

41st European Transport Conference 2013, ETC 2013, 30 September – 2 October 2013, Frankfurt, Germany

Can bus rapid transit be a sustainable means of public transport in fast growing cities? Empirical evidence in the case of Oslo

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Abstract

Statistics Norway (SSB) has forecast that the population in the greater Oslo metropolitan area will grow by more than 30 per cent in the period 2010-2030. This growth will induce a demand for transport, which in turn will increase the emission of greenhouse gases unless measures are taken to reduce it. In this paper, I investigate under what conditions the Bus Rapid Transit (BRT) system should be regarded as the best solution to meet the challenges facing the Oslo metropolitan area. The rationale is that there is currently no BRT system in Norway, and little is therefore known about its sustainability advantages over other forms of public transport.

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Peer-review under responsibility of the Association for European Transport

Keywords: Cost-benefit analysis; Bus Rapid Transit

1. Introduction

Oslo and Akershus is an area of growth. According to Statistics Norway (SSB), the number of inhabitants in Oslo and Akershus was 617,481 as of 1 January 1951, while in early 2010 it had risen to approximately 1.1 million (SSB, 2011). The estimated population for 2030 is 1,476,521 (an increase of 31.4 per cent compared to 2010). Population growth in this region will lead to increased transportation demand, and can thus lead to more greenhouse gas emissions. On the other hand, the Norwegian government aims to cut greenhouse gas emissions.

In passenger transportation, bus solutions are considered to be among the transport systems that are least energy-intensive (International Energy Agency – IEA, 2009, p. 52). Therefore, I examine under what conditions Bus Rapid

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Transit (BRT) may be one of the solutions to meet the transport challenges in Oslo and Akershus. I ask the question of whether BRT can be a more economically efficient transport solution than regular bus or Light Rail Transit (LRT) for a given projection of passenger numbers on the current bus route 31 in Oslo. I apply standard cost-benefit analysis (CBA) to elucidate this problem. To assess the efficiency of this project, I will identify critical variables, such as capital costs per kilometre roadways, which make project implementation desirable from a societal point of view. I focus on two different transportation options (BRT and LRT) versus a baseline scenario along route 31 in Oslo. This route is the most heavily frequented bus route in Norway today (Ruter, 2011b, p. 9). In Chapter 2, I describe the BRT system and compare this means of transportation with LRT. Chapter 3 presents the baseline scenario based on today's infrastructure. I outline relevant variables on the basis of the theory of CBA and of the properties of BRT. Chapter 4 describes the calculation model and gives the results of the cost-benefit analysis. In Chapter 5, I summarize and present the study's conclusion. All prices are adjusted to 2011 NOK. For further information, I refer the reader to my original thesis (Siedler 2011).

2. BRT: an alternative means of public transportation

2.1. The growing demand for transport

The transport sector will continue to have a major impact on society and the environment in the future – as a means of transportation, as an oil-consuming industry and as a source of greenhouse gases. The IEA estimates that the sector will account for more than half the oil consumption in 2020, and that it will cause about 25 per cent of global energy-based CO₂ emissions (IEA, 2002, p. 17). One reason is that the huge population growth until 2030 is expected to take place especially in urban areas (IEA, 2002, p. 18).

In his presentation at the seminar "Challenges in transport in Oslo and Akershus region", Arne Stølan (Rail) predicted a growth in transport demand for this region of 54 per cent until 2060. The seminar was held under the auspices of the Institute of Transport Economics, TØI, on Tuesday 13 September 2011 on the basis of a research project for more sustainable infrastructure investment to meet the expected population and economic growth in the region. In another presentation, Thomas Tvedt (Akershus County Council) set out the aims of good accessibility for all road users, a greater proportion using public transport and reduced environmental aims.

Minken et al. (2001) define modal shift measures in public transport as everything that increases the proportion using public transport, i.e. the proportion of passengers using public transport instead of private cars (Minken et al., 2001, p. 7). Fearnley et al. (2008) believe that "Buses with a High Level of Service, or Bus Rapid Transit concepts" (Fearnley et al., 2008, p. 1) should be considered as alternative public transport measures, but there is a one-sided focus on light rail solutions in Norway. Why then should BRT solutions be of greater interest at all? IEA argues generally for bus solutions as affordable, cost-effective and environmentally-friendly (IEA, 2002, p 22).

2.2. The BRT System

Deng & Nelson (2011) provide an overview of what is referred to as Bus Rapid Transit: high-capacity bus systems, high-quality bus systems, metro-bus, surface Metro, express bus systems, high-level bus service, busway systems.

