Summary

BYTRANS: Effects and consequences of capacity reduction in the Bryn tunnel Documentation report

TØI Report 1733/2019
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Oslo 2019, 397 pages, Norwegian language

The Bryn tunnel is located on the outer ring-road called Ring 3 in Oslo, and it carries annual average daily traffic (AADT) of about 70 000 vehicles. The capacity in the tunnel was reduced from four to two lanes in the period of February 2016 to April 2017. Road users adapted to the capacity reduction in ways resulting in a significant decrease in traffic volumes through the tunnel, by 26–34 percent in rush hour and 20-23 percent per day. The average traffic speed was, nevertheless, significantly reduced during the capacity reduction. In the normal situation, average measured speeds were close to or above the speed limit (70 km/h). During the capacity reduction, speed limits were reduced to 50 km/h, and the average measured speeds were 30–40 km/h. The southbound traffic in afternoon rush hour was different, and here average measured speeds were reduced from about 30 km/h to about 20 km/h. Average traffic speeds were also reduced in the hours adjacent to rush hour. Traffic volumes increased on two alternative routes on the main road system, which indicates that some road users chose to use this as an alternative route. We found only smaller changes in traffic volumes on more local roads. Apart from this, it seems that the effects of the Bryn tunnel capacity reduction were mainly limited to the road network in close proximity to the tunnel. Overall, it appears that the number of vehicles in the road system was somewhat reduced in the period with capacity reduction. Traffic increased when the tunnel regained normal capacity, but to a lower level than in the before situation. The information from public authorities about the capacity reduction seems to have reached the road users. In surveys, some of the employees in companies located in the Bryn area answered that they had adapted to the capacity reduction by choosing other routes when travelling to and from work, changing their mode of transport, travelling earlier or later or using their home offices more frequently. Freight and distribution traffic adapted by avoiding the tunnel in rush hour to a limited degree, and the effect was lower compared with that observed in passenger transport. Those who made changes to adapt to the situation chose other routes, reorganised routes or started their route earlier. Taxi drivers saw no need to make adaptions. Concerning consequences, a minority of commuters reported changes of routines and responsibilities in the household, and some experienced reduced satisfaction with their commutes. Some truckdrivers reported more stress and frustration, longer work hours and less predictable and comfortable workdays. We have not been able to find large negative consequences. Hence, it can be concluded that halving the capacity on one of Norway's heaviest trafficked roads mainly resulted in negative effects in the form of increased delays and variability in the Bryn tunnel and adjacent roads, but severe consequences were not experienced. The capacity reduction went relatively well, and better than expected, as it caused neither crisis nor chaos. This is in line with findings from previous research on similar cases, in Norway and elsewhere. The findings and experiences open for new ways of thinking about how we can develop the more efficient and sustainable transport systems and cities of the future.

Background and objectives

A challenge shared by many politicians, professionals and researchers across the globe is how to develop cities and urban transport systems in ways that ensure efficient mobility, while reducing local and global environmental effects from the transport sector and making cities more attractive and vibrant. In Norway, clear political goals have been defined for zero growth in car traffic in urban areas, efficient and environmentally friendly urban transport systems and climate-friendly, attractive and vibrant cities.

In the period 2015-2020, significant changes take place in transport systems in Oslo. These can be understood as representing natural experiments, offering great opportunities for developing new knowledge about the effects and consequences of such changes for the transport systems, users of the transport systems, society and the environment. Such knowledge can enable politicians, authorities and researchers to develop the more efficient and environmentally friendly urban transport systems of the future. This also affords the opportunity to develop knowledge about how mitigation and information measures introduced by the authorities work, as well as how they can be improved. The BYTRANS research project was initiated to document effects and consequences of these changes, and contribute relevant knowledge.

In this report, results of the investigations related to case Bryn tunnel are reported. The capacity of the tunnel was reduced from four to two lanes in the period of February 2016 to end of April 2017. We have studied how different users of the transport systems (commuters by different modes, freight and delivery traffic, taxi traffic) adapted to the capacity changes, and what effects and consequences it had for the transport systems, users of the transport systems, society and the environment.

Part of the material (data up to November 2016) was published in an under-way report in 2017 (Tennøy et al. 2017), to bring the information and knowledge to users of the knowledge as soon as possible. A shorter final report for case Bryn tunnel case is also published, which only includes the most important findings, conclusions and discussions.

Research design and methods

The research was organised as a case study, where the changes in the Bryn tunnel was the case. Existing knowledge and literature were used for designing the data collection and analyses. Data was collected in the before situation (before the capacity was reduced), in the underway situation (when the capacity was reduced) and in the after situation (after the capacity was back to normal). Traffic data were collected in the same pre-defined two-week periods in 2015, 2016, 2017 and 2018, and surveys and interviews were conducted in the spring/summer the same years. Data from the different phases were compared when analysing adaptions to, effects and consequences of the tunnel capacity changes.

