APPLICATION OF MULTIMODAL TRANSPORT MODELS FOR COST BENEFIT ANALYSIS: TRAM REGION BERN STUDY

Philipp Froehlich, TransSol GmbH, 8820 Wädenswil, Switzerland, froehlich@ig-modus.ch

Christoph Lieb, Ecoplan AG, 3005 Bern, Switzerland, lieb@ecoplan.ch

Milenko Vrtic, TransOptima GmbH, 4600 Olten, Switzerland, vrtic@ig-modus.ch

ABSTRACT

This paper describes the application of a multi modal transport model and its use in a cost benefit analysis (CBA) for a PuT project in Bern, Switzerland. The high level of congestion on many urban transport networks increases the complexity of transport models and CBA. The model used is able to consider modes including walking and biking as well as the impact of reliability and comfort. The CBA compared the additional costs and benefits of the tram in comparison to the bus reference case. The tram has a benefit-cost ratio of 2.8. Additional sensitivity analysis of the CBA results verified the findings.

Keywords: Transport model, Public Transport, Cost benefit analysis, comfort, reliability, Switzerland

1. INTRODUCTION

This paper presents results of a cost benefit analysis (Ecolpan, 2011a and 2011b) between bus and tram alternatives for the route Koeniz-Bern-Ostermundigen in Bern. Bern is the capital of Switzerland and the region has a population of approximately 390,000. Bern's transport policy is to emphasize the use of public transport and to concentrate future development in areas with good public transport access.

Cost benefit analysis (CBA) is a key technique for evaluating alternatives in the transport planning process and relies heavily on inputs from transport models. The high level of congestion on many urban transport networks increases the complexity of transport models and CBA. This requires that models are able to consider modes including walking and biking as well as concepts such as the impact of reliability and comfort.

Currently the Koeniz-Bern-Ostermundigen bus route Number 10 is severely overcrowded and needs to be improved, especially to meet the expected growing demand in the future. The reference case of the CBA is thus the bus system with more frequent services (in peak times a bus every 2 minutes). The project is to build a completely new tram line (Tram 10) on the same route as the bus. The tram project together with an additional small tram project (not considered here) forms the general project "Tram Region Bern". The following Figure 1 shows an overview map of the project.

