 seem to be largely neglected by the indicator “passenger frequency”. With integrated transport and land use planning becoming ever more important (cf. Curtis, 2008a; Hickman & 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.

Figure 3–1. Influence of system context on system structures
3. Classifying Railway Stations for Strategic Transport and Land Use Planning

3.1.2 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.

3.2 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.

3.2.1 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 minutes, 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, Scholz, 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. (2011b). The interviews led to the identification of five functions of railway stations, each influenced by multiple context factors.

3.2.2 Cluster Analysis

Where data was available, those context factors influencing at least three functions were quantified by means of indicators (Table 3–2). Data was 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 was prevalent for smaller stations with insufficient data on passenger frequencies (I5 only available for 60% of stations) or number of tourist visits for small municipalities (I6 only available for 65% of stations). Otherwise, original data was available for over 92% of all stations for all other indicators.

Data was log transformed (except for I3, I4 and I5), and Z- scores computed to secure even weighting of the indicators. The sole ordinal indicator, I4, 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 to 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.
3.2.3 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, Bertolini & De Jonge, 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).

3.3 Results

3.3.1 Context Factors of Railway Stations

Table 3–1 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 3–1, seven (CF2, CF3, CF6, CF7, CF10, CF11 and CF12) could be quantified by means of indicators (Table 3–2). CF1, CF4, CF5, CF8, CF9, CF13 and CF14 could not be quantified, although CF1 and CF4 are partly reflected by I3, and CF5 may be partly reflected by I1 and I2.
Table 3–1. 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.

<table>
<thead>
<tr>
<th>Context factor</th>
<th>Exemplary influences on functioning of railway station</th>
<th>Relevant for functions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>F1 F2 F3 F4 F5</td>
</tr>
<tr>
<td>Factors describing transportation infrastructure location</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CF1 Location of railway tracks</td>
<td>Location options for railway station</td>
<td>X</td>
</tr>
<tr>
<td>CF2 Centrality of railway station</td>
<td>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</td>
<td>X</td>
</tr>
<tr>
<td>Factors describing properties of the catchment area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CF3 Size&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Passenger frequencies; Demand for commercial uses of facility area</td>
<td>X</td>
</tr>
<tr>
<td>CF4 Concentration</td>
<td>Concentration favours short access distances and walkability; Concentration favours provision of feeder services</td>
<td>X</td>
</tr>
<tr>
<td>CF5 Topography</td>
<td>Access to railway station; Circumference of catchment area</td>
<td>X</td>
</tr>
<tr>
<td>CF6 Composition of goals/sources</td>
<td>Customer types distribution at the railway station; Daily, weekly or seasonal passenger frequency distributions</td>
<td>X</td>
</tr>
<tr>
<td>CF7 Proximate urban density</td>
<td>Options for railway station design, layout and developments</td>
<td>X</td>
</tr>
<tr>
<td>CF8 Reputation of vicinity</td>
<td>Security provision and perception</td>
<td>X</td>
</tr>
<tr>
<td>CF9 Cultural heritage and historical reference management</td>
<td>Local contributions to building maintenance costs; Development options of railway station buildings</td>
<td>X</td>
</tr>
<tr>
<td>Factors describing properties of the public transportation services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CF10 Connection frequencies</td>
<td>Passenger frequencies; Attractiveness of commercial areas; Necessary infrastructure sizes</td>
<td>X</td>
</tr>
<tr>
<td>CF11 Network density</td>
<td>Reachable goals/sources</td>
<td>X</td>
</tr>
<tr>
<td>CF12 Interconnection quality</td>
<td>Waiting time at the railway station; Number of passengers changing vehicles/modes</td>
<td>X</td>
</tr>
<tr>
<td>CF13 Reputation of public transport</td>
<td>Customer types distribution at railway station</td>
<td>X</td>
</tr>
<tr>
<td>CF14 Relative attractiveness of private transport&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Passenger frequencies; Customer types distribution at railway station</td>
<td>X</td>
</tr>
</tbody>
</table>

<sup>a</sup> 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

<sup>b</sup> Relative attractiveness of private transport may be described by comparing e.g. travel duration, travel time variability and uncertainty (congestions), costs
Table 3–2. Indicators for quantification of context factors.

<table>
<thead>
<tr>
<th>Indicator name</th>
<th>Description</th>
<th>Related context factors*</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1: Jobs</td>
<td>Number of jobs within a 700m radius</td>
<td>CF3, CF6, CF7, (CF5)</td>
</tr>
<tr>
<td>I2: Population</td>
<td>Number of residents within a 700m radius</td>
<td>CF3, CF6, CF7, (CF5)</td>
</tr>
<tr>
<td>I3: Centrality</td>
<td>Average distance to jobs and residents within a 700m radius</td>
<td>CF2, (CF1, CF4)</td>
</tr>
<tr>
<td>I4: Regional centre</td>
<td>Main station of a regional centre</td>
<td>CF3, CF6, CF12</td>
</tr>
<tr>
<td>I5: Frequency distribution</td>
<td>Passenger frequencies at weekends compared to weekdays</td>
<td>CF6</td>
</tr>
<tr>
<td>I6: Tourism</td>
<td>Arriving tourists per 1000 residents of the municipality</td>
<td>CF6</td>
</tr>
<tr>
<td>I7: Reachability</td>
<td>Number of reachable railway stations in 20 minutes</td>
<td>CF11, CF12</td>
</tr>
<tr>
<td>I8: Intercity trains</td>
<td>Number of departing intercity trains</td>
<td>CF10</td>
</tr>
<tr>
<td>I9: Regional trains</td>
<td>Number of departing regional trains</td>
<td>CF10</td>
</tr>
<tr>
<td>I10: Buses</td>
<td>Number of departing buses</td>
<td>CF10</td>
</tr>
</tbody>
</table>

* For description of context factors see Table 3–1. Factors in Brackets are only indirectly represented.

3.3.2 Description of Classification Results

Seven classes of stations were identified. Summary statistics for the indicators used and short descriptions of the classes are given in Table 3–3, 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.

3.3.2.1 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 3–4). 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 I1+I2+I7+I8+I9+I10) for the first component and use (Z-score of I5+I6) for the second component. Both proxies correlate well with the original components (cf. Table 3–5). The classes are presented in a scatter plot of these two proxies, called the density-use model (Figure 3–2).

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 I7–I10 were totalled and Z-scores computed. For the place factor—commonly quantified by describing
the spatial development at a station—the indicators I1 and I2 were totalled and Z-scores computed (Figure 3–3).

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 Figure 3–2 additionally shows differences in the use of the stations: use can vary from commuting-orientated (left side of Figure 3–2) to tourism- or leisure-orientated (right side of Figure 3–2). The stations in class 4 are thus frequented mainly on workdays 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 (Figure 3–3). For example, the average context density reduction from class 2 to class 3 is mainly due to a reduction of the node component (i.e. fewer transport connections), while the average context density reduction from class 3 to class 4 is mainly due to a reduction of the place component (i.e. fewer jobs and residents in the catchment area).
<table>
<thead>
<tr>
<th>Class Description</th>
<th>I1</th>
<th>I2</th>
<th>I3</th>
<th>I4</th>
<th>I5</th>
<th>I6</th>
<th>I7</th>
<th>I8</th>
<th>I9</th>
<th>I10</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 (N = 70)</td>
<td>1.71</td>
<td>1.29</td>
<td>-0.94</td>
<td>0.44</td>
<td>-0.44</td>
<td>0.36</td>
<td>1.97</td>
<td>1.72</td>
<td>1.64</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>(0.47)</td>
<td>(0.28)</td>
<td>(0.44)</td>
<td>(0.62)</td>
<td>(0.22)</td>
<td>(0.72)</td>
<td>(1.50)</td>
<td>(0.79)</td>
<td>(1.36)</td>
<td></td>
</tr>
<tr>
<td>C2 (N = 151)</td>
<td>0.63</td>
<td>0.50</td>
<td>0.00</td>
<td>0.23</td>
<td>-0.10</td>
<td>0.25</td>
<td>0.26</td>
<td>1.77</td>
<td>0.12</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td>(0.61)</td>
<td>(0.68)</td>
<td>(0.85)</td>
<td>(0.63)</td>
<td>(0.72)</td>
<td>(0.76)</td>
<td>(0.67)</td>
<td>(0.91)</td>
<td>(0.65)</td>
<td></td>
</tr>
<tr>
<td>C3 (N = 448)</td>
<td>0.48</td>
<td>0.52</td>
<td>-0.36</td>
<td>0.05</td>
<td>-0.26</td>
<td>0.35</td>
<td>0.20</td>
<td>-0.44</td>
<td>0.29</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>(0.57)</td>
<td>(0.51)</td>
<td>(0.66)</td>
<td>(0.68)</td>
<td>(0.42)</td>
<td>(0.74)</td>
<td>(0.31)</td>
<td>(0.74)</td>
<td>(0.96)</td>
<td></td>
</tr>
<tr>
<td>C4 (N = 274)</td>
<td>-0.30</td>
<td>-0.16</td>
<td>0.18</td>
<td>0.00</td>
<td>-0.24</td>
<td>-1.84</td>
<td>-0.04</td>
<td>-0.47</td>
<td>0.05</td>
<td>-0.37</td>
</tr>
<tr>
<td></td>
<td>(0.72)</td>
<td>(0.71)</td>
<td>(0.92)</td>
<td>(0.70)</td>
<td>(0.00)</td>
<td>(0.65)</td>
<td>(0.28)</td>
<td>(0.61)</td>
<td>(0.78)</td>
<td></td>
</tr>
<tr>
<td>C5 (N = 310)</td>
<td>-0.88</td>
<td>-0.79</td>
<td>0.40</td>
<td>0.00</td>
<td>0.26</td>
<td>0.54</td>
<td>-0.25</td>
<td>-0.41</td>
<td>-0.35</td>
<td>-0.76</td>
</tr>
<tr>
<td></td>
<td>(0.85)</td>
<td>(0.82)</td>
<td>(1.03)</td>
<td>(0.88)</td>
<td>(0.36)</td>
<td>(0.61)</td>
<td>(0.41)</td>
<td>(0.60)</td>
<td>(0.48)</td>
<td></td>
</tr>
<tr>
<td>C6 (N = 142)</td>
<td>-0.53</td>
<td>-0.77</td>
<td>0.08</td>
<td>0.02</td>
<td>1.43</td>
<td>0.69</td>
<td>-1.47</td>
<td>0.56</td>
<td>-1.29</td>
<td>-0.03</td>
</tr>
<tr>
<td></td>
<td>(0.96)</td>
<td>(1.28)</td>
<td>(0.89)</td>
<td>(1.56)</td>
<td>(0.55)</td>
<td>(1.30)</td>
<td>(1.11)</td>
<td>(1.40)</td>
<td>(0.93)</td>
<td></td>
</tr>
<tr>
<td>C7 (N = 11)</td>
<td>-3.20</td>
<td>-4.07</td>
<td>5.46</td>
<td>0.00</td>
<td>1.91</td>
<td>0.60</td>
<td>-1.06</td>
<td>-0.20</td>
<td>-0.75</td>
<td>-0.81</td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(1.59)</td>
<td>(0.89)</td>
<td>(0.93)</td>
<td>(0.56)</td>
<td>(0.98)</td>
<td>(0.66)</td>
<td></td>
</tr>
<tr>
<td>Total (N = 1406)</td>
<td>-0.03</td>
<td>-0.03</td>
<td>0.01</td>
<td>0.07</td>
<td>0.05</td>
<td>-0.01</td>
<td>-0.03</td>
<td>0.01</td>
<td>-0.02</td>
<td>-0.01</td>
</tr>
<tr>
<td></td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Class Descriptions (Working names of classes in quotes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 “Largest and most central stations”</td>
</tr>
<tr>
<td>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.</td>
</tr>
<tr>
<td>C2 “Large connectors”</td>
</tr>
<tr>
<td>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.</td>
</tr>
<tr>
<td>C3 “Medium commuter feeders”</td>
</tr>
<tr>
<td>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 Plantaiz, Nebikon, Courgenay.</td>
</tr>
<tr>
<td>C4 “Small commuter feeders”</td>
</tr>
<tr>
<td>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, Birwil, Brütten.</td>
</tr>
<tr>
<td>C5 “Tiny touristy stations”</td>
</tr>
<tr>
<td>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.</td>
</tr>
<tr>
<td>C6 “Isolated tourism nodes”</td>
</tr>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>
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.