Main sources for data collection were:

- Data concerning the before situation on precautionary, mitigation and information measures from responsible agencies;
- Data on car traffic volumes, bicycle traffic volumes and passenger volumes in public transport from the Norwegian Public Roads Administration (NPRA), Oslo municipality Bymiljøetaten, Ruter, VY;
- Data on speeds and delays for car traffic, public transport, and taxi traffic from NPRA, Municipality of Oslo Bymiljøetaten, Ruter, VY, Oslo Taxi, Telenor;
- Data on road users' travel behaviour, experience of transport quality, experience of mitigating measures and so on, from surveys and interviews conducted by researchers at the Institute of transport economics (TØI)

The purpose of using different types of data and analyses is investigating the situation from different perspectives and in different ways, and thus, increasing the robustness of the data, analyses, findings and conclusions.

Answers to the research questions

Through the investigations and analyses of the Bryn tunnel case, we have tried to answer several specific research questions. Below, these questions are posed and addressed as

briefly and concisely as possible. Figure S1 shows the location of the Bryn tunnel, as well as important traffic registration points and road links we refer to in the text. We hope the figure can make it easier to follow the discussions.

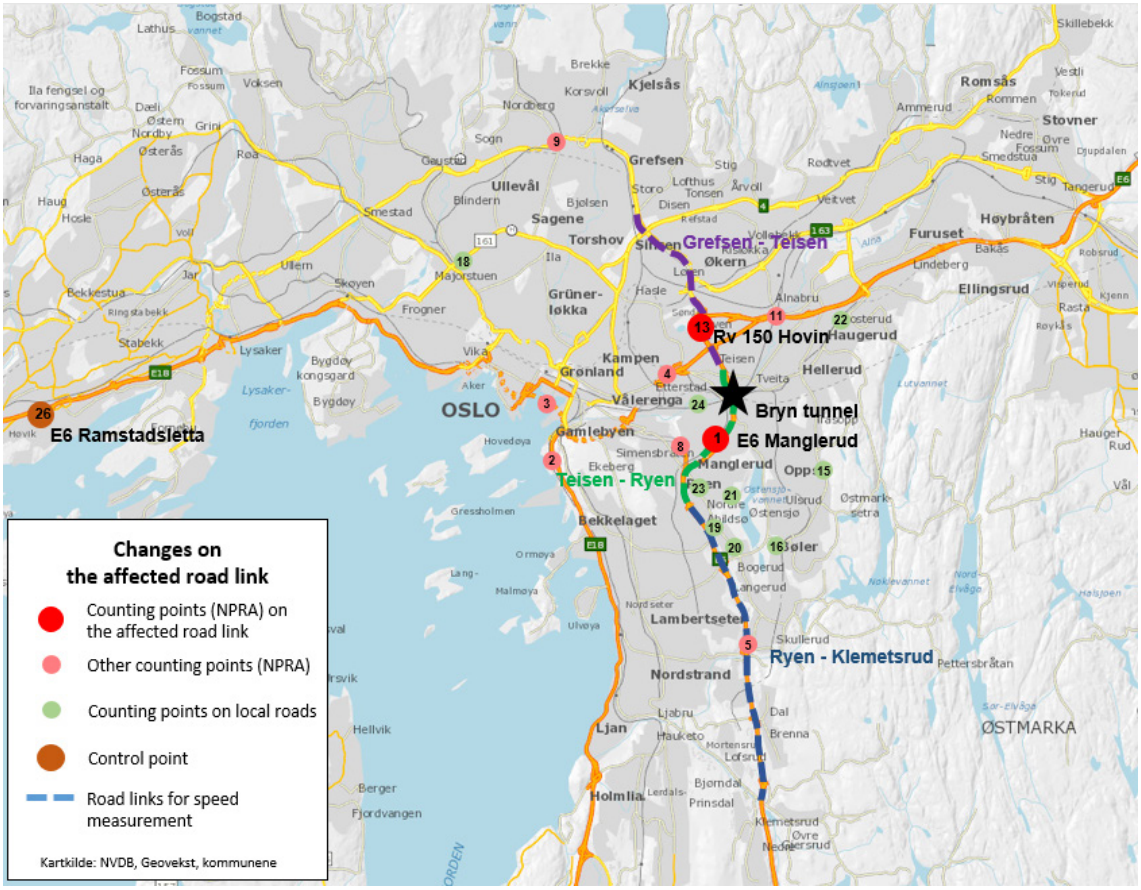

Figure S1: Map showing the location of the Bryn tunnel, as well as traffic registration points E6 Manglerud (13), Rv 150 Hovin (1) and the reference point E18 Ramstadsletta (26), as well as the links Grefsen–Teisen, Teisen–Ryen and Ryen–Klemetsrud, all mentioned in the text.