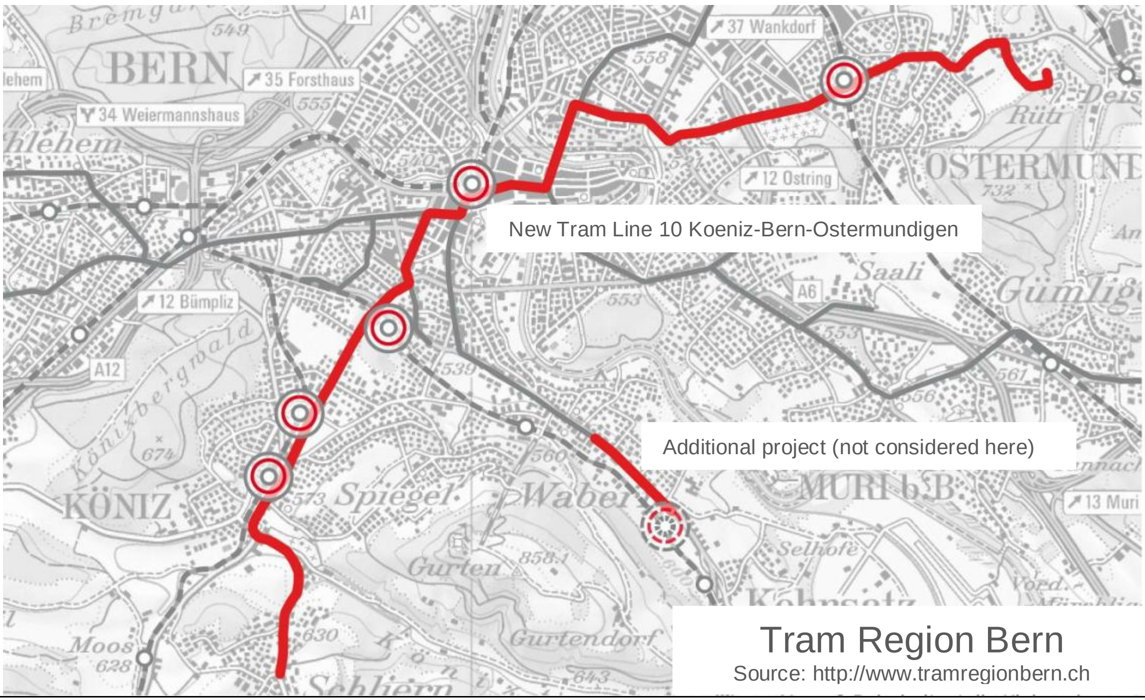

Table 4: Overview map "Tram Region Bern"

The cost benefit analysis and the application of the transport model presented in this paper are especially interesting because they explicitly considered the effect of comfort and reliability in public transport. It is well known that passengers value the comfort of trams higher than of buses (often called the “rail bonus”), but there are not many models that have explicitly considered this in the analysis (Axhausen et al. 2002).

The next section of this paper describes the transport model trend 2030 and the implementation of reliability and comfort in the model. Furthermore, the results of the demand and route choice reactions are reported. The third section describes the cost benefits analysis and results, and the final section presents conclusions.

2. APPLICATION TRANSPORT MODEL BERN

The Canton of Bern's multimodal transport model was used to estimate the demand for the different alternatives on the destination, mode and route levels. In all cases the trip generation was assumed to remain constant over the alternatives.

Since project and reference case (tram line 10 and improved bus line) are quite similar it is very important to differentiate between the service qualities offered by each alternative. The high quality of Bern's transport model makes this type of differentiation possible.

Bern's detailed multi-modal transport model (which includes walking and cycling) has been calibrated for the year 2007 (base line), and provides trend and reference model data for the year 2030. The model includes several different time periods including average work day, morning peak hour, non peak hour and evening peak hour (Vrtic et al. 2010). The model can calculate the change in transport demand due to changes in the transport system, spatial development, travel behavior and social demographics.

The base model used in this analysis was the trend scenario 2030. From 2007 to 2030 the number of public transport PuT trips increase by 43% and public transport mileage increases by 64%. For private transport PrT (automobile trips) the number of trips increase by 27% and mileage by 29%. It should also be mentioned, that the absolute increase of the private transport is higher than for public transport since private transport starts from a higher base.

2.1 Assumptions

In the analysis described in this paper, the only changes made were to the public and private transport networks, all other factors were kept constant. The objective was to model the difference between the two PuT alternatives on a line (tram and bus) and their impact on PrT. To accomplish this, a workshop was organized with experts from the local public transport operator, local transport planning organizations and roadway operators. During the workshop assumptions for each of the following were developed:

- Ride time and headway differences between bus and tram alternatives;
- Reduction of road capacity due to shorter headway by the bus line were estimated using traffic simulations; and,
- Reliability of the bus and tram line due to differences in alignment, headway and road congestion.

In order to calculate the demand effects, several skim matrices needed to be calculated to account for changes in the transport system:

- Private transport: travel time (60% average work day and 40% peak hour), cost;
- Public transport: access and egress time, headway, number of transfers, ride time, cost, comfort and reliability.

The cycling and walking time were kept constant, because only very marginal changes to these variables were expected.

The analysis consisted of comparing the bus alternative (reference case) to the tram alternative. This was done in two steps:

- First, analyzing the effects on destination and mode choice.
- Second, analyzing the effects on public transport and private transport route choice.

The transport demand software VISEVA (Vrtic et al. 2007) was used in the first step to derive new O/D-matrices (Chapter 2.3). The inputs change mainly due to changes in ride time, headway, reliability and comfort. The latter two attributes have not been considered in this model before and are therefore discussed in more detail in the following Chapter (2.2). The second step, route choice, is discussed in Chapter 2.4.