* 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).

a For explanations of indicators see Table 3-2
b Ordinal indicator
c Mean ≠ 0 and/or standard deviation ≠ 1 because 301 cases with missing data were excluded from cluster analysis

d Table 3–4. Principal component loadings.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I1: Jobs</td>
<td>.845</td>
<td>.110</td>
<td>.209</td>
</tr>
<tr>
<td>I2: Population</td>
<td>.764</td>
<td>-.114</td>
<td>.008</td>
</tr>
<tr>
<td>I3: Centrality</td>
<td>-.381</td>
<td>.247</td>
<td>.220</td>
</tr>
<tr>
<td>I4: Regional centre</td>
<td>.512</td>
<td>.365</td>
<td>-.520</td>
</tr>
<tr>
<td>I5: Frequency distribution</td>
<td>-.220</td>
<td>.676</td>
<td>.313</td>
</tr>
<tr>
<td>I6: Tourism</td>
<td>-.266</td>
<td>.722</td>
<td>.247</td>
</tr>
<tr>
<td>I7: Reachability</td>
<td>.796</td>
<td>-.164</td>
<td>.372</td>
</tr>
<tr>
<td>I8: Intercity trains</td>
<td>.718</td>
<td>.381</td>
<td>-.073</td>
</tr>
<tr>
<td>I9: Regional trains</td>
<td>.767</td>
<td>-.065</td>
<td>.435</td>
</tr>
<tr>
<td>I10: Buses</td>
<td>.508</td>
<td>.294</td>
<td>-.544</td>
</tr>
</tbody>
</table>

| Total variance explained | .382 | .146 | .115 |

3.3.2.2 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 3–5), but passenger frequencies of the single classes overlap significantly (Figure 3–4). 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 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 3–6). Resident dynamics within the 700m perimeters of the stations for 1990 to 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, 4 and 5, whereby the increase in class 4 is again significantly larger compared to class 6 (Table 3–7). Job dynamics within the 700m perimeters of the stations for 1995 to 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.

![Density-use model of Swiss railway stations (N = 1000; random selection)](image)

Figure 3–2. Density-use model of Swiss railway stations (N = 1000; random selection)
Figure 3-3. Node-place model of Swiss railway stations (N = 1000; random selection)

Figure 3-4. 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 3–5. Correlations of principal components, proxies, passenger frequency and Ward clustering solution.

<table>
<thead>
<tr>
<th>Principal componentsa</th>
<th>Proxies</th>
<th>Passenger frequency</th>
<th>Clustering solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, “Density”</td>
<td>.014</td>
<td>.818**</td>
<td>-.152**</td>
</tr>
<tr>
<td>2, “Use”</td>
<td>1.000</td>
<td>-.089**</td>
<td>.725**</td>
</tr>
<tr>
<td>Density</td>
<td>1.000</td>
<td>-.190**</td>
<td>.925**</td>
</tr>
<tr>
<td>Use</td>
<td>1.000</td>
<td>-.114**</td>
<td>-.251**</td>
</tr>
<tr>
<td>Node</td>
<td>1.000</td>
<td>.604**</td>
<td>.768**</td>
</tr>
<tr>
<td>Place</td>
<td>1.000</td>
<td>.690**</td>
<td>-.671**</td>
</tr>
</tbody>
</table>

** Pearson correlation is significant at the 0.01 level (2-tailed)
* Pearson correlation is significant at the 0.05 level (2-tailed)

a For explanations of principal components see Table 3–4

### Table 3–6. Resident and job dynamics in the catchment area per class.

<table>
<thead>
<tr>
<th>Class</th>
<th>Resident dynamicsb (% change from 1990 to 2000)</th>
<th>Job dynamicsb (% change from 1995 to 2005)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
</tr>
<tr>
<td>1</td>
<td>100%</td>
<td>-3.828</td>
</tr>
<tr>
<td>2</td>
<td>99.3%</td>
<td>4.666</td>
</tr>
<tr>
<td>3</td>
<td>100%</td>
<td>4.278</td>
</tr>
<tr>
<td>4</td>
<td>98.5%</td>
<td>8.377</td>
</tr>
<tr>
<td>5</td>
<td>93.5</td>
<td>7.294</td>
</tr>
<tr>
<td>6</td>
<td>81.8</td>
<td>1.030</td>
</tr>
</tbody>
</table>

b Data for class 7 not given as n=0 for residents and jobs in the catchment area

### Table 3–7. Difference in mean dynamics of residents and jobs between classes.

<table>
<thead>
<tr>
<th>Class</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.43</td>
<td>1.69</td>
<td>1.36</td>
<td>7.57</td>
<td>13.13</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>8.49</td>
<td>0.73</td>
<td>3.78</td>
<td>10.00*</td>
<td>15.56**</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>8.11*</td>
<td>0.39</td>
<td>3.05</td>
<td>9.27**</td>
<td>14.83**</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>12.21**</td>
<td>3.71</td>
<td>4.10</td>
<td>6.21</td>
<td>11.78*</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>11.12**</td>
<td>2.63</td>
<td>3.02</td>
<td>1.08</td>
<td>6.26</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>4.86</td>
<td>3.64</td>
<td>3.25</td>
<td>7.35*</td>
<td>6.26</td>
<td></td>
</tr>
</tbody>
</table>

a Grey cells represent differences in dynamics of residents, white cells represent differences in dynamics of jobs. Computed according to Table 3–6

** Pearson correlation significant at the 0.01 level (2-tailed)
* Pearson correlation significant at the 0.05 level (2-tailed)
3.4 Discussion

In a preliminary survey of the results we conclude, first, that there are many context factors that influence the functioning of stations (Table 3–1), and, second, that the classes resulting from the quantification and clustering of these factors are well interpretable (Table 3–3). 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 (Figure 3–4).

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.

3.4.1 Identifying Comparable Railway Stations Based on Contextual Requirements

A variety of context factors were identified, representing both transport and land use related issues (Table 3–1). 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 F1, but context factors from the perspectives of F2, F3 & F4. 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 (F3, F4). 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. Figure 3–3), but are considerably differentiated in the density-use model due to different use characteristics (cf. Figure 3–2). 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 & 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 Figure 3–2. The third principal component (cf. Table 3–4) could not be satisfactorily interpreted and relies on indicators, which are either ordinal (I4 “Regional centre”) or rely on sketchy data (the indicator I10 “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 I3 “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. Chen, Chen & Barry, 2009; Dallen, 2007). 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 & 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 & 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 Vanslender (2009) 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, Bertolini & De Jonge, 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 (Figure 3–1). Identifying contextual requirements for the functioning of stations allows for a systematic derivation of classification criteria and leads to well interpretable classes.

3.4.2 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 & 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 3–3: 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 & 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. AAG GCLP, 2003; Miller, 1978). 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 3–6 and 3–7). 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 & 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.

3.4.3 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-&-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 I7, 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 & 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 Figure 3–1, 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 fulfill requirements of scientific soundness but also of practical relevance. Having discussed potential contributions of the classification system to strategic planning in section 3.4.2, 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\(^5\) (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 3–5). 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. Hirsch Hadorn et al., 2006; Scholz, 2000; Stauffacher et al., 2008) should support later applications, but cannot replace them.

### 3.5 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

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\(^5\) 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 5 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, Scholz & Lezzi, 2005).
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.

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.
Acknowledgements

The authors would like to thank: all experts for their contributions to the expert interviews; the project partners from the Swiss Federal Railways (SBB): Johannes Schaub, Marionna Lutz and Beat Hürzeler for their support in many phases of the work; Grégoire Meylan, Corinne Moser, Dominik Reusser, Martin Vinzens and Christian Schmid for their comments on earlier versions of the text; Heather Murray for editorial support. This work was conducted within a broader study entitled “Sustainable Positioning of Railway Stations” funded by the SBB.
Appendix: Supplementary Material

Supplementary data associated with this article is available from the journal homepage.