What effects did the capacity changes cause in in the Bryn tunnel and on this part of Ring 3?

Traffic volumes and average speeds were reduced in the Bryn tunnel and in adjacent parts of Ring 3 as capacity was reduced. When the tunnel regained normal capacity, traffic volumes and speeds increased, but traffic increase to somewhat lower levels than in the before situation. We did not find the same changes at the reference point, and our conclusion is that the changes were caused by the capacity changes in the Bryn tunnel.

Traffic volumes

Total traffic volumes through the traffic counter closest to the Bryn tunnel, E6 Manglerud, were significantly reduced during the capacity reduction, by 26–34 percent in rush hour and by 23 percent per day, returning to somewhat lower levels than in the before situation as the tunnel regained normal capacity. Traffic in morning and afternoon rush hours (total traffic for two rush hours, and in both directions, average for weekdays in two-weeks periods) are illustrated in figure S2. As the tunnel regained normal capacity, traffic volumes increased, but so far to lower levels than in the before situation.

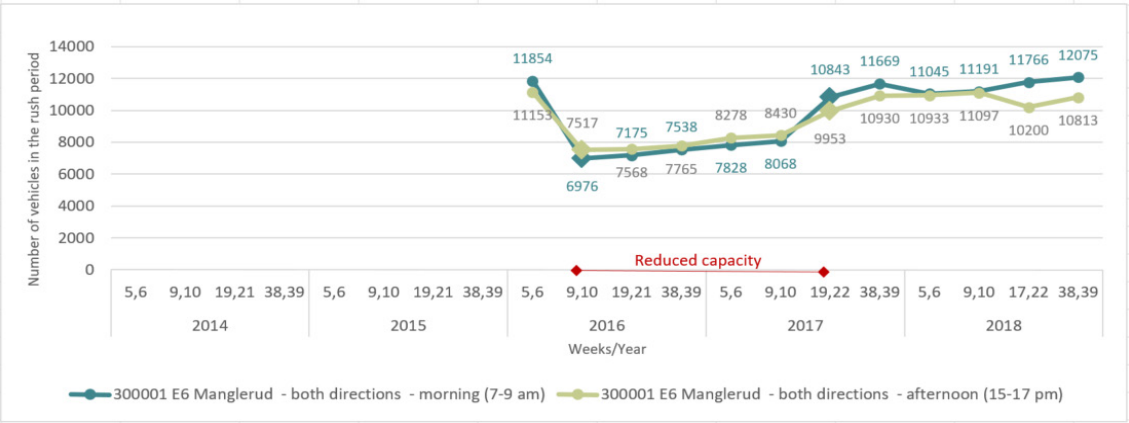

Figure S2: Average traffic volume on E6 Manglerud in the morning rush (7:00–9:00) and afternoon rush (15:00–17:00), summing both directions for the selected weeks. Capacity reduction was initiated in week 7 in 2016. Discrete data are displayed as a continuous line for better readability.

The number of long vehicles (5,6 meters and longer) decreased by 4 percent (386 vehicles) per day when comparing weeks 5 and 6 in 2016 (before capacity reduction) and 2017 (during capacity reduction) in the E6 Manglerud registration point and by 13 percent (1 523 vehicles) in the Rv 150 Hovin registration point. This was substantially less relative reductions than for the total number of vehicles (all lengths). The number of long vehicles increased in both registration points as the tunnel regained normal capacity, and to higher levels than in the before situation.

At the reference point, E18 Ramstadsletta, we did not find similar traffic reductions. Based on this, and on comments in the survey and interviews with road users, we conclude that the registered changes in traffic volumes in the Bryn tunnel were caused by the changes in road capacity and the increased delays following from this.

Average speed and delays

Despite the substantial traffic reduction, the average speed on the part of Ring 3 including the Bryn tunnel was significantly reduced in both the morning and afternoon rush hours (see results for morning rush hours in Figure S3). In the before and after situation, average measured speeds were close to or above speed limit (70 km/h), except from southbound traffic ("out of the city") in the afternoon rush where average measured speed was about 30 km/h. During the capacity reduction, speed limits were reduced to 50 km/h, and the average measured speeds to 30–40 km/h. Again, the southbound traffic in afternoon rush hour was the exception, with average speed reduced to around 20 km/h.