Although there is no unique definition of BRT (Sandberg, 2011, p. 12), a simple way to identify BRT systems is given in Levinson et al. (2002): *BRT is a flexible, rubber-tired rapid transit mode that combines stations, vehicles, services, running way, and ITS elements into an integrated system with a strong positive image and identity. BRT applications are designed to be appropriate to the market they serve and their physical surroundings and can be incrementally implemented in a variety of environments. In brief, BRT is a permanently integrated system of facilities, services, and amenities that collectively improve the speed, reliability, and identity of bus transit. In many respects, BRT is rubber-tired light rail transit (LRT), but with greater operating flexibility and potentially lower capital and operating costs.* (Levinson et al., 2002, p. 2).

Based on discussions in Jarzab, Lightbody & Maeda (2002) and Sandberg (2011) the main characteristics of BRT are identified in Table 1.

Table 1 Main characteristics of Bus Rapid Transit

Characteristics	Description
Roadways	Vehicles can operate in all kinds of traffic, but provision of own lanes increase the speed, reliability and identity.
Stations	BRT stops resemble stations rather than regular bus stops and have an easily recognizable design.
Rolling stock	BRT vehicles are designed to improve comfort, speed and safety. They have distinctive designs, colours and graphics.
Service	The system offers fast, regular and reliable high-frequency service.
Ticketing	BRT offers fast and efficient ticketing. The tickets are checked at the stations.
ITS	Using digital technologies improves comfort, speed and reliability as well as safety for passengers, drivers and planners.

2.3. Comparing BRT with LRT

I have chosen to concentrate on BRT and LRT and compare both alternatives with the existing situation along bus route 31 (Snarøya - Grorud - Snarøya) in Oslo. The reason for using this route to compare BRT and LRT is that these two transport systems have almost the same characteristics (Deng & Nelson, 2011, p. 83). Moreover, passengers appreciate BRT and LRT almost equally (Currie, 2005, p. 41). Therefore, it is easier to keep the analysis at a manageable level because the number of variables that must be considered is reduced significantly.

In the following, I will compare BRT with LRT with regard to several characteristics in order to emphasize similarities, and particularly to distinguish differences. Table 2 is based on the study of Deng & Nelson (2011). Their comparison takes into account important variables such as average speed and passenger occupancy, and is more detailed than, for example, IEA (2002).

Examining individual items, there are three criteria where differences between BRT and LRT are significant: roadways, propulsion technology and costs. I choose to concentrate on these categories since they are crucial for decision makers when it comes to investments in new transportation projects (Hensher and Golob, 2008, p. 504).

Table 2 A simple comparison of Bus Rapid Transit and Light Rail Transit

Transport mode	BRT	LRT
Priority	Shared or exclusive	Shared or exclusive
Roadways	Bus lanes or similar	Rail tracks
Propulsion technology	Combustion or electricity	Electricity
Vehicle control	Visual	Signal
Construction time	< 18 months	2 to 3 years
Areal	2 to 4 lanes	2 to 3 lanes
Flexibility wrt implementation and operation	High flexibility	Limited flexibility
Passengers per vehicle	160	170 to 280
Minimum headway (sec)	12 to 30	75 to 150
Transport units per hour	120 to 300	24 to 48
Passengers per hour	9 000 to 30 000	12 200 to 26 900
Top speed (km/h)	60 to 80	60 to 80
Average speed (km/h)	15 to 25	15 to 25
Capital costs (per km, mill. 2011-NOK)	90.07 (90.18)	232.12 (23.66)
Operation costs(per vehicle km, mill. 2011-NOK)	31.64 (27.12)	81.68 (80.28)

3. The case study: Route 31-Snarøya – Grorud – Snarøya

There are two reasons for my decision to conduct a cost-benefit analysis of the 31 bus:

- Already today Ruter is considering replacing the current route 31 by a tram between Sinsen and Tonsenhagen (Ruter, 2011a, p. 39).
- "Route 31 is Norway's busiest bus route" (Ruter, 2011b, p. 9).

The 31 route is interesting because it may be necessary to replace parts of the route by a tram. It is thus a typical example of weighing up between rail transport and public transport on roads. The route serves a stretch with heavy traffic, and the number of travellers has increased in recent years so that capacity limits have been reached and often exceeded (Ruter 2011b, p. 6).

3.1. Core assumptions and conditions

I made some assumptions on aspects that are supposed to be equal for all three transport alternatives (baseline, BRT and LRT). Variables and parameters that are assumed to be equal or to have equal development are:

- Time span, discount rate and region
- Route
- Development of passenger numbers
- Air pollutants and greenhouse gases
- Development of carbon price

Further details can be found in Siedler (2011), including assumptions made for the baseline scenario, i.e. the development of the current situation, and parameter values for both transportation alternatives: BRT and LRT.