Supplementary Figure S1. Classification of Swiss railway stations: Overview of cluster locations. Underlying map provided by SBB Trafimage.
4 Multi-perspective Assessment of Railway Stations with Regard to Sustainable Development: Focusing on Functional Potentials

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Abstract

Railway stations are interfaces of transport networks and land use systems. Their redevelopment is a challenge due to the many stakeholders and the complexity of the various systems involved. We present a systemic assessment approach for railway stations with regard to sustainable development addressing complexity, supporting the coordination of actions and fostering the integration of knowledge in the decision-making processes of station redevelopment. Based on the Sustainability Potential Analysis (SPA), the guiding question of the assessment approach is whether a station can sustain performance and vitality with regard to the station’s specific functions within a specific but dynamic context. Consequently, stations at risk of not functioning well, and thus requiring further attention and potentially higher investments, are identified. Applying the approach to Swiss railway stations resulted in two assessment tools: A qualitative assessment protocol guiding a comprehensive and systematic assessment of single stations and a quantitative portfolio screening of stations based on a reduced set of indicators.
4.1 Introduction

Railway stations are interfaces of multiple transport networks and their surrounding land use systems (Bertolini & Spit, 1998; Stauffacher, Scholz & Lezzi, 2005). As a node of multiple public transport networks, a railway station (hereafter, station) must be aligned to several modes of transport. A station must support interchange between these modes while moderating the inherent downsides of interchanges such as transfer efforts and wait time (Kaufmann, Jemelin & Joe, 2000). As part of a land use system, stations contribute to forming settlement, housing and business areas (Debrezion, Pels & Rietveld, 2007a; Pol, 2008; Trip, 2007). Thus, a station can represent a community and moderate the disruptive nature of rail lines and increased traffic concentration. Designing and operating a station to simultaneously meet all of these requirements is in itself a challenging task for planners, operators and regulators (Peek & Louw, 2008b). Furthermore, integrated transport and land use policies aspiring to support sustainable development of urban areas place great hope on stations (Banister, 2008). To reduce negative effects of transport and land use consumption, concentrated development around nodes of public transport, typically stations, is proposed (Haywood, 2005; Verhetsel & Vanelslander, 2009). Such concentration puts additional pressure on the already challenging task of station redevelopment.

The interface nature of stations implies that multiple stakeholders are involved in station redevelopment (Wolff, 1999; Wucherpfennig, 2006). Users, operators and regulators can be defined from the transport and land use perspectives. These stakeholders not only have different perspectives but may also see different development goals and requirements, apply different methods and follow different regulations, procedures and timelines (Bertolini, le Clercq & Straatemeier, 2008). The combination of a multitude of stakeholders and ever-increasing demands on stations results in very complex redevelopment processes and a significant potential for conflicts. Paradoxically, bargaining processes or even simple unilateral solutions become tempting for single stakeholders, although such processes will most probably not lead to satisfactory results in the long term. Successful station redevelopment thus requires integrated approaches to foster concerted actions and find solutions matching the many complex and seemingly contradictory requirements.

Such integrated approaches require common system understanding and knowledge integration of many stakeholders. Assessments are a pivotal step in this process. Currently, no proven models or concepts are available that support stakeholders in a systemic and comprehensive assessment of stations in a structured manner. Existing guidelines have been designed from the perspective of one or two selective stakeholder groups and thus may not

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6 Because development may range from orderly reinvestment to completely new construction, we speak of redevelopment.
lead to results acceptable to all parties. In this paper, we therefore present a framework enabling the assessment of stations from different perspectives with regard to the concept of sustainable development. We refer to sustainable development as a normative guiding principle. We further take advantage of the fact that stations are very common. In Switzerland alone, there are more than 1700 train stations (VOEV, 2010), and large European countries such as France or Germany count many more. This allows not only for comparative assessments but also for the application of insights to many cases.

We take Swiss stations as an example and starting point. When speaking of stations, we first focus on stations used for passenger transport, that is, we omit freight transport, and second, we do not consider technical operations such as guiding or servicing trains, providing operational safety and managing the station premises and facilities.

The paper is structured as follows: Section 4.2 presents the theoretical foundations of the assessment approach, which is based on Sustainability Potential Analysis (SPA). Section 4.3 presents a qualitative (in-depth assessment of single stations) as well as a quantitative (screening method for a portfolio of stations) implementation of the assessment procedure derived from applying the framework to Swiss stations. The discussion and conclusion sections explore the relevance of the approach for station redevelopment processes.

4.2 Framework for Assessing Railway Stations with Regard to Sustainable Development

This section presents the theoretical foundations we rely on to assess stations with regard to sustainable development. The first subsection describes the underlying definition of sustainable development, with the following subsections then explicating our approach to sustainability assessments.

4.2.1 Sustainable Development

To assess stations with regard to the concept of sustainable development, a specification of the general definition given by the WCED (1987, p. 43) is necessary. Therefore, we refer to Laws et al. (2004), who derive from a survey of key experts three commonly used complementary understandings of sustainable development. The latter define sustainable development as being:

- the maintenance of a system within functional limits. This requires identifying the functional limits of the system and its environment and mastering managing the system within those limits to preserve development options. Therefore, an
understanding of the functions of the system, the internal structures and processes of the system and their relationships with its context are required.

- an ethical relationship with the past and the future. Actions and their respective distribution of costs and benefits must be evaluated with regard to their significance for and impacts on other actors, including current (intra-generational equity) and future generations (inter-generational equity). Sustaining options for future generations is an important aspect when distributing these costs and benefits.

- a form of ongoing inquiry. We cannot predict the needs of future generations, the advance of knowledge and technology or the exact development of complex systems and their environments. These uncertainties require learning from experiences and anticipating future challenges to revise our goals and actions. Thus, sustainable development is a commitment to a process where action is important not only for reaching provisional goals but also for forming the reinterpretation of these goals.

4.2.2 Discerning System Functions, Structures and Context

Laws et al.’s (2004) reference to maintaining a system within functional limits refers to a systemic approach. To assess stations, we therefore rely on an explicit differentiation of three basic systemic concepts: function, structures and context. A function describes what a system should do, that is, refers to an end attributed to a system. Functions are solution neutral—how they are fulfilled remains to be defined at a later point (Pahl et al., 2007). We define functions as the goals and requirements imposed on a system by its stakeholders (adapted from Lang, Scholz, et al., 2007). An example of a function of a station is to “support the transfer between different modes of transport” or to “convey the corporate image of the transport firm”. Structures refer to the system elements securing functionality (i.e., they include material structures and organizational processes), their spatial and temporal relationships and partitioning (cf. Scholz & Tietje, 2002). They define how functions are fulfilled. Examples of station structures are the length and number of platforms, opening hours of ticket booths and organization of station maintenance. Context is defined as encompassing all environmental constraints that are relevant system or impact factors (cf. Scholz & Tietje, 2002). Accordingly, context refers to the demands and conditions under which the structures of a station must fulfill their functions. Examples are density of population in the catchment area or frequency of public transport services.

Functions, structures and context of a system are interrelated. Context defines which functions are demanded at a certain area and subsequently which structures are necessary to fulfill these functions. Context also defines the conditions for functioning, that is, the situational opportunities and limitations to which the structures of the system must be adapted. The structures of a system should be organized in such a way that they fulfill the required system functions within the given context in an optimal manner.
4.2.3 Assessing Functional Potentials

Sustainable development demands for a system to develop adequate system structures to fulfill its functions—in a certain manner—within the given context. For the built environment, the structures must be implemented accordingly. Adapting a method called Bio-Ecological Potential Analysis\(^7\) (Scholz & Tietje, 2002), Lang et al. introduced Sustainability Potential Analysis (SPA, cf. Lang, Binder, et al., 2007; Lang, Scholz, et al., 2007) to assess whether a system has the potential to contribute to sustainable development. The basic notion of the SPA is that a built system—such as a station—itself cannot be sustainable, but it can contribute to or inhibit sustainable development of society by fulfilling its designated functions in a certain manner. Once the current (and possibly future) functions of the system are known, as well as the conditions under which the functions must be fulfilled, it is possible to assess the potential of the systems structures to fulfill them. Thus, SPA focuses on current system characteristics to assess future performance potentials. SPA belongs to a family of systemic methods focusing on the vitality, viability or integrity of a system as well as its interrelations with other systems (cf. Bossel, 1999; Miller et al., 2010).

SPA proposes six perceptors to assess system structures (Table 4–1): c1 performance and efficiency; c2 well-structuredness; c3 interdependencies; c4 buffer capacity; c5 adaptive capacity; c6 inter- and intra-generative equity. As indicated by their name, the abstract perceptors structure the identification of case-specific assessment criteria. Each function of a system is analyzed with regard to the six perceptors, leading to the identification of system-specific assessment criteria called functional key variables (FKV). When analyzing infrastructures such as stations, bad performance with regard to the FKV essentially indicates risks of lower future functionality and thus potentially higher procedural or financial costs to retain functionality.

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\(^7\) The key concepts of SPA have already been described by Scholz and Tietje. They observed, "The Bio-Ecological Potential Analysis (BEPA) is a means of assessing the performance and vitality of an ecological or organismic system relative to its present possibilities and boundaries with regard to certain functions in a sustainable evolutionary dynamic" (Scholz & Tietje, 2002, p305).
Table 4–1: The SPA proposes six perceptors for assessing the functional potentials of a system (adapted from Lang, Scholz, et al., 2007; Scholz & Tietje, 2002)