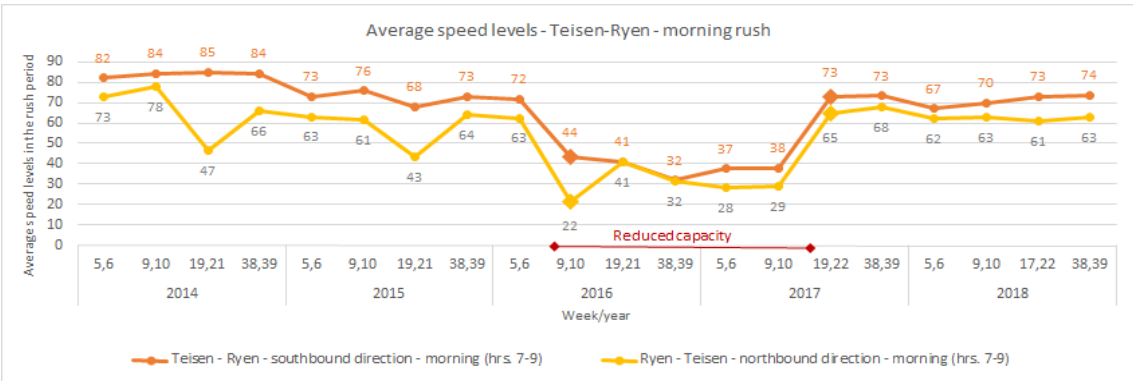

Figure S3: Average speeds of the Teisen–Ryen route in the morning rush hours (7:00–9:00) in selected weeks in 2014, 2015, 2016, 2017 and 2018. Capacity reduction was initiated in week 7 in 2016. Discrete data are displayed as a continuous line for better readability.

Comparisons of weeks 5 and 6 in 2016 and 2017 revealed extra time used on the 3,3 km long Teisen-Ryen road link in 2017, varying from 2,5 minutes (morning, southbound) to 5,1 minutes (afternoon, southbound). When also including the road links to the south and to the north of the Teisen-Ryen road link, extra time used on the 13 km stretch between Klemetsrud and Grefsen varied from 2,5 minutes (morning, southbound) to 12 minutes (afternoon, southbound).

Average speeds in the hours adjacent to rush-hours were also analysed. In the normal situation, traffic was almost free-flowing, at speeds close to and higher than speed limits (70 km/h), see Figure S4. In the period when the capacity and the speed limit were reduced (to 50 km/h), average measured speeds were reduced to around 30 - 50 km/h in different hours (adjacent to rush hours) and directions. This was most evident in in the northbound direction ('into the city') between 9.00 and 10.00 in the morning, when average speeds (over two-week periods) were down to 30 km/h.

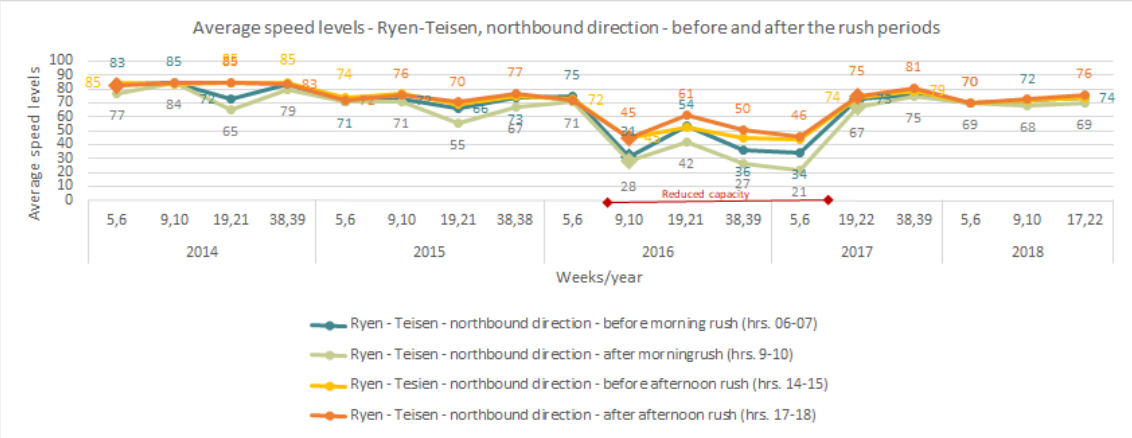

Figure S4: Changes in average speeds in the hours before and after rush hour on the stretch from Ryen to Teisen (directional). Capacity reduction was initiated in week 7 in 2016. Discrete data are displayed as a continuous line for better readability. Data from Reisetider.no.

The capacity reduction did, hence, cause reduced average speeds and increased delays in rush hours in the Bryn tunnel and on this part of Ring 3. We also found that the traffic situation was less predictable in the period when capacity was reduced.

What changes did commuters, freight traffic and taxis do to adapt?

The main finding, when investigating how different road users adapted to the capacity reduction, was that most did not make significant adjustments. Concerning adaptions resulting from the tunnel regaining normal capacity, few commuters had made changes, while freight transport operators said they had reverted to previous routines. Taxi drivers did not report significant adaptions to any of the capacity changes.

How commuters adapted

In the survey to employees working in businesses in the Bryn area, 24 percent (2016), 6 percent (2017) and 6 percent (2018) answered that their commute had been affected positively or negatively by the at capacity changes in the Bryn tunnel, *and* that they had made changes to their commutes to adapt to the situation.