4. Cost-Benefit Analysis

4.1. Cost-Benefit categories and calculation model

In the above section, I define the differences between BRT and LRT as three aspects: roadways, propulsion technology and costs. Moreover, the transport alternatives BRT and LRT are described using the same categories when presenting the baseline alternative. As a result, I focus on the cost and benefit categories given below in each period to compare BRT and LRT relative to the baseline scenario:

- Costs due to higher investment costs for roadways ($C_{t,baneinv,i}$)
- Costs due to higher operation and maintenance costs for roadways ($C_{t,banedrift,i}$)
- Costs due to higher investment costs for stations instead of simple bus stops ($C_{t,stasjinv,i}$)
- Costs due to higher operation and maintenance costs for stations ($C_{t,stasjdrift,i}$)
- Benefits or costs due to lower or higher dimensioning costs of vehicle stock ($C_{t,vogndim,i}$)
- Benefits or costs due to lower or higher operation and maintenance costs of vehicle stock ($C_{t,vogndrift,i}$)
- Benefits due to travel time saved ($B_{t,tid,i}$)
- Benefits due to lower emissions of greenhouse gases ($B_{t,miljø,i}$)
- Benefits from upgrading stations with ITS ($B_{t,ITS,i}$): the benefit shall be interpreted as travel costs, i.e. disadvantages experienced during the journey measured in NOK, being reduced by about 2 krone per trip if there is ITS at the stations (Ruter, 2011d, p. 25). According to Ruter (2011d), there may be a gain of about 2 krone per trip for shelters at the stop/station in addition to this. I assume shelters will be set up at all stations in each scenario so that the benefit will not make any difference (Ruter, 2011d, p. 25)
- Index i separates BRT and LRT.

The sum of the values in the nine categories for period t , shown in the equation below, equals the net benefit of the project in this period:

$$NB_{t,i} = B_{t,tid,i} + B_{t,milj\emptyset,i} + B_{t,ITS,i} - (C_{t,baneinv,i} + C_{t,banedrift,i} + C_{t,vogndim,i} + C_{t,vogndrift,i} + C_{t,stasjinv,i} + C_{t,stasjdrift,i})$$

The net present value of a project i , discounted to period 0, can be described by:

$$NNV_{0,i} = \sum_{t=0}^{24} \frac{NB_{t,i}^{SG} + NB_{t,i}^{FT}}{(1.045)^t} \geq 0$$

Index SG means subsection Snarøya–Grorud, FT stands for Fornebu–Tonsenhagen. The term $NB_{t,i}^{SG}$, hence describes the net benefits of project i relative to baseline in period t on subsection Snarøya–Grorud and $NB_{t,i}^{FT}$ accordingly on subsection Fornebu–Tonsenhagen.

Investment costs roadway: I assume investment in the entire stretch (25.52 km). The construction period is estimated at two years (2011 and 2012). I therefore split investment costs equally between the two periods. I assume the roadways in each scenario have a technical lifetime of 25 years. Therefore, there will not be any residual value at the end of the analysis period.

Operation and maintenance costs roadways: Annual operating and maintenance costs per kilometre for the BRT route are equal to the costs for bus lanes in my model. Tram pathways, however, are different – for example due to the rails. Operating and maintenance costs per kilometre per year are slightly higher than for the base case and BRT option. Thus, costs occur in the LRT project in this category.

Investment costs for stations instead of bus stops: I assume there are two shelters or similar on all stops along the route except at the final destinations, where there is only one in each option. I assume that the planner must invest in new stops in the baseline scenario and in stations in both transport options (BRT and LRT). Furthermore, the stop distance increases from about 500 metres in the baseline scenario to 600 metres in both transport options (BRT and LRT). Investment costs for stations are higher than for single stops (Ruter, 2011e, pp. 48 and 53). The lifetime of stops in the baseline is shorter. The social planner must invest in new stops during 2023 and 2024 (periods 12 and 13). I distribute investment costs in periods 0 and 1 and in periods 12 and 13 equally over two years.

Operation and maintenance costs for stations: Annual operating and maintenance costs are believed to be higher for stations (Ruter, 2011d, p. 25). Another difference is ITS at stations for BRT and LRT. Marginal costs of ITS are calculated per year and include investment, operating and maintenance costs (Ruter, 2011d, p. 25).

Sizing costs rolling stock: Benefits or costs in this category are caused by lower or higher sizing costs in a transportation alternative in relation to the baseline scenario. Bekken (2004) estimates the annual cost of sizing rolling stock on the basis of variables that characterize the timetable (frequencies) and the vehicle being used. Important figures in his calculation are route length, average speed, space capacity and departures per hour.