<table>
<thead>
<tr>
<th>Perceptor</th>
<th>Description with regard to SD</th>
<th>Focus of assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 Performance and efficiency</td>
<td>A system should fulfill its functions as effectively and efficiently as possible. If not, the utilization of resources is suboptimal and does not comply with the concept of SD.</td>
<td>- Performance indicators</td>
</tr>
<tr>
<td>C2 Well-structuredness</td>
<td>Structural properties influence the quality of the performance of a system. These qualities should be in accordance to the demands and requirements of the stakeholders. If not, the stakeholders will call for changes to the system, inducing costs.</td>
<td>- Key qualitative demands and requirements of stakeholders (also regarding procedural rules of decision making)</td>
</tr>
<tr>
<td>C3 Interdependencies with other systems</td>
<td>Each system influences or is influenced by other systems, e.g. through material flows. Interactions should be minimised, preferably be of benefit to both systems and asymmetric relations (exploitation or dependencies) avoided. If not, the system may become vulnerable to external changes or opposition to the system may arise.</td>
<td>- Negative influences on other systems</td>
</tr>
<tr>
<td>C4 Buffer capacity</td>
<td>The system must be able to cope with short-term, temporary but possibly recurring dynamics using current structures and interdependencies. Such short-term dynamics may refer to performance requirements, availability of inputs and sinks, or context conditions. Missing buffer capacity may jeopardise performance and efficiency or equity.</td>
<td>- Tolerable amount of stress/hazard sources (frequency and force)</td>
</tr>
<tr>
<td>C5 Adaptive capacity</td>
<td>The system must be able to anticipate both long-term dynamics as well as permanent changes and adapt its structures and interdependencies to them. Such long-term dynamics or permanent changes may refer to (in- or decreasing) performance requirements, availability of inputs and sinks, or context conditions. Missing adaptive capacity may jeopardise performance and efficiency or equity.</td>
<td>- Return times to normal states</td>
</tr>
<tr>
<td>C6 Inter- and intra-generative equity</td>
<td>Costs and benefits of any system should be fairly allocated within the present generation and between the present and the future generations. If not, opposition may arise and the stability of the system become endangered.</td>
<td>- Crucial long-term changes</td>
</tr>
</tbody>
</table>

4.3 Application to Swiss Railway Stations

The general framework presented in section 4.2 was developed and applied to Swiss stations. Two preliminary steps were conducted to prepare the assessment (Figure 4–1): identifying generic system functions of stations as well as classifying the stations according to the context within which they must fulfill their functions. These preliminary steps have been detailed in other publications (cf. Zemp et al., 2011a, 2011b), and are therefore described only briefly here. The assessment itself consists of the application of SPA to the multifunctional system railway station. We thereby present two different specifications of SPA (Figure 4–1). The first is a qualitative assessment protocol resulting in a detailed and
structured description of a single station. The second is a quantitative screening applicable to a large portfolio of stations based on selected indicators, thus generating a rough overview.

Figure 4–1: Components of the assessment approach

4.3.1 Preliminary System Description

Before stations could be assessed with SPA, which functions a station must fulfill and the contextual circumstances under which the functions must be fulfilled had to be clarified.

4.3.1.1 Generic Functions of Railway Stations to Understand Multiple Stakeholder Perspectives

To understand the goals and requirements against which stations should be assessed, we derived generic functions of stations. We introduce the qualifier generic to highlight that the elaborated system functions are potentially required in most stations, but their relevance can differ fundamentally. To identify the set of functions, multiple qualitative research methods were applied to survey all stakeholder groups of stations (cf. Zemp et al., 2011b). The latter resulted in a set of five generic station functions, specified in 16 subfunctions (Table 4–2). These functions range from supporting transfers between different modes of transport (involving the subfunctions access, standing and loading of vehicles; locomotion; spatial orientation; waiting; information; and ticketing for travelers) to the contribution of the station to the identity of the surrounding area. Each function can be related to users, producers, regulators, etc., thus illustrating the many different, and often conflicting, perspectives related to station redevelopment. In so doing, the set of functions supports communication and the development of a common system understanding between the stakeholders.
Table 4–2: Functions of railway stations and related subfunctions as presented by (Zemp et al., 2011b)

<table>
<thead>
<tr>
<th>Function</th>
<th>Subfunction</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1 Link catchment area and transport network</td>
<td>F1,1 Localize public transport demand</td>
</tr>
<tr>
<td></td>
<td>F1,2 Provide public transport supply</td>
</tr>
<tr>
<td>F2 Support transfer between modes of transport</td>
<td>F2,1 Secure access, loading and standing of vehicles</td>
</tr>
<tr>
<td></td>
<td>F2,2 Support locomotion</td>
</tr>
<tr>
<td></td>
<td>F2,3 Secure spatial orientation</td>
</tr>
<tr>
<td></td>
<td>F2,4 Support waiting</td>
</tr>
<tr>
<td></td>
<td>F2,5 Inform on transport services</td>
</tr>
<tr>
<td></td>
<td>F2,6 Provide ticketing</td>
</tr>
<tr>
<td>F3 Facilitate commercial use of real estate</td>
<td>F3,1 Operate business and retail area</td>
</tr>
<tr>
<td></td>
<td>F3,2 Operate advertising and promotion area</td>
</tr>
<tr>
<td></td>
<td>F3,3 Convey corporate image</td>
</tr>
<tr>
<td>F4 Provide public space</td>
<td>F4,1 Provide public space</td>
</tr>
<tr>
<td></td>
<td>F4,2 Simplify meeting of users</td>
</tr>
<tr>
<td>F5 Contribute to the identity of the surrounding area</td>
<td>F5,1 Structure area</td>
</tr>
<tr>
<td></td>
<td>F5,2 Provide spatial orientation</td>
</tr>
<tr>
<td></td>
<td>F5,3 Serve as cultural heritage and historical reference</td>
</tr>
</tbody>
</table>

4.3.1.2 Classification of Stations to Identify Comparable Cases

The structures of a station must be adapted to its specific context, thus making a direct comparison with the structures of another station impossible. Depending on the context, different structures may be necessary to adequately fulfill the functions. A station used primarily by foreign tourists must prioritize waiting-, information- and orientation-related structures, whereas a station used primarily by commuters can prioritize direct and short paths, even if these are more difficult to find. Some stations must be prepared for significant passenger growth rates, while others will probably not experience relevant changes. Comparisons of system structures based on SPA therefore require an understanding of the context of the system, that is, an understanding of which systems must fulfill their functions in comparable context. We therefore identify classes of stations with a similar context. The more similar their context, the more adequate it seems to compare the assessment of the two stations.

In our study, the 1700 Swiss stations were classified according to the key demands and requirements context poses for the functioning of the stations (Zemp et al., 2011a). Examples of included context factors are the number of jobs and inhabitants in the catchment area, or the number of transport services at the station. A cluster analysis of the Swiss stations with regard to these context factors identified seven context classes. The context classes mainly differentiate with regard to their density (number of transport services, number of jobs and inhabitants in the catchment area) and use (ranging from regular weekday commuter transit to diverse weekend tourism). An example is the context class “medium commuter feeders”. Stations in this class have a slightly denser context than the national average, due to the above-average number of inhabitants and jobs in the catchment area, regional trains and busses. These stations are practically never serviced by intercity trains. The communities in
which these stations are embedded are seldom regional centers and do not have much tourism. As the name suggests, these stations are located in the inner agglomeration areas of the Swiss Plateau.

4.3.2 Systemic Multi-perspective Sustainability Assessment

Applying the six SPA perceptors to each of the five generic functions of stations provides the basis for a multi-criteria assessment (Figure 4–2). In the following, we present qualitative and quantitative implementations of this approach.

![Figure 4–2: Each generic function of the system is assessed according to the six SPA perceptors. This leads to the identification of functional key variables (FKV), which can be operationalized using indicators (Ind<sub>wxyz</sub>). The FKV<sub>wxy</sub> or indicators may vary according to the context type class. For a description of the SPA perceptors (C<sub>1</sub>–C<sub>6</sub>), see Table 1; for a description of the generic functions (F<sub>1</sub>–F<sub>5</sub>) of stations, see Table 4–2.](image)

4.3.2.1 Qualitative Assessment Protocol for Single Cases

Assessing each function of a station according to the six SPA perceptors provides a framework for a detailed assessment of stations with regard to sustainable development. Many FKV are identified in this approach, which can be compiled in a qualitative assessment protocol for single cases.

The first version of this protocol was developed in multiple iterations. An initial set of FKV was derived using the 28 expert interviews conducted to define station functions (cf. Zemp et al., 2011b). The project team (consisting of the authors and three experts from SBB Infrastructure) then adapted this initial set of FKV by piloting it at two stations. The resulting version of the protocol was tested and the FKV further refined by eight experts representing different stakeholder groups who applied it to assess one of four stations along their field of expertise. Examples of FKV are given in Table 4–3. The whole set of FKV is
available as part of the supplementary materials. The key challenges during the development of the protocol were translating the general systemic SPA perceptors into specific FKV for each function and organizing the FKV in a meaningful way—the resulting protocol lists more than 150 FKV.

The resources required to apply the resulting protocol vary depending on the rigor of implementation. A two-hour inspection of a site and its closest surroundings, together with short and informal interviews of local stakeholders, should result in a good overview of the main issues. An explicit assessment of the dynamics the station faces (effects of changing daytime, weekday, season, context, processes among stakeholders, etc.)—as necessary for larger station redevelopment projects, for example—requires many more resources.

The protocol enables a systematic and broad assessment of a station or its redevelopment options, moderating the user’s knowledge or perspective. The many FKV highlight issues that may otherwise be overlooked. The protocol supports the user in reasoning why a situation is satisfying or not, substantiating initial gut feelings. Thus, the protocol supports stakeholders in developing a common system understanding. The qualitative nature of the protocol also has important benefits. Relevant FKV for which quantitative data is hard to collect or almost impossible to derive, for example, sightlines, can easily be included. Despite the extensiveness of more than 150 key functional variables, the experts involved appreciated the protocol and considered it a useful tool for guiding assessments of single cases.

4.3.2.2 Quantitative Portfolio Screening

Quantitative application of SPA to stations is possible when relying on a reduced set of FKV. It is not possible to find quantitative data for each of the more than 150 FKV, but a few FKV highlighting key issues can be quantified, resulting in a rough overview—a screening—of a portfolio of stations. It is thereby possible to compare stations functioning under similar contexts in a relative assessment. Such a screening provides a first overview of a class of stations and allows for cases to be selected for further examination with regard to certain interest.

A screening was conducted for the 255 stations of the S-Bahn Zurich Network to investigate feasibility and illustrate possible results. The S-Bahn Zurich consists of 28 lines crossing Zurich and Winterthur and their surrounding agglomeration on a synchronized timetable (ARE, 2004b). The S-Bahn Zurich network was chosen as it represents a rail network and a functional metropolitan area (German: "funktionaler Raum", cf. ARE, 2011). Data availability proved to be a major challenge for the screening. An initial set of FKV was chosen based on the number of times the FKV were mentioned by the experts while developing the qualitative assessment protocol. This set was then adapted according to data availability. Several important FKV therefore could not be included in the assessment (e.g., information about the number, capacity or length of the underpasses). Finally, 17 indicators were included (Table 4–3). A relative benchmarking approach was applied within each
context class (cf. Zemp et al., 2011a): the station with the best indicator value received the score “1”, and the station with the worst indicator value received the score “0”. A conservative weighing scheme was applied: All functions were evenly weighted to achieve the global weighted sum. Further, within each function the perceptors were also evenly weighted. This means we assume each SPA preceptor to be equally important. Finally, within each perceptor the indicators were evenly weighted.