Of the 40 percent of the respondents (2016) answering that their commutes had been affected positively or negatively by the capacity reduction in the Bryn tunnel, 41 percent had not made any changes to their commutes to adapt to the situation. 33 percent answered they had changed the starting time of their commute, 22 percent that they had

changed routes, 13 percent that they had changed mode of transport, 7 percent that they had home-office more frequent, and 7 percent other changes (see figure S5). Among those reporting they drove a car on their latest commute (in 2016), fewer reported 'no changes' (34 percent). 43 percent of the car-drivers said they had changed the starting time of their commute, and 28 percent that they had changed routes. As figure S5 shows, a large majority of respondents reported in 2017 and 2018 that they had not made any changes in their commute after the tunnel regained normal capacity (in April 217).

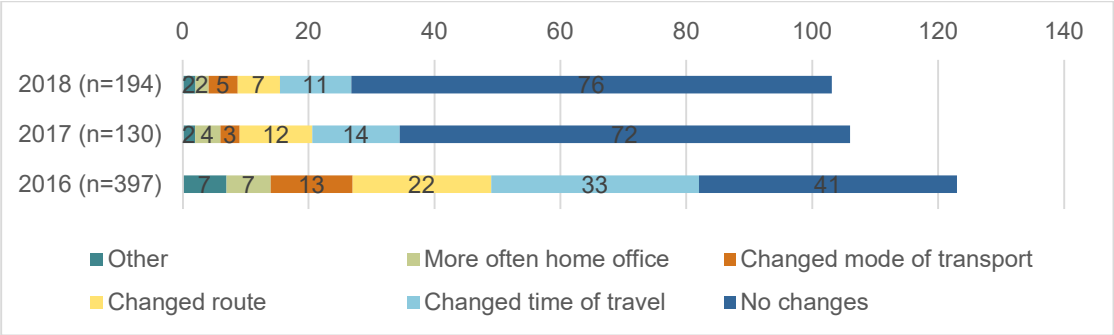

Figure S5: 'What changes have you done in your commute, to adapt to the capacity changes in the Bryn tunnel?' Multiple answers were allowed. Percentage. The question was asked only those answering that their commute had been affected by the capacity changes.

The BYTRANS project was designed to measure road-users' adaptions to the capacity reductions also in other ways than asking people directly through surveys. Using traffic data, we analysed changes in traffic volumes on alternative routes, to see if there were any measurable evidence of rerouting of traffic. We found that there had been some redistribution of traffic between routes, and that this mainly did not significantly increase delays on these routes. When we compare the situation when the capacity of the Bryn tunnel was reduced with the before situation, we found:

- Strongest increase in traffic volumes on the alternative routes Svartdal tunnel and E6 Helsfyr (morning rush), indicating that these were the most important alternative routes
- Some traffic increase on Rv23 Oslofjord tunnel, taking traffic around the Oslo road system, indicating that this was an alternative route for some
- Only small increases in traffic volumes on municipal roads, indicating that these more local roads were not important alternative routes Delays increased on some of these roads, but this was mainly due to local road works, and not the capacity reduction in the Bryn tunnel

Increased traffic volumes (12 - 37 percent) in the Svartdal tunnel resulted in somewhat reduced travel speed in rush hours. In the registration point E6 Helsfyr, travel speed was significantly reduced in afternoon rush hours, northbound. On the link Karihaugen – Helsfyr, we found reduced travel speed in morning and afternoon rush hours, southbound. These speed reductions were probably due to backblocks associated with the capacity reduction in the Bryn tunnel. Beyond this, we did not find any significant changes in traffic volumes and speeds. These results, together with the findings showing a 26 - 34 percent reduction in traffic volumes during the rush hour in the Bryn tunnel, confirm that some motorists changed route to adapt to adapt to the capacity reduction.

We did not find any indications of motorists adapting to the capacity reduction in the Bryn tunnel by driving in the hours before or after rush hours, as measured in the traffic registration point E6 Manglerud. The number of vehicles in the hours before and after rush hours decreased in the period when the Bryn Tunnel had reduced capacity (see Figure S6).