Operation and maintenance rolling stock: I assume that only the required rolling stock is running. Spare rolling stock is not. I use the formula depicted in Bekken (2004), p. 15, as the basis for the calculation of operating and maintenance costs in the baseline and the BRT option.

Saved travel time: I base calculations of the valuation of savings in travel time on changes in travel time elements. These may change during the analysis period for all transport options (baseline, BRT, LRT) in each operating period (rush, non-rush, weekend).

Emissions of greenhouse gases: I base the calculation of emissions on fuel and electricity consumption on the one hand, and on emissions of CO₂ equivalents per litre of fuel and per kWh on the other.

Upgrading with ITS: As expressed in footnote 6, benefits from upgrading with ITS at stations only depends on the passenger number in period t .

4.2. Estimates

The benefits and costs for both projects over the entire analysis period (2011 to 2035) including sums for each benefit and cost category discussed in the above section can be retrieved by Siedler (2011). Here I show only the total for each category here.

4.2.1. Results from the first calculation

Table 3 summarizes my findings and makes it possible to rank opportunities by their net present value. Positive values reflect the benefits of a transportation option relative to the baseline scenario, negative values reflect costs.

Table 3 Summary of the cost-benefit analysis: first calculation

Benefit and cost categories	Sums over all periods (million 2011-NOK)	
	BRT	LRT
Investment costs roadway	-7328.5	-7871.4
Operation and maintenance costs roadways	0.0	-75.3
Investment costs for stations instead of bus stops	-106.2	-106.2
Operation and maintenance costs stations	-25.2	-25.2
Dimensioning costs rolling stock	34.9	-1183.0
Operation and maintenance rolling stock	151.6	-2118.6
Saved travel time	3213.5	5009.6
Emissions of greenhouse gases	0.3	6445.7
Upgrading with ITS	499.1	499.1
Total sum of benefits	3899.4	5515.2
Total sum of costs	-7458.9	-11379.7
Net present value	-3559.5	-5864.5

Fig. 1 and 2 illustrate the results from calculations for both project alternatives. The results so far are that none of the transport options are desirable and that the LRT project is least desirable.

Two green peaks (2023 and 2024) mark reinvestment in bus stops in the baseline scenario as benefits in both options. The reason for that is a longer lifetime of BRT and LRT stations. The contribution of less emission of greenhouse gases is not visible any of the scenarios. Note that the annual dimensioning and operating & maintenance costs for the rolling stock is a cost category in the LRT option, while it is a benefit category in the BRT option. The charts are based on the work by Siedler (2011).

I use a low carbon price scenario in accordance with SFT (2009) and a discount rate of 4.5 per cent ($r = 4.5\%$) according to the SSØ (2010). As mentioned above, I use figures for investment costs for the transport options BRT and LRT as given in Ruter (2011f), and an adjusted value for a bus lane in the baseline scenario from Griffin et al. (2005). The stream of discounted net benefit is shown for each year over the analysis period (2011 until 2035, 25 years) and can be read as the “difference between bars above the x axis minus bars below the x axis”. With the assumptions made, this stream becomes positive for the first time in the year 2013 for both projects. Net present value of each project is given in Table 3, and can be read as the sum of all the columns from 2011 to 2035. Note that the bars of “investment costs roadway” actually exceed the diagram’s margins in both options. Therefore, the sum of all columns is negative. If Fig. 1 is compared with Fig. 2, it becomes clear that costs in the BRT option are lower by 2013. This is primarily due to differences between both projects with respect to annual dimensioning costs and the operating and maintenance costs of the rolling stock. In the BRT option, these posts are benefit categories, while they are cost categories in the LRT project.