2.2 Comfort and Reliability

Public transport passengers use several factors to set a value on comfort. The main factors are characteristics such as vehicle interior, capacity, right-of-way (separate or mixed with cars) and passenger attitude.

The parameters used in this analysis were taken from a stated preference (SP) study completed in Zurich (Vrtic et al. 2005). Since the travel time parameter components have been validated against empirical data, it can be assumed that the parameter for reliability and comfort have a similar quality. However, it is questionable whether the results of the SP study can be directly transferred to the Bern region. Therefore, a sensitivity analysis was completed in the cost benefit analysis whereby the model inputs were varied by ± 30%.

Using the results of the bus and tram comfort analysis and based on a typical trip length in urban areas it was possible to derive an additional negative utility of 12% of the ride time in a bus instead of in a tram. This penalty was added to the relevant O/D-relations in the bus scenario (reference case).

Reliability is a measurement of the public transport line or network's time table stability. Public transport users value on time arrivals highly, especially when they need to transfer to other lines. For the demand calculation the probability of delays between 5 to 10 minutes were analyzed using time table stability statistics from bus line 10 of the operator, BERNMOBIL. On average the probability for delays were 3.5% for the year 2010.

In 2030 more busses will be needed on the line to accommodate demand and additional road traffic is also expected. Together, these factors are expected to increase the delay rate to 8%. This is on the low side of the expected range because the number of delays was assumed to increase linearly with traffic. While many studies have shown that delays increase non-linearly with traffic above a certain Volume to Capacity level, insufficient data were available to model delays more accurately. Therefore, the calculations were done assuming a delay rate of 8% keeping in mind that the rate could be much higher.

For the tram scenario, because of a partly separate alignment and longer headways (due to higher vehicle capacity) the delay rate is assumed to be zero. From the SP-Study we derived a value of Willingness to Pay (WTP) for a 1% decrease in the delay probability of 0.2 Swiss Francs (in 2006 the exchange rate 1 CHF = 0.80 U$).

For the demand calculation, the O/D-relations on the bus line were identified and a reliability matrix was generated for the mode choice. The newly calculated O/D-matrices were assigned to the public and private transport networks and validated. The model calculations were done for the average work day and afternoon peak hour for the year 2030.

2.3 Demand reactions

Table 1 presents the transport demand model results for the bus (reference case) and tram alternatives for Average Annual Weekday Traffic (AAWDT) (Vrtic and Fröhlich, 2010).

	Private transport trips	Public transport trips	Cycling trips	Walking trips
Tram	4'294'150	1'182'350	580'300	1'549'200
Bus	4'300'750	1'171'450	581'500	1'552'300
	Difference to reference case (Bus)			
Tram	-6'600	10'900	-1'200	-3'100

Table 1 Demand matrices for different modes and scenario for AAWDT 2030

As shown in Table 1, the tram alternative is expected to attract an additional 11,000 trips over the bus alternative. Approximately 60% of these additional trips come from private transport and 40% from the slow modes.

Additional demand calculations were performed to obtain a better understanding of the demand shift due to comfort and reliability. Therefore, either the reliability or the comfort attribute was omitted in the calculation to test the demand reaction as shown in Table 2. The effects of the comfort and reliability show little difference in magnitude.

Scenario	Public transport trips
With reliability and comfort (reference)	1'171'450
Without reliability	1'175'650
Without comfort	1'176'900
Difference to reference	
Without reliability (all courses on time)	4‘200
Without comfort (same comfort as tram)	5‘450

Table 2 Public transport demand for reference case bus with different attributes

2.4 Assignment and network loading

For the route choice the demand matrix was assigned on the network in the software Visum 11.5 (PTV 2009). Table 3 presents the passenger trips and the mileage for the bus and tram alternatives.

		Passengers	Mileage (Passenger km)
Tram		84‘400	238‘050
Bus		68‘300	190‘950
	Relative to reference (bus)		
Tram		16‘100 (+23.6%)	47‘100 (+24.7%)

Table 3 Passenger trips and mileage on work day 2030 for the line for tram and bus

As shown in Table 3 the tram alternative has an additional 16,100 passengers compared to the bus alternative. The following Figure 2 illustrates the public transport link loading.