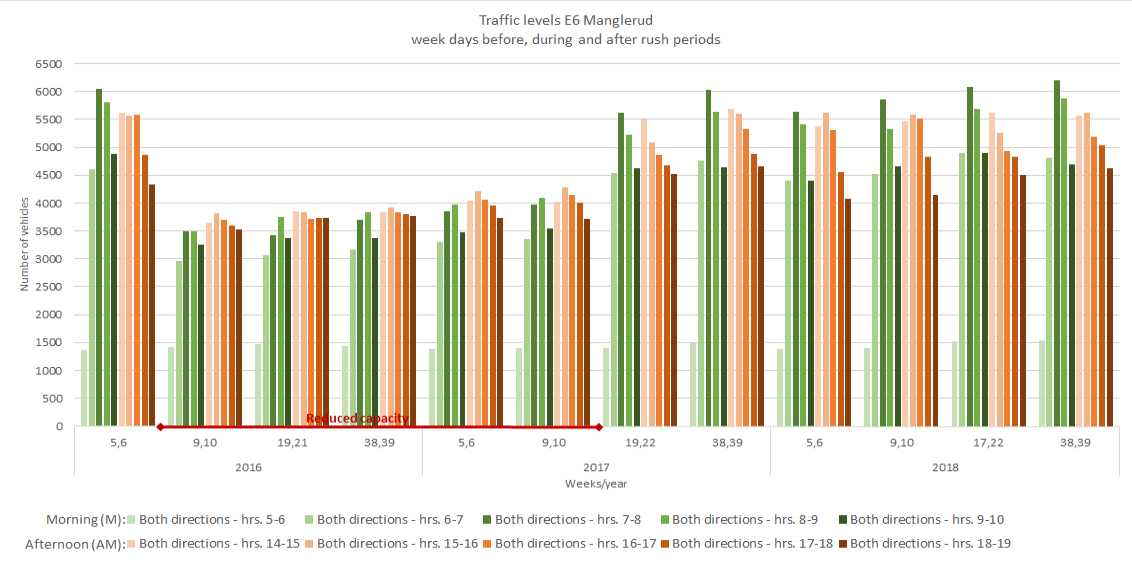

Figure S6: Traffic volumes (vehicles per hour) in rush hours and hours adjacent to rush hours (5:00–6:00, 6:00–7:00, 9:00–10:00, 14:00-15:00, 17:00-18:00 and 18:00-19:00) in the E6 Manglerud traffic registration point, both directions. Capacity reduction was initiated in week 7 in 2016.

This contrasts with the fact that 'changing the time of travel' was the adaptation most commuters answered they had done, in the survey. With support in the interviews, we understand this answer as essentially to mean that they started their commute somewhat earlier to compensate for increased time spent due to extra delays.

We analysed whether employees in businesses located in the Bryn area changed mode of transport as a response to the capacity changes in the Bryn tunnel. In the surveys conducted in 2015, 2016, 2017 and 2018 we asked what mode of transport respondents had used for the longest part of the journey last time they travelled to work and met where they normally meet. Answers to this question revealed a substantial change in modal split. We found a substantial decrease of respondents answering that they had been driving, from 39 percent in 2015 to 29 percent in 2016 (see Figure S7). The decrease continued, to 27 percent car-drivers in 2017 and 21 percent in 2018. The share of respondents answering that they had travelled by public transport and bicycle increased. Important to mention here, is that a metro-line was closed for rehabilitation when the 2015-survey was done, and had reopened before the 2016-survey. In comparison to these results, only 13 percent (of those reporting in the survey that their commute had been affected by the rehabilitation works in the Bryn tunnel) answered that they had changed mode of transport as an adaption to the capacity reduction in the Bryn tunnel.

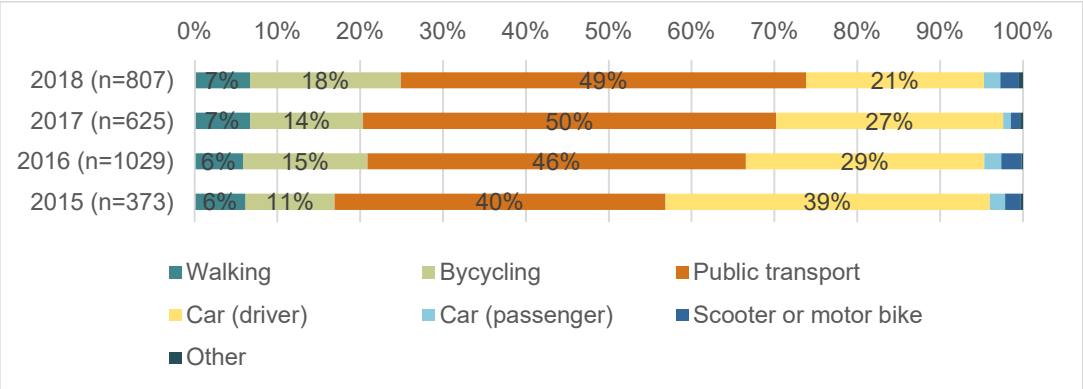

Figure S7: Answers to the question: 'Which mode of transport did you use the last time you travelled to work and met where you normally meet?'.

We also asked how often respondents had used home-office the previous week. In 2015, 89 percent answered 'none'. This decreased to 82 percent in 2016 and to 76 percent in 2017, and increased to 81 percent in 2018. Interviewees told that their employers had been less strict about the use of home-office in the period with capacity reduction, to ease the negative impacts, and the interviewees appreciated this. This increase in use of home-office is in accordance with what respondents answered were asked directly about their adaptions to the capacity reduction in the Bryn tunnel.