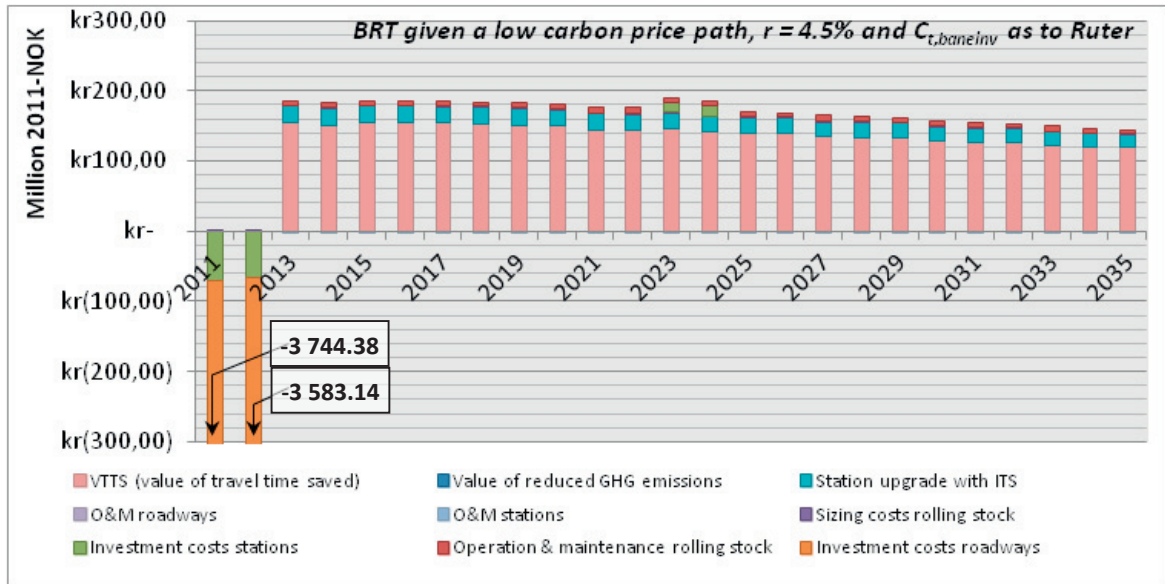


Fig. 1 Stream of discounted benefits and costs: BRT alternative

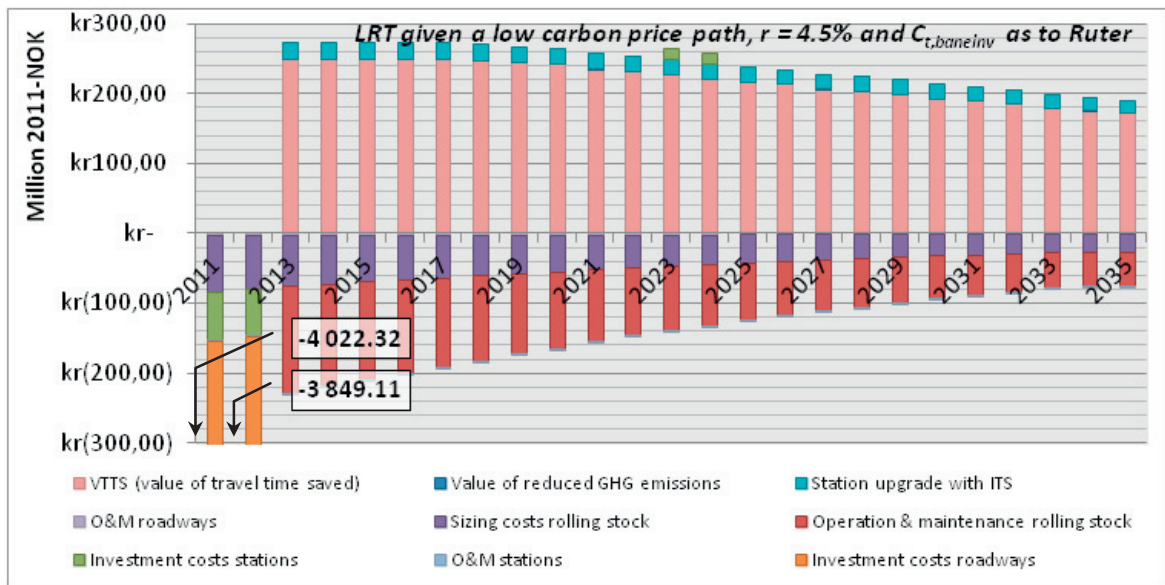


Fig. 2 Stream of discounted benefits and costs: LRT-alternative

Table 3 and a comparison of Fig. 3 and 4 illustrate this indirectly. The pie diagrams are based on total sums for the entire analysis period.