We will illustrate some of the results using the stations from context class 3, named “medium commuter feeders” (cf. Section 4.3.1.2). Of the 255 stations in the dataset, 92 belonged to this class. Of these 92 stations, 35 were omitted due to missing data. The remaining 57 stations illustrate the screening results. Figure 4–3 compares the global SPA result of the stations and their distance to the cluster centroid. The stations are numbered according to their global SPA result, with station 1 achieving the best result in the class. The larger the distance to the cluster centroid, the less comparable the station context with the context of the other stations. Thus, station 2 may have achieved a very high global SPA result, but under conditions that are somewhat different from those of the other stations in that class. Care must be taken when interpreting the results of such stations. Analysis of the classification data revealed that station 2 lies in a larger city than typical of class 3, positively influencing some of the indicators.

The global SPA result is compiled from the SPA result for each function. Interesting insights can therefore be gained from the standard deviations between the results for the different functions. Two stations with an average global SPA result and low distance to the cluster centroid may illustrate this: stations 34 and 35 (cf. Figure 4–3). As illustrated in Figure 4–4, these stations differ with regard to the deviations between the functions. Station 34 has similar ratings for each function, and thus a low diversity between the functions, while station 35 has large differences between the ratings of the single functions. The SPA results for each function of these two stations are presented in Figure 4–5. Stakeholders assessing station 35 predominantly from the perspectives of the link between the catchment area and the transport network (F1) or the contribution to the identity of the municipality (F5) will most probably have satisfactory results, while a stakeholder focusing on the perspective of the transfer (F2) will hardly be satisfied (a case inspection supported these assumptions). The standard deviation between the functions not only illustrates the importance of the multi-perspective approach but may also indicate potential controversies among stakeholders at otherwise inconspicuous stations. Figure 4–4 can thus be read in the following manner: stations toward the bottom left have generally low results for all functions and require closer inspection, while stations toward the top left have comparatively good results for all functions and may serve as role models. Stations toward the right, that is, with high diversity, generally require a more careful interpretation. In the latter cases, a station perfectly meets the requirements of some stakeholders while others would demand immediate changes, or some functions may be overdeveloped on the cost of others.
Table 4–3: Indicators used to assess the S-Bahn Zurich railway stations

<table>
<thead>
<tr>
<th>Functions</th>
<th>Perceptors</th>
<th>Functional Key Variables (FKV)</th>
<th>Specification: Indicators</th>
</tr>
</thead>
</table>
| F1: Link catchment area and transport network | C1: Performance and efficiency | Is the passenger potential being realized? | a) Passenger frequency per number of train and bus connections  
b) Passenger frequency per number of inhabitants and jobs within the catchment area*
| C2: Well-structuredness | | Is the station centrally located? | a) Average distance of inhabitants and jobs within the catchment area* to the station  
b) Minimal distance from the station to the centre of the community or to the next central zone (“Zentrumszone”)*
| C5: Adaptive capacity | | Is urban growth directed toward the station? | a) Change of the average distance of inhabitants and jobs within the catchment area* to the station in the last 10 years |
| F2: Support transfer between modes of transport | C1: Performance and efficiency | Are the built structures used efficiently? | a) Number of platforms per trains per day  
b) Yearly cleaning and maintenance costs per passenger frequency |
| | C4: Buffer capacity | Do the built structures reach load limits? | a) Total platform length per passenger frequency |
| F3: Facilitate commercial use of real estate | C1: Performance and efficiency | Are the commercial offers attractive? | a) Number of commercial offer categories (including: Billboards, display cabinets, vending machines, offices and medical practices, kiosks, restaurants, shops) |
| | C4: Buffer capacity | Can daily passenger fluctuations (i.e., off-peak hours) be compensated by local inhabitants and jobs? | a) Number of park-and-ride parking spaces per passenger frequency |
| | C5: Adaptive capacity | Can the commercial offers be adapted to changing demand? | a) Sales floor area |
| F4: Provide public space | C1: Performance and efficiency | Is the station being used as a public space? | a) Fraction of commercial use which is taxed |
| | C2: Well-structuredness | Does the station provide agreeable amenity values? | a) Number of vandalism incidents per platform and year  
b) Safety index: whether there have been incidents of aggression or theft and of sexual harassment on the station premises |
| | C4: Buffer capacity | Does the station lose its amenity values at night? | a) Number of commercial uses categories attracting non-passengers (includes: kiosks, restaurants, shops, apartments) |
| F5: Contribute to the identity of the surrounding area | C3: Interdependencies | Are the buildings and structures useful for their primary functions? | a) Fraction of vacant building floor area |
| | C5: Adaptive capacity | Is the municipality actively planning the development of the station? | a) Whether the station is in a municipal building zone and whether developments in this zone require a design plan |

* The catchment area is defined as the area around the railway station within a radius of 700 m  
* This indicator is only included if the distance is less than 700 m, i.e., lies within the catchment area
4. Multi-perspective Assessment of Railway Stations with Regard to Sustainable Development

Figure 4–3: Global SPA result and distance to the cluster centroid of S-Bahn Zurich railway stations in context type class 3. The stations are numbered according to their global SPA result. Stations 34 and 35 are further discussed in Figure 5.

Figure 4–4: Global SPA result and diversity between functions of S-Bahn Zurich stations in context type class 3. The stations are numbered according to their global SPA result. Stations 34 and 35 are further discussed in Figure 4–5.
4.4 Discussion

We departed from the insight that the redevelopment of stations—which represent a crucial entity in transport and land use systems—is a complex challenge, requiring coordination of action and integration of knowledge of a diverse set of stakeholders. To support these challenges, we developed an approach for an integrated assessment of stations with regard to sustainable development based on the SPA. The forward-looking framework focuses on the functional potentials of the stations and what could endanger or maintain their functionality. The framework relies on identifying stations’ generic functions, an understanding of which stations function in comparable contextual conditions and an assessment of the stations’ structures according to the six SPA perceptors. A qualitative protocol for the systematic and comprehensive assessment of single cases and a quantitative approach for the rough screening of whole portfolios are presented and illustrated using examples. In the following, we discuss the results and how they may support station redevelopment. Furthermore, we outline further research to enhance the method.

4.4.1 Application to Station Redevelopment

The qualitative protocol and the quantitative screening lead to better understanding of the potential of stations to contribute to the sustainable development of society. Stations with bad results are seen as risking lower future functionality and thus potentially requiring higher procedural or financial costs to maintain functionality in the future. In the following, we discuss how the assessment approaches may support specific stakeholder groups in station redevelopment processes.
Some stakeholders deal with only a single station (e.g., local communities and landlords), while other stakeholders deal with many stations (e.g., cantonal and federal authorities, real estate companies, rail infrastructure firms, rail passenger transportation firms and many other public transport firms such as bus firms). We call the first group local stakeholders and the second regional stakeholders. We emphasize that the term regional stakeholder refers to transport- and land-use-related stakeholders and not only to rail companies. The application of the protocol or screening differs for local and regional stakeholders. Local stakeholders may for example be more concerned with adapting a single station to their specific requirements, while regional stakeholders may be more concerned with standardizations and generalizations to allow for systematic and efficient management of their portfolio of stations.

4.4.1.1 A Body of Knowledge for Station Redevelopment

When introducing the protocol and screening in section 4.3, we illustrated how these instruments contribute toward a multi-perspective assessment of stations with regard to sustainable development to support redevelopment processes. In the following, we would like to highlight the importance of applying a systemic methodology. Not only are each of the five generic functions of stations addressed, but they are each addressed in the same manner. Stakeholders of a redevelopment process can therefore not only comprehend the analysis approach and results in their own field of expertise but also relate to those of the other fields. Diverse interests and complex sectorial analyses can be integrated into a single framework. Just as the concept of sustainable development provides a common denominator for all the stakeholders involved in station redevelopment and is thus a good point of departure for integrating their multiple perspectives, the systematic methodology contributes to the development of a common system understanding among the stakeholders and facilitates knowledge integration.

The systemic approach allows a body of knowledge for station redevelopment to be developed by explicitly articulating experiential knowledge (cf. Nonaka, Toyama & Konno, 2000). The many FKV included in the protocol are a valuable knowledge base describing the benevolent structural characteristics of a station. Such a reference not only serves as a guide for local stakeholders in addressing the complex topic of station redevelopment and deriving a clear picture of their stakes and goals but also supports them in adequately articulating their own stakes in the redevelopment process. Regional stakeholders can use the protocol or screening to secure quality in the single redevelopment process, and derive standards, benchmarks and guidelines.

4.4.1.2 Deriving Standards, Benchmarks and Guidelines

The screening results presented for context class 3 can be used to select interesting cases for further examination with the assessment protocol. The best (e.g., 1, 3 and 4), worst (e.g., 56 and 57) as well as outlier stations (e.g., 2 and 33) of context class 3 with regard to the
screening might be good candidates. Such a process can be repeated several times, improving
the understanding of the screening results and identifying additional or adapting existing
FKV of the assessment protocol—possibly considering specificities of the assessments for
each class. But the most important effect of such an iterative application would be identifying
decisive issues for station redevelopment, allowing the assessment protocol to be
consolidated and the screening improved (i.e., choice of better and fewer indicators). These
decisive issues—FKV that prove to be of particular importance—can then be further
specified with benchmarks, leading to the definition of standards.

Standards are the (implicit or explicit) basis of every redevelopment process. Regional
stakeholders compare their stations with their standards to prioritize their actions. It may be
illusionary to assume that stakeholders always systematically focus their actions based on a
comprehensive assessment procedure. However, once a single stakeholder decides action is
necessary at a certain station, the tools presented here make it possible to develop a
comprehensive picture and motivate all stakeholders for an integrated redevelopment
process.