How freight transport adapted

Analyses of traffic data showed that only a minority of drivers of long vehicles (longer than 5.6 meters, representing freight and distribution vehicles here, but also including other long vehicles) adapted to the capacity reduction by avoiding the Bryn tunnel, in morning rush hour and during the day (see also Caspersen et al. in review for more detailed information). The number of long vehicles decreased by 4 percent (386 vehicles) per day when comparing weeks 5 and 6 in 2016 and 2017 in the E6 Manglerud registration point and by 13 percent (1 523 vehicles) in the Rv 150 Hovin registration point (see Table S1). This was substantially less reductions than for the total number of vehicles (all lengths), that decreased by 23 and 20 percent respectively. In morning rush hour, the number of long vehicles was stable at E6 Manglerud and down 14 percent (216 vehicles) at Rv 150 Hovin, while the total traffic volumes were reduced by 34 and 23 percent, respectively. This indicates that only a minority of drivers of long vehicles who normally drove through the Bryn tunnel adapted by avoiding the tunnel, and that they did so to a lesser degree than other drivers did.

An increased number of long vehicles on the most logical alternative route, the Svartdal tunnel on the main road system, indicated that some drivers chose this as an alternative route. The number of long vehicles increased by 41 percent (838 vehicles) per day and 29 percent (70 vehicles) in morning rush hour (comparing weeks 5 and 6 in 2016 and 2017). The data also showed that drivers of long vehicles did not use the more local roads as alternative routes, as the number of long vehicles on those routes were stable or reduced. After the Bryn tunnel regained full capacity, the number of long vehicles increased to higher levels than in the before situation, while the traffic was reduced toward 2016-levels in the Svartdal tunnel.

Table S1: Average number of vehicles equal to or longer than 5,6 m per day before, during, and after the capacity reduction in the Bryn tunnel, and the share of long vehicles compared to all vehicles.

	Before (Weeks 5 og 6, 2016)		During (Weeks 5 og 6, 2017)		After (Weeks 5 og 6, 2018)	
Traffic counter	Vehicles	Share	Vehicles	Share	Vehicles	Share
E6 Manglerud	9 918	12 %	9 532	15 %	10 407	14 %
Rv 150 Hovin	11 879	13 %	10 356	14 %	12 577	15 %
E6 Svartdal tunnel	2 043	6 %	2 880	8 %	2 404	9 %
General Ruges vei	968	9 %	900	8 %	721	8 %
Tvetenveien v/ Haugerud	569	4 %	589	4 %	506	4 %
E18 Ramstadsletta	8 414	10 %	9 167	11 %	9 568	11 %

Interviews with 19 truckdrivers, including ten drivers who made various adaptions and nine drivers who did not, gave more information about how they adapted. This concerned different ways of avoiding the Bryn tunnel, especially in rush hours, by using alternative roads, reorganizing delivery routes, and starting earlier or later to avoid congestion and/or compensate for extra time usage. Some companies made adaptions, including rerouting,

changing departure times, and guiding truckdrivers out of the most congested areas at the most congested times. Some transport planners at freight companies had adaptions planned but found them un-necessary to implement. Truckdrivers and transport planners alike claimed limited flexibility, due to strict customer contracts. This is in line with results from the analyses of the traffic data. After the rehabilitation work finished in 2017, truckdrivers said they had mainly returned to their old routines.

How taxi traffic adapted

Taxidrivers said, in group-interviews in 2016, that they had not seen any need to adapt. They could use the public transport lanes, and was not much delayed by the capacity reduction.

What effects and consequences did the capacity changes, and the adaptions to the changes, have for the transport system and for the local and global environment?

Effects and consequences for road traffic mainly were concentrated to the Bryn tunnel and adjacent road links. There was some redistribution of traffic to other links, but only marginal traffic increases on local roads. However, there were increased delays here, mainly due to local road works. It seems that total traffic in the system was reduced during the period of capacity reduction, both per rush hours and per day. If this is correct, it very likely means that greenhouse gas emissions were also reduced during the period. Pollution concentrations were lower in the period of capacity reduction than in the normal situation.

Mainly local effects in the transport system

Concerning the overall consequences for the transport systems, and based on what has been discussed above, it seems that the effects of the capacity reduction were mainly limited to the Bryn tunnel and adjacent links. Here, delays increased significantly. This resulted in road users adapting in several ways, including by choosing other routes and other means of transport, and by traveling less frequently and changing the time of the journey. This resulted in significant reductions in the traffic volumes in the Bryn tunnel and on this part of Ring 3, which has contributed to reducing the delays and disadvantages due to capacity reduction. The adjustments led to some changes in traffic volumes on alternative routes. The redistribution did not result in significantly increased delays on these links. The delays increased on the link Karihaugen - Helsfyr (afternoon, south).