Public transport link load AAWDT for tram

Difference link loading (Tram – Bus)

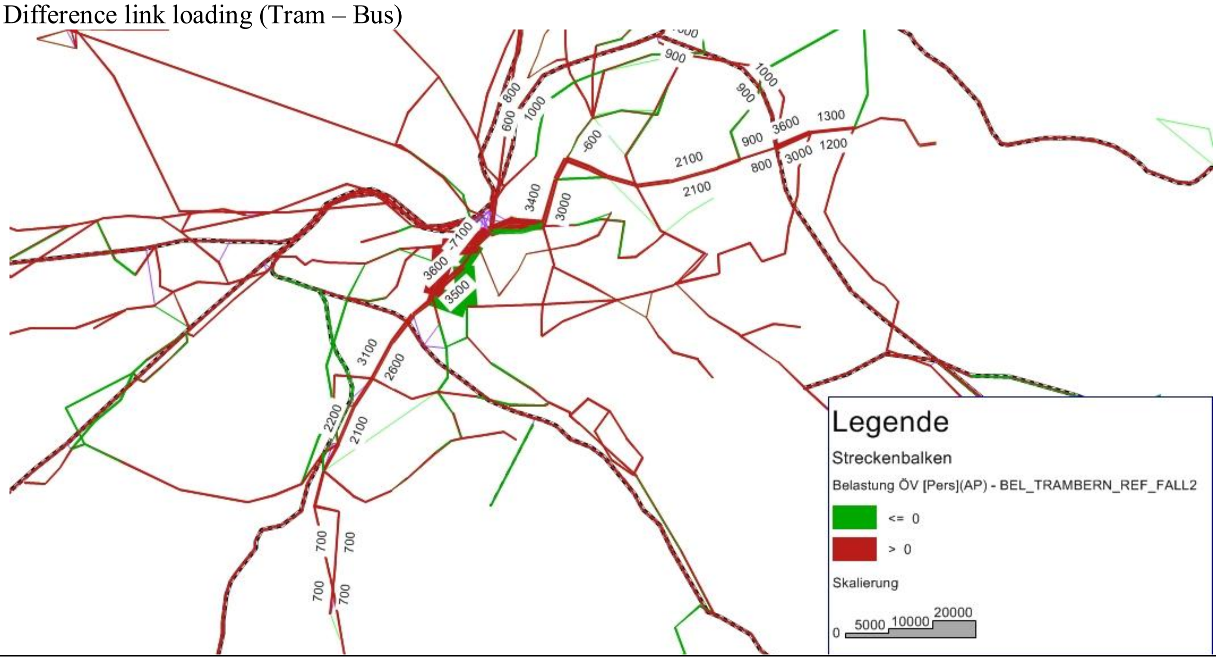

Figure 2 Tram: Public transport- und loading difference AAWDT 2030

The transport demand must be converted from daily workday trips to annual trips for the cost benefit analysis. This was done by using conversion factors taken from the Swiss national travel behavior survey Mikrozensus 2010 (ARE and BFS, 2012). The conversion rates are presented in Table 4.

Trip purpose / *Modes*	Slow modes	PrT	PuT	All modes
Work	0.78	0.78	0.76	0.78
Education	0.73	0.73	0.71	0.73
Shopping	0.89	0.94	0.85	0.91
Business	0.87	0.83	0.73	0.82
Leisure	1.05	1.24	1.05	1.14
All purposes	0.91	0.98	0.85	0.94

Table 4 Conversion factors from Average Annual Weekday Traffic (AAWDT) to AADT (Annual Average Daily Traffic) per trip purpose and mode

Using 365 days per year, the following projection factors were derived:

- for public transport: 310,
- for private transport: 358.

The projection factors were used to convert the model derived AAWDT results into values per year, which are afterwards used in the cost benefit analysis.