4.4.1.3 Monitoring Developments

The screening, supported by the assessment protocol, can also be used by regional
stakeholders to monitor the development of single stations, whole classes, context and
generic functions. Comparing data from different years enables changes in the sustainability
potential of single stations and whole classes to be tracked. For example, the federal
government could monitor the actions of its subsidized rail companies or identify and
anticipate slowly arising challenges. Time series allow for more than just identifying the best
or worst cases. Similar to the iterative application of the screening and assessment protocol
described in subsection 4.1.2, a more detailed assessment of stations with the smallest or
largest changes may further support a better understanding of decisive issues for station
redevelopment.

Monitoring changes over longer timeframes would support a better understanding of
changes in the context of stations, the conditions and demands under which they must
function. Examples are land use densities and local public transport connections at the
stations. In addition, changes in the functionalities can be monitored. This can include
changes such as the relative weights of the functions or the development of new functions.
An example therefore is cargo handling, which was once required at most Swiss stations and
is now centralized in large terminals.

4.4.2 Methods Enhancement

For a better understanding of the developed tools, we briefly compare our assessment
approach to an earlier SPA application before discussing potential enhancements of the
assessments.
4. Multi-perspective Assessment of Railway Stations with Regard to Sustainable Development

4.4.2.1 Second Application of Sustainability Potential Analysis

This paper presents the second application of SPA. There are two major differences compared to the first application, which involved landfills (cf. Lang, Binder, et al., 2007; Lang, Scholz, et al., 2007). The first difference is the explicit consideration of multiple system functions. Explicitly identifying the generic functions of a system leads directly to the stakeholders of the system and thus provides a basis for an integration of their perspectives. Stakeholders are supported in better understanding their interrelations—a consistent challenge in station redevelopment (Bertolini & Spit, 1998; Wolff, 1999): Transport-related stakeholders may better understand the impact of station organization on land use, while a stakeholder related to land use may better understand the requirements and constraints of the transport system. The multiple functions dramatically increase the number of FKV. We have tried to address this challenge by developing quantitative and qualitative applications of the SPA, as well as by focusing the quantitative screening not only on the overall score but also on the diversity between the functions.

The second difference of our application of the SPA compared to the first is the explicit differentiation of context types, leading not only to a novel quantitative classification approach for stations but also refining the definition of the SPA perceptors. The classification further enabled comparisons between stations with similar context, allowing for a relative assessment of the stations, as well as for a single station to represent more than just a case study but to be representative for a certain context type. The context types have not been characterized with regard to their adequacy for station functioning. The next step could therefore be to describe how far context can be redeveloped to provide optimal environments for station functioning. Such knowledge could be either directly included in station redevelopments or indirectly inform the transport and land use actors.

4.4.2.2 Weighting of the Functions and Utility Values for the Indicators

Currently, the screening weighs all five generic functions evenly and derives utility values from comparisons of the stations. This will hardly lead to an optimal representation of site-specific redevelopment values and priorities (Lélé & Norgaard, 1996). Including class-specific function weights and absolute utility values for the indicators may therefore seem a logical approach for improving the representation of the actual situation within the class. However, because the screening results provide only a rough overview and always have to be complemented with local assessments, we feel such specification would be adequate only after extensive iterative improvements of the portfolio screening and the assessment protocol (cf. Section 4.1.2). Assessment results should not define but support a case-specific redevelopment process. From this perspective, it seems reasonable to keep the assessment as simple as possible. More promising may be the development of an overall quantitative summary rating for the assessment protocol—although this requires utility values to be adapted according to stakeholder group and station context class.
4.4.2.3 Indicator Selection and Data Availability

The limited data severely curtailed indicator choice for the quantitative screening. Nonetheless, the authors were astonished how well the analysis results reflected the actual situations—possibly an indication of the quality of the assessment design. In section 4.2.2, structures are defined as encompassing material structures and organizational processes. Partly also due to data (un-) availability, the screening currently focuses more strongly on the built structures of the stations, with a corresponding underrepresentation of procedural structures. Future iterative applications of the portfolio screening and assessment protocol (cf. Section 4.1.2) should further investigate the FKV describing procedural aspects of station redevelopment. Although indicator selection will remain a compromise between importance and data availability, insights from such a process could reduce the number of necessary indicators and provide a strong argument for acquiring data for crucial indicators.

4.5 Conclusions

Assessment results are heavily dependent of the stakeholder perspective taken. By securing the structured integration of different stakeholder perspectives both the qualitative protocol and the quantitative screening support the necessary coordination of actions and foster the integration of knowledge in the decision-making processes of station redevelopment. The applied definition of sustainable development encompassing i) the maintenance of a system within functional limits, ii) an ethical relationship with the past and the future and iii) a form of ongoing inquiry is thereby pivotal. It not only serves as a common denominator upon which different stakeholders can establish a common system understanding but also relates to key challenges of the assessment tools. Firstly, SPA does enable the application of a system limits approach to infrastructures such as stations, but elaborating the corresponding system characteristics is not straightforward. Secondly, the multi-functionality of stations leads to the question of weighing functions and balancing trade-offs between functions. We see this not only as a matter of optimizing utility for single stakeholders but also as a question of an ethical relationship with the past and the future that must be addressed within the redevelopment process. Finally, the constant development of the functions and the contexts of stations require an ongoing learning process with regard to adequate system structures.

All stakeholders concerned with station redevelopment may profit from such integrated assessment tools. The financial bottlenecks and development challenges Swiss public transport currently faces due to the rapid increase in travel demand may accelerate the development of standards to improve efficiency, for example. The tools presented in this paper can contribute to developing these standards, and help ensure that the interests of all stakeholders are considered, thus fostering adequate solutions within the larger context of concentrated development around nodes of public transport.
Acknowledgements

The authors would like to thank all experts for their contributions to the expert interviews and feedback on the assessment protocol during station inspections; the project partners from the Swiss Federal Railways (SBB): Johannes Schaub, Beat Hürzeler and Marionna Lutz for their support in many phases of the work; and Ulrich Weidmann for his comments on an earlier version of this text. This work was conducted within a broader study entitled “Sustainable Positioning of Railway Stations”, co-founded by the SBB and the Natural and Social Science Interface.
Sustainable Positioning of Railway Stations
Abstract

This thesis aspired to conceptualize stations and enable their assessment with regard to the challenge of sustainable development, thus fostering knowledge integration and the coordination of stakeholders’ actions. The key challenge was the development of an adequate conceptualization that allowed for the analysis and assessment of stations with regard to sustainable development. A systemic approach was elaborated, framing stations as systems that utilize their structures to fulfill certain functions within specific contexts. The functions, contexts, and structures of stations were each explicitly addressed in three separate publications. Integration of knowledge and coordination of actions were not only a goal of this thesis, but were already applied during its elaboration, in the form of a mutual learning process between science and society. The following concluding remarks, therefore, first describe the transdisciplinary learning process within which the systemic conceptualization was elaborated. The two concluding subsections then reflect on the systemic conceptualisation, the thereby derived insights and future potentials both with regard to practical questions of station redevelopment and methodological questions of assessment fostering integration and coordination for sustainable development.
5.1 Transdisciplinary Learning Process

This thesis was developed within the project Sustainable Positioning of Railway Stations (SPRS), a joint project of the SBB Infrastructure and ETH Zurich, Natural and Social Science Interface (cf. Section 4.1.3.3). The following subsection briefly outlines the mutual learning processes of the SPRS project, in order for the reader to better comprehend the setting within which the research results presented here were developed.

If the SPRS project can be described as a success, then it is because of the mutual learning process among the involved experts. The co-leaders and the members of the working group jointly advanced the constantly developing research project. The cliché may be that in a transdisciplinary process science contributes the current state of knowledge and practitioners contribute the real world challenge; but in practice, the contributions were much less delineated. Most important was the open and productive atmosphere allowing for a critical reflection of theories, options and examples, as well as the genuine interest of all participants in both the case and the applied theories.

Intermediate project results and potential advancements were presented to the stakeholder board, which again critically reflected upon their utility from different perspectives (Table 5–1). Just as the topics discussed with the stakeholder board varied greatly, so the composition of the stakeholders also varied. The reactions of the stakeholders to the meeting were generally very positive. We attribute this success not only to the given presentations, but also to the fact that the ETH Zurich was perceived as a neutral host, as well as to the unusually wide range of participating stakeholders. Together these factors enabled participants who otherwise only meet as “opponents” in the negotiation processes of specific projects to openly discuss critical issues of station redevelopment—a first step of knowledge integration. Accordingly, the discussions were always the most important element of the meetings. The stakeholder board also enabled contact with further experts, who provided additional insights into current developments and valuable data.
Table 5–1. Meetings of the SPRS Stakeholder Board.

<table>
<thead>
<tr>
<th>Date</th>
<th>Title: Agenda</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.01.2007</td>
<td>SPRS Kick-off: Introduction of project, specification of guiding question, first results from focus groups, outline of next steps</td>
<td>11 (only SBB)</td>
</tr>
<tr>
<td>06.02.2008</td>
<td>Functions of Railway Stations: presentation and discussion of seven generic station functions, weighting of functions with regard to two specific stations, outlook on qualitative assessments</td>
<td>24</td>
</tr>
<tr>
<td>29.10.2008</td>
<td>Classification of Railway Stations: Presentation and discussion of initial classification approach and results, data availability, processes of station redevelopment</td>
<td>21</td>
</tr>
<tr>
<td>04.02.2011</td>
<td>Final meeting: Project overview, insights from portfolio screening and assessment protocol, utility for practice</td>
<td>18</td>
</tr>
<tr>
<td>11.02.2011</td>
<td>Forum Station Redevelopment: Presentation of SPRS results, relevance from the perspective of transport systems, relevance from the perspective of land use (the Forum was a follow-up event using the results from SPRS to invite selected leading experts for discussion of station redevelopment)</td>
<td>17</td>
</tr>
</tbody>
</table>

Two reports were compiled for the stakeholders involved in the SPRS project. These subsume results from the research project, SPRS, and discuss their relevance in station redevelopment practice. The two reports, both in German, are:

Zemp et al. (2008) *Funktionen des Bahnhofs: Grundlagen zur Analyse des Beitrags von Bahnhöfen zu einer nachhaltigen Entwicklung*. The five generic functions of stations are presented. The process of their elaboration, as well as how they can be applied within station redevelopment projects, is described. A first set of assessment criteria based on the functions and the SPA are given. The main conclusion is that station redevelopment requires an integrative perspective consolidating the goals and requirements of many stakeholders.