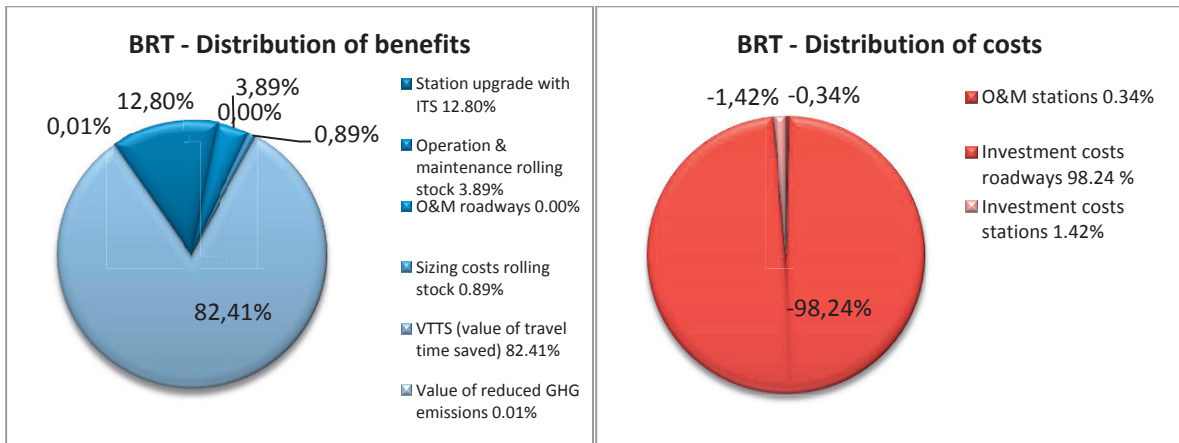


Fig. 3 Distribution of benefits and costs: BRT alternative

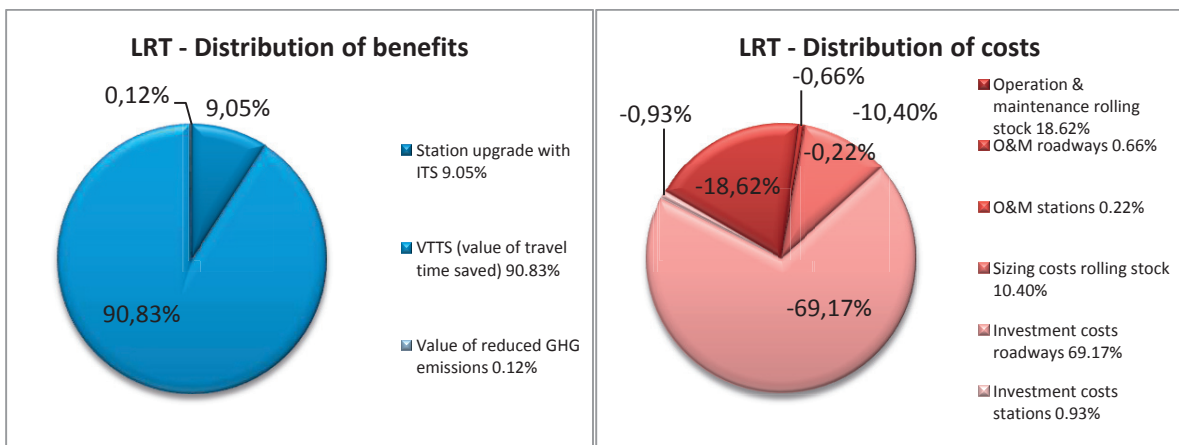


Fig. 4 Distribution of benefits and costs: LRT alternative

Benefits from reduced travel time are large in both transport options and represent the biggest proportion of the total of all benefit categories (see Figs 4 and 5). This is primarily due to better accessibility and higher average speeds than in the baseline scenario. With regard to my research question about environmental economics, I can conclude that the effects from savings in greenhouse gas emissions are modest but positive. A positive net benefit of savings in environmental costs arises in both options, and the effect is largest for LRT, but the proportion of total benefits is very small. In the BRT option, the benefits of reduced greenhouse gas emissions represent roughly 0.01 per cent of the sum of total benefits. In the LRT option, the share is approximately 0.12 per cent. The BRT option, though, leads to savings associated with the dimensioning, operation and maintenance of the rolling stock (shown in Fig. 4). The reason is that the social planner can wait to set up more departures in this scenario compared to the baseline scenario since BRT buses have a bigger capacity. Generally, fewer buses run during the analysis period. This applies in the case for LRT vehicles, too, and even to a greater extent, but sizing costs are much higher if Bekken's formula is applied. Seat capacity is the key variable determining cost differences. In addition, LRT operating costs per vehicle kilometre are roughly twice as high as in the other options. However, fewer vehicles being used in both transport options is the main reason for benefits with respect to greenhouse gas emissions. Upgrading with ITS leads to a positive net benefit that is equal in both transport options because the valuation per trip is equal and the development of passenger numbers is assumed to be the same in all three scenarios. The sum of

benefits is not large enough to compensate for project costs in any of the transport options. The main reason is the huge investment costs for roadways in both cases.

Positive values mean benefits and negative values costs. The benefit of reducing greenhouse gas emissions is approximately 0.01 per cent in the BRT alternative and 0.12 per cent in the LRT alternative. The share is not visible in any of the left diagrams. The same applies for costs from the operation and maintenance of stations in the right diagram (BRT: -0.34 per cent, and LRT: -0.22 per cent).