3 COST BENEFIT ANALYSIS

The cost benefit analysis (CBA) was completed to identify whether or not the tram has a favorable benefit-cost-ratio. Furthermore, the effects on the public, users, operator and the environment were analyzed. The goal of the CBA is to compare the differences in costs and benefits between the new tram line and the bus line. Operations were assumed to start in December 2018, and a dynamic CBA was performed using a service period of 40 years (2019-2058). Furthermore, the construction time of 4 years (2014 - 2018) is taken into account. The calculations are based on real values and do not consider inflation. The real interest rate is 2% (SN 641 821). The results of the CBA are annuities that represent the yearly costs and benefits with a price base in the year 2006. The CBA method used in this analysis is consistent with the Swiss norms (SN 641 820 to SN 641 828).

3.1 CBA Assumptions

The infrastructure investments for the tram project are CHF 391 mio. based on 2006 prices. The rolling stock consists of 22 new 42-meter trams, but 45 busses are no longer needed. In terms of investment costs, rolling stock of the tram project costs CHF 66 million more than the bus reference case (but the buses have half the life time of new trams).

3.2 CBA Results

A cost benefit analysis compares the cost of an investment with the benefits. The result was that the tram alternative had a positive benefit-cost ratio of 2.8, meaning that it is expected to generate 2.8 times more benefits than it costs. Table 5 presents detailed results of the CBA.

indicator	mio. CHF per year
benefit and costs users PuT	**10,9**
ride time PuT	-3,8
Number of transfers PuT	1,1
walking time during transfer PuT	0,7
comfort PuT	8,1
reliability PuT	4,7
benefit and costs operator PuT	**13,5**
revenues from tickets	10,6
savings from operation /maintenance tram *)	2,9
benefit and costs PrT	**3,8**
journey time PrT	3,8
variable vehicle costs PrT	0,0
benefits from accidents and environment	**5,9**
accidents	5,3
noise	0,5
air pollution and climate change	0,1
revenues and cost of government *)	**1,2**
net benfit without investment costs	**35,2**
investment costs	**-14,7**
net benefit with investment costs	**20,5**
benefit cost ratio (BCR) *)	**2,8**

*) For the calculation of the BCR the following components are treated as costs: investment costs, savings from operation /maintenance tram as well as traffic control by the police. The costs of the tram project are thus 11.1 mio. CHF and benefits sum up to 31.6 mio. CHF, which gives the BCR of 2.8.

Table 5: Detailed result table of the CBA

As shown in Table 5, public transport users benefit from additional CHF 10.9 million per year, the majority comes from improved comfort. Due to the improvements in service quality on line 10, public transport users even take longer routes to use the tram instead of using commuter trains. The tram alternative generates an additional CHF 10.6 million of income for the public transport operators (income for BERNMOBIL, the local tram and bus operator, increases by CHF 5 million/year, the rest goes to train operators). The change from bus to tram also leads to an operational cost savings of CHF 2.9 million/year since fewer trams than buses are needed to operate the service because of their higher passenger capacity.

The private transport system profits from higher available road capacity due to longer headways and shorter waiting times at some traffic lights by a total of CHF 3.8 million/year. Also the environment and traffic safety improves, leading to an additional benefit of CHF 5.9 million/year. These additional benefits for the tram alternative come with the investments cost of CHF 15 million per year.

3.3 Sensitivity analysis

Forecasting the differences between two alternatives over a 40-year time period always has uncertainties attached. Furthermore, some of the calculations done in this analysis were based on assumptions or study results from other regions (e.g., comfort and reliability). So that 16 different sensitivity runs were performed always changing one assumption at a time. The sensitivity results show that the benefit-cost ratio for the tram alternative varies between 2.1 and 3.9. Since in all sensitivity runs the ratio stays over 2, the CBA provides a robust positive result for the tram alternative.

In addition to the overall CBA calculated for the project as a whole, the costs and benefits of the two alternatives were further disaggregated for different authorities' (federal, cantonal and municipality level), operators and user groups. Understanding the complex relationships inherent in the public finance system and in particular for transport investments in Switzerland requires a great deal of background information. That isn't in the scope of the paper and therefore as an example the net benefits for Bern's local public transport operator, BERNMOBIL, is shown in Figure 3. As shown in the figure, BERNMOBIL can improve their income on average by CHF 2.6 million per year over the 40-year period 2019 - 2058. The clear improvement in 2030 is due to a change in timetables (for tram and bus). The reinvestment for the tram infrastructures is paid by BERNMOBIL and start in 2050 and deteriorates the result.