Zemp (2012) *Nachhaltige Positionierung von Bahnhöfen: Zusammenfassung der Projektergebnisse für die Praxis*. Each of the three scientific papers from the SPRS project is introduced and insights for station redevelopment are discussed. Examples of how the results already are or could be implemented in the everyday practice of station redevelopment are given. An extensive appendix of over 100 pages includes the original text of the three scientific publications, the local assessment protocol, as well as additional material that illustrates the developed station classes. The report is an attempt to introduce and make the scientific publications of the SPRS project available to practice, as we consider these publications highly relevant for practice.
5.2 Redeveloping Transport Nodes

This thesis elaborated a systemic conceptualization of stations in order to support integration of knowledge and coordination of actions for station redevelopment. The derived results illustrate how stations can be meaningfully assessed with regard to the challenge of sustainable development and support for forward-looking and proactive development. The following section reflects on why the chosen approach may have been so productive, whether the achieved results may be applied to other countries and transport nodes, and how the assessment results may foster coordinated and integrated decision-making processes.

5.2.1 Analytical Guides for Integrated Redevelopment

Together, the results of the three publications (cf. Zemp et al., in prep.; Zemp et al., 2011a, 2011b) provide a systematic language for station description, and have the potential to change how stakeholders perceive their stations. Due to the mutual learning process, the practice partners of the SPRS project have already translated many of the lessons learned into everyday practice.

Identifying different generic functions was initially thought of as an unavoidable first step for targeted assessment. With due hindsight, identifying the generic functions may actually have been the key step for the development of the systemic conceptualisation presented in this thesis. The explicit description of the multifunctional nature of stations not only formed the basis for the subsequent classification and assessment steps, but also illustrates what may be the key challenge of station redevelopment: aligning a diverse set of partly conflicting goals and requirements imposed on the system by its stakeholders. The functions provide a common language for station description while illustrating the requirement of integrated redevelopment. Acknowledging and understanding the multifunctional nature of stations may also have been a key to the development of station-internal zoning plans—one of the developments that the partners from the practice describe as a project spin-off.

The quantitative classification of station contexts allows for the identification of stations that function under comparable conditions—a prerequisite for comparative assessments and strategic planning. The classification again illustrated the one-sidedness of current station redevelopment initiatives and the need for integrated redevelopment. Not only could the multifunctionality of stations be introduced to classification, but classification itself was much more closely linked to station assessment. The results especially show how the many stations with lower passenger frequencies may be more adequately described. Although the results illustrate the potentials of classifications as strategic management tools, practical implementation of novel classifications will be slow at best. Classifications influence (public) resource distributions; actually developing and implementing a new classification therefore requires a laborious political process. Directly applicable—and thus possibly more influential—is an improved understanding of which stations are actually comparable, and by
which measures. Questions of classification, or categorization, are also questions of framing—of how we simplify the problem at hand. Stereotypes, or heuristics, i.e., what we perceive as a comparable example or situation, contribute heavily to framing. This is a key aspect of decision-making, potentially reversing judgement outcomes (Tversky & Kahnemann, 1981). From this perspective, the importance of the question of classification cannot be overstated for the sustainable positioning of stations. In this respect, the 1700 Swiss stations allow for much comparison and learning. The classification relying on station contexts once more highlights the important interrelations of a station and its surroundings. The involved practice partners have already integrated such insights, for example, into new signage concepts.

The portfolio screening and the assessment protocol derived from the SPA are first rough outlines of proofs of concept. These two assessment tools can provide a body of knowledge for station redevelopment to both industry and authorities, can contribute to the development of standards, and can support the monitoring of developments. For future improvements, a practical learning process from iterative applications of the portfolio screening and assessment protocol can lead to demanding but highly practical tools for everyday station redevelopment. Issues to be addressed afterwards may include the weighting of functions (both per class and for a single case); the handling of trade-offs; the validity of the portfolio screening results (which could be addressed through single-case assessments or historic comparisons); and the inter-rater reliability of the assessment protocol.

5.2.2 Importance of the Anthropocentric System Description

The anthropocentric approach, especially with regard to the definition of the term “function”, may have been the key for the explicit elaboration of the functions, contexts, and structures, to become so instructive.

We defined “functions” as the goals and requirements imposed on a system by its stakeholders (Zemp et al., 2011b). This definition not only relates to utility concepts, thus providing a link to the systems stakeholders, but also results in solution-free descriptions, i.e., without predefining the structures of the system. The field of ecosystem services provides an alternative definition of the term “functions”. The Millennium Ecosystem Assessment (2005) refers to the “ecosystem functions” definition of de Groot et al.: “the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly (de Groot, 1992). Using this definition, ecosystem functions are best conceived as a subset of ecological processes and ecosystem structures” (de Groot, Wilson & Boumans, 2002, p. 394).

Comparing these two definitions highlights the influence of the anthropocentric viewpoint. While all of the processes and structures of built systems such as stations are purposefully built and maintained in order to fulfil certain functions, this is not the case for ecosystems.
On the contrary, most processes and structures of ecosystems were present before humankind noticed that some of them might provide valuable functions to humankind. What we describe with the term “function” is therefore described under the term “goods and services”, and, consequently, the term “function” is used to describe the capacity of a system to provide such goods and services, i.e., related to the functioning of the ecosystem.

The anthropocentric reference to system utilities allows for interlinking the stakeholders with the system. As such, the functions provide a pivot between the technical literature and the planning literature on station redevelopment. They further allow for a hierarchical approach: each function may be broken down into subfunctions, allowing for the choice of an adequate assessment level. This hierarchy is developed according to the goals and requirements of the system stakeholders, while for ecosystems it is more likely to be developed according to their existing processes and structures.

5.2.3 Adaptability to other Nodes of Public Transport

In presenting the generic functions of Swiss stations we argued that these functions could not only be applied to all types of stations, but also to stations in other countries (cf. Zemp et al., 2011b). The main argument was that no additional important functions are to be expected, but that the structures of the system must be adapted to the specific context of the station.

Our focus on passenger stations may have introduced a bias into our assumption that station functions are rather stable over time and space. Cargo transport was an important function of Swiss stations (cf. Zemp et al., 2011b). Excluding cargo thus also meant not having to deal with questions of changing functions—possibly an important consideration for stations of other countries.

The argument of adapting structures according to context also provides insights into how the results of this thesis may be translated to station redevelopment in other countries. The context classes would certainly have to be reconsidered, possibly also the context factors relevant for station functioning upon which the classification relies. The functional key variables identified for the assessment protocol and the portfolio screening would also have to be adapted to the different context classes.

If the results can be applied to all types and sizes of railway stations, then possibly they can also be applied to other modes of public transport. On the one hand, the differences between high-speed rail, regional rail, metro, and tram services, are gradual, concerning mainly the distance and speed of the transport services. Similarly, one can argue that ships and airplanes are just other types of vehicles, but that they also require specific nodes where passengers may board and disembark. Railway stations may serve as a general example for such nodes of public transport.
5.2.4 Contribution to Decision-making Processes

Sustainable development is a process. This last section discusses how the achieved results may contribute to and influence the decision-making processes in station redevelopment. When applied in parallel to each function of a system, the perceptors of the SPA may miss questions relating to the system as a whole, possibly described as balance or diversity. The conflicts between the functions illustrate this point. The SPA can thus be understood as analysing a system in the classic sense: the separation of a whole into its constituent elements. From this perspective, a better integration with decision-making processes may be understood as an important step towards synthesis.

A decision-making process can be conceptualized as an iterative cycle composed of the interrelated steps of problem identification, system analysis, alternatives development, choice of alternative (the decision), implementation (i.e., action), and evaluation (learning) (cf. Argyris, 1999; Rotmans, Kemp & Van Asselt, 2001; Scholz & Tietje, 2002; Wysocki, 2007). Sustainable development requires that the decision-making processes (i.e., actions) of actors are coordinated, and that knowledge from all actors is integrated into the decision-making process.

Generally, the systemic approach supports both integration and coordination by illustrating the many interrelations (i.e., among functions, between functions and context) in the system railway station. The results presented in this thesis may specifically foster the coordination of decision-making processes, i.e., actions, by illustrating these interrelations. The described classifications, screening tools, and assessment protocols, may lead to the development of standards or guidelines. Their development and constant improvement can also serve as a form of indirect coordination. Most of the results presented in this thesis further foster knowledge integration for decision-making processes. Illustrating the many interrelations serves as an argument and a motivation for integration. The functions allow for a systematic identification and inclusion of potential stakeholders in a redevelopment process (e.g., users, providers, regulators, etc., for each function). The systemic approach, together with the functions, provides a common language for the actors. Relating to the functions, it is possible to discuss what the goals of the system are and how they interrelate, e.g., how trade-offs are managed. The broad approach relying on multiple functions and their interrelations within a context generally results in the need for integrative tools.

The assessment of alternatives is a key step in decision-making. It is not only explicitly applied in order to choose from alternatives, but it also implicitly guides problem identification and system description. A shortcoming of this thesis may be the generally strong concentration on built structures, and the associated under-representation of procedural structures that influence everyday station functioning and redevelopment (cf. Zemp et al., in prep.). Future research, both on station redevelopment and systemic sustainability assessment, may focus on such procedural aspects, by e.g., analysing how...
decision-making processes are formally organized. The concepts of transdisciplinarity and mutual learning, fundamentals of the project within which this thesis was elaborated (cf. Section 1.3.3), will most certainly be of central importance.

5.3 Systemic Assessment with Regard to Sustainable Development

This thesis relied on the SPA in order to assess stations with regard to sustainable development. The explicit elaboration of system functions, contexts and structures can also be ascribed to the SPA, which makes a clear reference to these basic system elements. Given the pivotal role the SPA served in this thesis, and the space available here, some of the insights, questions, and research potentials with regard to this method are discussed. This may also help better understand the role, strengths, and limitations of the achieved research results.