4.2.2. Sensitivity analysis for the first calculation

I carried out a sensitivity analysis for changes in the discount rate: "A sensitivity analysis is intended to examine the sensitivity of efficiency to changes in key assumptions" (SSØ, 2010, p. 64).

Since both projects lead to costs in the calculation in the above section, an increase in the discount rate is assumed to lead to even greater inefficiency. A higher value for the discount rate equals higher risk-free opportunity costs and/or a higher price for the project's risk. To show the effect of a higher discount rate, I have used a discount rate of 7 per cent (according to Ang-Olson & Mahendra, 2011, p. 25). I can summarize the effect of a higher discount rate to be small with respect to the overall outcome: an increase does not alter my conclusion as to the overall profitability of both projects.

Thus, changing the discount rate in the opposite direction can be more interesting for the efficiency evaluation. In a second sensitivity analysis, I chose a discount rate of 0 per cent as an extreme case. There is practically no discount in this case. My conclusion about the overall efficiency of both projects is the same: they remain undesirable.

4.2.3. Results from a more optimistic calculation

The main reason for inefficiency in both the transport options in the first calculation is the enormous investment costs. In these calculations I have used figures from Ruter (2011f). These were the latest estimates I could find. In table 4 I assume figures for investment costs being as in Fearnley et al. (2008). Investment costs per kilometre in the second calculation are much lower in the BRT option, and somewhat lower in the LRT option. The difference between Fearnley et al. (2008) and Ruter (2011f) is that Fearnley's figures are based on already existing systems. Ruter's report estimates figures for a project that has not yet been implemented. Changing this parameter does not affect any other benefit or cost category. In addition, I change my assumption about carbon price paths from low to high. I want to show the consequence of a higher valuation of (savings in) greenhouse gas emissions. The price change affects no other benefit or cost category.

Table 4 Results from a more optimistic analysis

Benefit and cost categories	Sums over all periods (million 2011-NOK)	
	BRT	LRT
Investment costs roadway	-1669.9	-4948.8
Operation and maintenance costs roadways	0.00	-75.3
Investment costs for stations instead of bus stops	-106.2	-106.2
Operation and maintenance costs stations	-25.2	-25.2
Dimensioning costs rolling stock	34.9	-1183.0
Operation and maintenance rolling stock	151.6	-2118.6
Saved travel time	3213.5	5009.6
Emissions of greenhouse gases	1.4	22.7
Upgrading with ITS	499.1	499.1
Total sum of benefits	3900.5	5531.4
Total sum of costs	-1801.2	-8457.0
Net present value	2099.3	-2925.6

The BRT project is desirable under these assumptions. Even under a low carbon price scenario, the project is desirable if the figures from Fearnley et al. (2008) are used. Transport option LRT remains undesirable, but to a

much lower extent than shown in the above section. With regard to environmental economics, I can conclude that a high carbon price results in slightly higher savings in environmental costs for the BRT option in comparison with the scenario with low carbon prices. The effect is much larger for LRT. The explanation is that the carbon price path is steeper in the high-price scenario than in the low-price scenario. Carbon prices increase more rapidly during the analysis period in the second scenario than in the one with low carbon prices.

4.3. Limitations and uncertainty in the model and results

Project assessment is no more than an indication of the project's desirability. This is particularly because of the assumptions being made with regard to welfare weights.

Furthermore, the central premise in my estimation model is that passenger-number development is the same in all scenarios (baseline, BRT and LRT). The mode share is thus constant in all three options. My results do not therefore capture any benefits or costs arising from reduced or increased travel time of transferred traffic. For instance, let us assume that the proportion of travellers who use public transport is greater in the BRT scenario than in the baseline scenario. If this leads to a reduction in traffic jams, then traffic flow increases and travel time for car drivers and passengers is reduced in the BRT alternative. At the same time, some former car drivers and passengers now choose BRT instead of a car. Let us further assume that the choice leads to shorter travel times for these former motorists. Total travel time, then, is even shorter in the BRT scenario than in the baseline scenario given an increase in the proportion of those using public transport. This causes even more reduced travel time costs than in my estimation. If the choice results in longer travel times for those who switched from car to BRT, the sum of the reduction in the "queue time" and increase in "travel time by BRT instead of private cars" must be examined to be able to give a definitive answer as to whether this transfer leads to reduced or increased travel costs. The same idea holds for why results do not show reduced or increased environmental costs as a consequence of less or more greenhouse gases due to such a transfer. The interpretation of my findings, therefore, is limited to the effects caused by the systems as such (for example, a lower number of vehicles in the BRT project than in the baseline scenario).