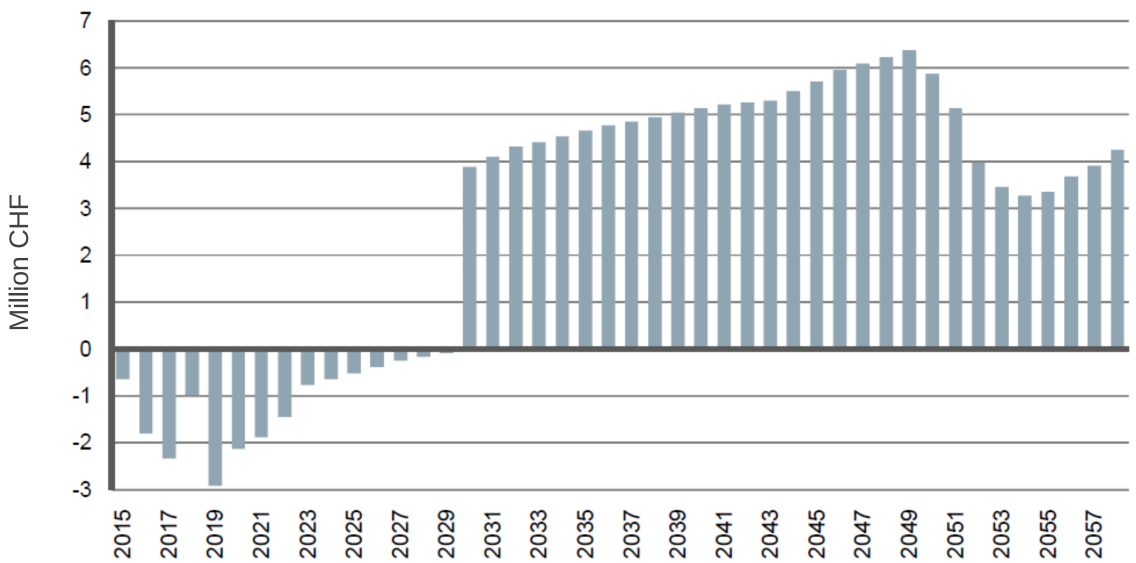

Figure 3 Net income per year for local public transport operator, BERNMOBIL

4 CONCLUSIONS

This paper describes how public transport comfort and reliability were integrated into an analysis of two different public transport alternatives (bus and tram) in Bern, Switzerland. The transport demand model shows plausible results and the effects were as expected. The tram alternative was shown to generate approximately 11,000 more public transport passengers than the bus alternative. Approximately 60% of these additional passengers come from automobile trips and 40% from slow modes. The mode shift is caused by 40% from the better reliability, 50% from the higher comfort and 10% from a shorter ride time in the tram alternative. When route choice is included in the analysis, the tram line gains 16,000 passengers which means an increase of 24% in line loading compared to the bus line.

The transport demand model results were used to complete a cost benefit analysis of the tram project. The CBA compared the additional costs and benefits of the tram in comparison to the bus reference case. Overall, the tram has a benefit-cost ratio of 2.8. A sensitivity analysis of the CBA showed that these results were robust.

The study clearly showed the importance of using detailed multi modal transport models for analysis of complicated urban transport scenarios. Simpler transport demand models would not capture these benefits leading to biased results. The importance of considering passenger reliability and comfort in the CBA process (in addition to the classical attributes such as travel time or road accident rates) is demonstrated to obtain an understanding of the different scenarios.

REFERENCES

ARE and BFS (2012) Mobilität in der Schweiz: Ergebnisse des Mikrozensus Mobilität und Verkehr 2010, Report, Bundesämter für Raumentwicklung und für Statistik, Bern und Neuenburg.