After a first application to landfills (supporting the development of new landfill regulation, cf. Lang, Binder, et al., 2007; Lang, Scholz, et al., 2007), this thesis includes the second practical application of the SPA (cf. Zemp et al., in prep.). Lang, Scholz et al. (2007) demonstrated that the SPA is both feasible and sensitive to issues of sustainable development. Key insights elaborated by this thesis result from the explicit differentiation of functions, context, and structures, thus identifying multiple functions and comparable contexts, and specifying the SPA as an assessment of system structures with regard to system functions and context. The functions serve as a pivot between stakeholder integration and system assessment. For the interpretation of the perceptors of the SPA, this is a significant difference to Lang, Scholz, et al. (2007). They describe the SPA perceptors as together addressing the functional, structural, and contextual issues of a system, while Zemp et al. (in prep.) interpret the perceptors as assessing system structures with regard to specific functions in a specific context. This modification opens questions mainly concerning the definition of the perceptors—a challenge that relates directly to identifying the perceptors.

5.3.1 Describing Well-structuredness of Systems

Through the explicit differentiation of system functions, structures, and contexts, it becomes clear that the SPA deals with the structures of systems and their relation to system functions and context—i.e., the SPA is concerned with the well-structuredness of systems. The respective perceptor \( C_2 \), referring to “internal organization and interfaces” (Scholz & Tietje, 2002, p. 323) and once introduced in the Bio-Ecological Potential Analysis (BEPA) in order to circumvent a “black-box consideration” (Scholz & Tietje, 2002, p. 323) of systems, thus requires reconsideration.
5. Concluding Remarks

The above argument may be used in order to directly omit the perceptor “well-structuredness”, especially given the fact that Scholz and Tietje acknowledge that the “well-structuredness evaluation does have some commonalities” with the other perceptors (Scholz & Tietje, 2002, p. 323). On the other hand, intuition suggests that certain implementations of a system are more or less well-structured than others. So two questions must be asked when reconsidering the perceptor “well-structuredness”: 1) is the issue intuitively allocated to the topic of well-structuredness also addressed by another of the five perceptors (i.e., does one structural implementation of a system compared to another lead to, for example, less efficiency?); and 2) what are generally benevolent characteristics of system structures? Scholz and Tietje (2002) mention that system structures can be described according to the number, size, and form of the subunits of a system, as well as their spatial arrangement and functional interrelations. Assessment must focus on the required system subunits, whether they are suitably connected, adequate in size and numbers, etc. Scholz & Tietje (2002) speak of “functional subunits”, when referring to an optimal size for system subunits and their significance to the functionality of the whole system (Scholz & Tietje, 2002, p. 323). But system subunits may have many more attributes besides quantity, size or interrelatedness. It therefore remains unclear as to how this perceptor should be defined, as each of the other five also either directly deal with structural properties of the system, or at least refer to well-structuredness (e.g., in order to achieve efficiency). Within the SPRS, this perceptor was related to the demands and requirements of the users of a function, while the SPA otherwise more generally refers to a perspective of society as a whole.

5.3.2 System Response to Context Change

The SPA currently includes two perceptors referring to the response of the system to context change. Buffer capacity \( C_4 \) refers to short-term context changes, which must be addressed primarily by using existing system structures, while adaptive capacity \( C_5 \) refers to long-term or permanent context changes requiring adaptations to the existing system structures.

It is interesting to note that current literature on the resilience of social-ecological systems uses three terms to describe system responses to context change: resilience, adaptability, and transformability (Folke et al., 2010). Their definitions refer to the metaphor of a three-dimensional stability landscape with the system sitting within a certain basin of attraction, or a stability domain (cf. Walker et al., 2004). Folke et al. (2010) provide the following definitions: Resilience is generally defined as “the capacity of an ecosystem with alternative attractors to persist in the original state subject to perturbations”, which is equivalent to the perceptor buffer capacity \( C_4 \) of the SPA. This definition highlights that a system may be pushed into another basin of attraction, resulting in a critical transition to a qualitatively different system state (e.g., the change from forest to scrubland due to heavy logging). The second term, adaptability, is defined as “the capacity of a social-ecological system to learn, combine experience and knowledge, adjust its responses to changing external drivers and
internal processes, and continue developing within the current stability domain or basin of attraction”, which is equivalent to the perceptor adaptive capacity ($C_a$) of the SPA. The third term, transformability, is defined as “the capacity to create a fundamentally new system when ecological, economic, or social structures make the existing system untenable” (Walker et al., 2004). Using the terminology introduced in this thesis, transformability refers to changing functions and different levels of system hierarchy. In order for the system to maintain functionality at a higher level it must change functions at a lower level. Examples given by Folke et al. (2010) are “when a household adopts a new direction in making a living or when a region moves from an agrarian to a resource-extraction economy”. Hence, securing functionality at a higher level may require a subsystem to be abandoned or dismantled. Together the three terms are used in order to illustrate that resilience theory is not about preventing “novelty, innovation and transitions to new development pathways”, but that system change is a requisite to persisting in a constantly changing context.

With regard to the SPA, the term “transformability” opens questions concerning the integration of system hierarchies—which we discuss below—and of changing functions. From the perspective of the SPA, transformability can only be assessed after new functions of a system are known. This challenge is reflected in the debate on general vs. specific resilience (Carpenter et al., 2001) and by the fact that Folke et al. (2010) acknowledge that transformability generally requires “high levels of all forms of capital, diversity in landscapes and seascapes and of institutions, actor groups, and networks, learning platforms, collective action, and support from higher scales in the government structure”. Similarly, architects design their buildings with increased redundancy and with options to switch use in order to support variability for unknown future use (cf. Ellingham & Fawcett, 2006).

These definitions highlight that context changes include both changes of the conditions for functioning and changes of the functions imposed upon the system. A historic example of changes in station functions is the rise of passenger transport and the demise of freight transport. Without being able to consider transformability, i.e., the adaptation of a system to new functions, the SPA may well be described as function-conservative. As such, the SPA may be better suited for the assessment of systems where functions evolve slowly. But such a conservative definition of the SPA somewhat contradicts the idea of sustainable transitions—although transition literature does generally seem to focus more on structural changes than changes of functions (cf. de Haan & Rotmans, 2011; Gunderson & Holling, 2001; Loorbach & Rotmans, 2006; Rotmans, Kemp & Van Asselt, 2001). The challenge of transformability can be taken as an indication that future applications of the SPA do not only require a thorough understanding of system functions, but also that future definitions of the SPA perceptors should include procedural issues such as learning, foresight, and anticipation, in order to identify upcoming changes of system functions.
5.3.3 Hierarchies—Interrelation of System Structures and Context

From a transport perspective, stations are part of a railway line, which are again part of a railway network. Multiple such networks (e.g., for rail, cars, bicycling, walking, planes, ships) together encompass a transportation network. From a land-use perspective, a station is one site of many in a neighbourhood or region. A railway station can thus be described from different hierarchic levels.

The interrelations of these levels could not be satisfactorily represented in the assessments, despite the according perceptor, as networks have different functions than transport nodes. Examples are requirements concerning comparable platform length throughout a rail line, and interrelations of commercial uses at different stations. How the SPA can adequately address networks or hierarchies, how networks and hierarchies can adequately be assessed with regard to sustainable development, is not only an interesting, but also an important future research topic. Many of the reasons why railway stations have become a focus within the realm of sustainable transport and land use developments can only be described using multiple hierarchic system levels. Identifying critical constellations in the network—as e.g. Wiek et al. (2007) have illustrated for actor networks—may provide a first starting point.

5.3.4 Perceptor Identification and Definition

Is the SPA an adequate approach to assess infrastructures with regard to sustainable development? As interdependencies are explicitly addressed, it is probably more adequate than e.g., triple bottom line approaches. The functioning of a system is considered within its context. As the triple bottom line approaches deal with three resources, a focus is often laid on efficiency, measured e.g., by life-cycle assessment (LCA), life-cycle costing (LCC), and social life-cycle assessment (S-LCA) Such methods can be an important contribution to an SPA, but must be complemented with additional insights. When developing the assessment protocol, all perceptrons were necessary for addressing the issues mentioned by the stakeholders, and all the issues mentioned by the stakeholders could be represented using the six perceptrons. The general perceptrons describing benevolent system characteristics could easily be specified for the case of stations. This may serve as a first indication of the sufficiency of the method.

Generally, as already discussed for certain perceptrons above, a further specification of the perceptrons of the SPA would be instructive. This could include negative definitions, much like the partial complementarity of resilience and vulnerability (Miller et al., 2010). Improved definitions may support the identification of a reduced set of key functional variables of a system. Simple models can be extremely powerful in explaining key aspects of a system (cf. Ghaffarzadegan, Lyneis & Richardson, 2010). The challenge lies in simplification; the adequate framing that separates what is important from what is noise.
A further specification of the SPA perceptors will quickly raise the general question of which systems the SPA may be applied to and how the perceptors are identified, respectively. Currently the identification of the perceptors and, e.g., their advancement by Lang, Scholz et al. (2007) and Zemp et al. (in prep.) is based on inductive reasoning. A deductive approach, which would require either temporal data or comparisons between cases and systems, is missing. The SPA may therefore be justified in providing a structure that guides a systematic assessment of a system and supports the stakeholders in identifying crucial system structures—but proof, therefore, remains to be put forward.

Further, one must also acknowledge that the perceptors of the SPA were defined without a specific system in mind. Better understanding of which types of systems the SPA can be applied to and where the limitations of the SPA are, will support the identification and definition of the perceptors. A possible boundary may be drawn between built systems (e.g., infrastructures such as stations) and living systems (e.g., self-organizing ecosystems). Although, on the contrary, the SPA was originally inspired by the field of ecosystem management, and Bossel similarly draws from living systems in order to assess built systems (Bossel, 1999, 2000).

5.3.5 Learning from other Fields

A future application of the SPA to the field of agricultural systems may be able to address some of the methodological questions arising from the case of railway stations. This field relates to concepts similar to those of the SPA (cf. Antrop, 2000). Landfills and stations can both be considered infrastructures or elements of the auxiliary system (i.e. built environment) that humankind maintains in order to fulfil its needs. But agricultural systems are both ecosystems and built systems, thus relating to the origins, and testing the limits, of the SPA. Further, multifunctionality was identified as a challenge for both the case of station redevelopment and for the SPA method. Agricultural systems are multifunctional—the prioritization of resource investments is an integral element of their discussion on sustainable development (cf. Brandt & Vejre, 2003; Hagedorn, 2007; Helming & Wiggering, 2003; Selman, 2009). Swiss agriculture law even explicitly lists multiple functions of agriculture, including the secure supply of the population, conservation of natural resources, care of the cultivated land, and decentralized settlement of the country.
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