One of my core assumptions has been that there are no geographically different values of travel time saved, i.e. all passengers are assumed to live in Oslo. If the amount of saved travel time increases, benefits from travel time saved will also increase. The benefit of this category is further enhanced if the valuation of travel time elements increases. If these differences are taken into account, those aspects can be expected to lead to changes in travel costs.

I conclude with the contribution of reduced environmental costs generally not being critical to efficiency assessment in either transport option regardless of the quota price (low or high). Nevertheless, I would like to point out that I have limited the concept of greenhouse gases to CO₂, CH₄ and N₂O. I omit an assessment of any other greenhouse gases. I do not take local air pollution into account either, but refer to Wöhrnschimmel et al. (2008) who describe possible effects in their section 3.2. LRT leads to no air pollution at all. Consequently, the effect of reduced emission of air pollutants must be expected to be even greater than in the BRT option. Neither do I consider the effects of reduced or increased noise levels in this paper. Other aspects that I do not include in the cost-benefit analysis, but which can form separate benefit or cost categories, include the effects on land development (Deng & Nelson, 2011, pp. 87-92) and accidents (TØI, 2010) along route 31.

During the analysis period the number of departures on both subsections increases. This is a consequence of the necessity to deal with growing passenger numbers. I do not know about the practical feasibility, such as whether it really is possible to run more than five departures per hour per subsection, but there are BRT systems with a 30-second headway, i.e. 120 departures per hour.

None of the equations that I use to calculate the net present value of a project take the tax funding into account. However, it can be imagined that part of the project costs is financed by taxes. If parts are tax financed, the Ministry of Finance (2005) recommends using a tax charge of 20 øre per tax krone funded (Ministry of Finance, 2005, p. 27).

In my estimation model, great uncertainty is related to cost figures for investment and operating costs for roadways and the rolling stock. The reason for this is large variations in figures found in respective sources. Therefore, I show one calculation based on figures from Ruter (Ruter, 2011f) and another one based on figures from TØI (Fearnley et al., 2008). The calculations show a possible range that efficiency assessments may lie within.

The valuation of goods that are not traded in markets, such as travel time, is based on valuation techniques, which in itself can be characterized by uncertainty. Results obtained in these categories must be interpreted with caution.

5. Conclusions

In this paper we tried to investigate whether, for a given projection of passenger numbers, a Bus Rapid Transit (BRT) system could be more desirable than regular bus or tram. We considered the case study of bus route no. 31 in Oslo, i.e. the Norway's busiest bus route today, and compared the BRT project versus the option (by Ruter AS) of replacing parts of the route by tram. It is thus an example of weighing up between rail transport and public transport on roads. The central assumption in my calculations is that the development of passenger numbers is the same in all scenarios (baseline, BRT and LRT).

In my first calculation of net present values, I use figures for investment costs provided by Ruter. The costs compared to other sources are high, and the result is that none of the transport options are desirable (i.e. positive Net Present Value) and the LRT project is most undesirable.

In a simple sensitivity analysis I show that the effect of a variation in the discount rate does not alter my conclusion. Both projects remain undesirable even if I assume a discount rate equal to zero. In this calculation the contribution from saved environmental costs is very small but positive. The main reason leading to inefficiency in both transport options is large investment costs.

In addition, I choose to run a calculation where I use investment costs per kilometre in accordance with Fearnley et al. (2008). Figures are much lower in the BRT option, and somewhat lower in the LRT option. In addition, I change my assumption about the carbon price path from low to high in order to show the consequence of a higher valuation of (reductions in) greenhouse gas emissions. This can be seen as a more optimistic scenario. The result under these assumptions is that the BRT project has a positive NPV, and that the LRT alternative remains undesirable, but to much lower extent than before.

Overall, I can conclude that the benefits of reduced travel time in both transportation options and under both calculations are large. The benefits from reduced greenhouse gas emissions, however, are small, even for a high carbon price path. In fact, both alternatives show a significant improvement in travel time compared to the baseline option and the benefit from reducing greenhouse gas emissions is modest and is not essential for efficiency assessment.

Whether the project is desirable is heavily dependent on the investment costs applied. The net present value of both projects can increase if variations in the proportion of those using public transport is taken into account as discussed in the previous section. This may lead to both the BRT and the LRT project being desirable, even under the assumption of high investment costs for the roadway.

In conclusion, I find that even if we completely ignore the fact that BRT may induce less traffic and a higher mode share of public transport, BRT along route 31 are more desirable than both regular buses and trams given the lower investment cost figures found. Using the highest cost figures found, regular buses perform best.

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