Axhausen, K. W., T. Haupt, B. Fell and U. Heidl (2002) Searching for the rail bonus: Results from a panel SP/RP study, European Journal of Transport and Infrastructure Research, 1 (4) 353-369.

Ecoplan (2011a) Tram Region Bern Wirtschaftlichkeitsrechnung, Report for Amt für öffentlichen Verkehr des Kantons Bern, Bern.

Ecoplan (2011b) Inputdaten und Annahmen für die Wirtschaftlichkeitsrechnung Tram Region Bern, Report for Amt für öffentlichen Verkehr des Kantons Bern, Bern.

Ecoplan, B+S, Metron und Emch+Berger (2008) Schlussbericht ZMB Bern Süd. Report for Bau-, Verkehrs- und Energiedirektion des Kantons Bern, Bern.

PTV (2009) Benutzerhandbuch VISUM 11.5, Planung Transport Verkehr AG, Karlsruhe.

Rapp Trans AG (2008) ZMB ÖV Ostermundigen. 3. Zwischenbericht mit Ergebnissen aus der Phase 2 Technische Machbarkeit und Phase 3 Variantenvergleich, Studie im Auftrag der Regionalen Verkehrskonferenz Bern-Mittelland.

SN 641 820 (2006) Kosten-Nutzen-Analysen im Strassenverkehr. Grundnorm. Schweizer Norm des Schweizerischen Verbandes der Strassen- und Verkehrsfachleute. Zürich.

SN 641 821 (2006) Kosten-Nutzen-Analysen im Strassenverkehr. Diskontsatz. Schweizer Norm des VSS (Schweizerischer Verband der Strassen- und Verkehrsfachleute). Zürich.

SN 641 822a (2009) Kosten-Nutzen-Analysen im Strassenverkehr: Zeitkosten im Personenverkehr. Schweizer Norm des VSS (Schweizerischer Verband der Strassen- und Verkehrsfachleute). Zürich.

SN 641 823 (2007) Kosten-Nutzen-Analysen im Strassenverkehr: Zeitkosten im Güterverkehr. Schweizer Norm des VSS (Schweizerischer Verband der Strassen- und Verkehrsfachleute). Zürich.

SN 641 824 (2006) Kosten-Nutzen-Analysen im Strassenverkehr. Unfallraten und Unfallkostensätze. Schweizer Norm des Schweizerischen Verbandes der Strassen- und Verkehrsfachleute, Zürich.

SN 641 827 (2009) Kosten-Nutzen-Analysen im Strassenverkehr. Betriebskosten von Strassenfahrzeugen. Schweizer Norm des VSS (Schweizerischer Verband der Strassen- und Verkehrsfachleute), Zürich.

SN 641 828 (2009) Kosten-Nutzen-Analysen im Strassenverkehr. Externe Kosten. Schweizer Norm des VSS (Schweizerischer Verband der Strassen- und Verkehrsfachleute). Zürich.

Vrtic M. and Ph. Fröhlich (2010) Tram Region Bern: Modellberechnungen. Kurzbericht im Auftrag des Amtes für öffentlichen Verkehr des Kantons Bern, Olten and Bäch.

Vrtic, M., P. Fröhlich, N. Schüssler , K.W. Axhausen, C. Schulze, P. Kern, F. Perret, S. Pfisterer, A. Zimmerman and U. Heidl (2005) Verkehrsmodell für den öffentlichen Verkehr des Kantons Zürich, IVT ETH Zürich, Ernst Basler + Partner, Zürich and PTV, Karlsruhe.

Vrtic, M., P. Fröhlich, R. Neuenschwander, P. Walker and D. Amstadt (2010) Gesamtverkehrsmodell Kanton Bern, Bau- Verkehrs- und Energiedirektion des Kantons Bern, Bern.

Vrtic, M., D. Lohse, Ph. Fröhlich, C. Schiller, N. Schüssler, H. Teichert and K.W. Axhausen (2007) A simultaneous two-dimensionally constraint disaggregate trip generation, distribution and mode choice model: Theory and application for a Swiss national model, Transportation Research Part A 41 (9) 857-873.