Effects and consequences for local roads and residential areas

Residents of the area and other users of the municipal roads reported increased delays and more congestion during parts of the period when the Bryn tunnel had reduced capacity. The informants found that the increase in traffic was surprisingly large and that it was perceived as a major disadvantage and a deterioration of the living environment. Based on analysis of traffic data, we concluded a traffic increase for the six local roads for which we have data of 6,8 percent (a total of 626 vehicles on all roads) in the morning rush hours and 4,5 percent (a total of 460 vehicles) in the afternoon rush hours. Mitigation measures were implemented that reduced traffic volumes on some local roads, and which may have resulted in increased traffic on other roads, of which we do not have data. Local roads were not used as bypass routes by vehicles longer than 5,6 meters, as discussed.

Residents of the area and other users of the municipal roads also experienced increased delays and more queuing during parts of the period when the Bryn tunnel had reduced capacity. Our assessment is that this was mainly due to roadworks on the local roads, including works on local roads related to the tunnel works (especially at Østensjø bridge), as well as some increase in traffic volumes on local roads. Measurements via counting points do not show significant changes in average speeds (except for Østensjøveien), but

measurements of time usage for the buses on Hellerudveien show increased delays. We assume that this also contributed to the road users experiencing the increase in traffic stronger than it was. The extra delays were nevertheless perceived as negative, and they had consequences.

According to interviews and open answers in the surveys, this also caused disadvantages for pedestrians and cyclists. Those bicycling expressed that they were 'forced' up on the sidewalk, which is disadvantageous for both pedestrians and cyclists. This problem was enhanced by insufficient bicycle infrastructure on parts of the network.

Reduced total traffic volumes and greenhouse gas emissions

As previous research has found that capacity reductions might result in 'disappearing traffic' (Cairns et al. 2001), we analysed if that also was the case here. We summarized traffic volumes from different traffic registration points, on routes understood as alternatives to each other. Getting this right is not an easy task, and it can be discussed if some traffic is double-counted or missed out. Traffic volume in the selected registration points in weeks 5 and 6 2016 (before capacity reduction) were compared to traffic volumes the same weeks in 2017 (during capacity reduction), see figure S8. The results showed that total traffic in these registration points were reduced by 2 800 vehicles (4,2 percent) in the morning rush hours (7.00 – 9.00), by 1 900 vehicles (2,9 percent) in afternoon rush hours (15.00 – 17.00), and 12 300 vehicles (2,2 percent) per day. After the tunnel regained normal capacity, traffic volumes increased, but to somewhat lower levels than in the before situation[7].

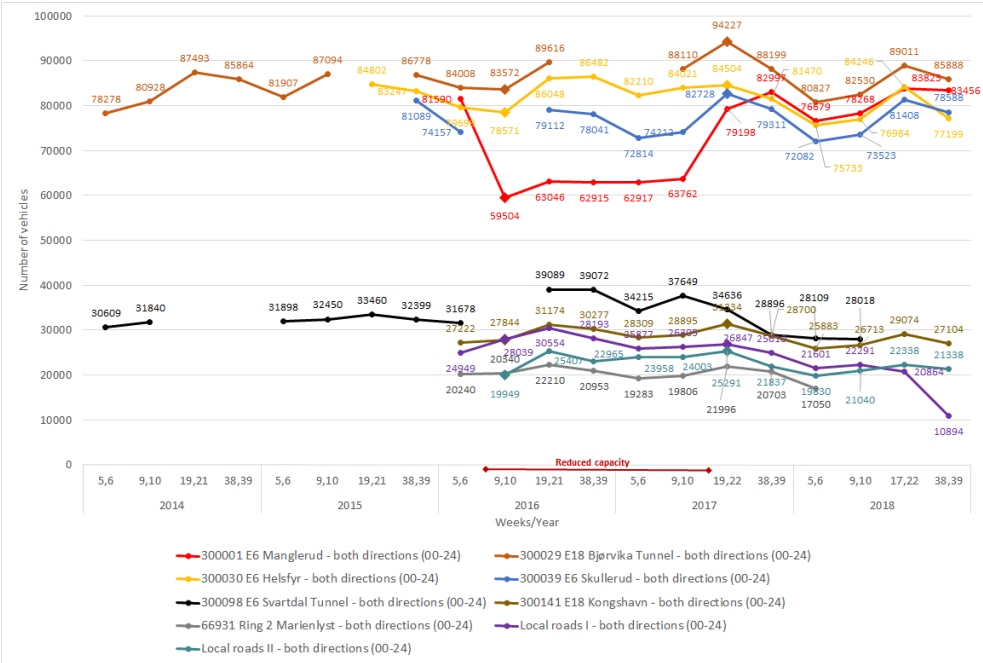

Figure S8: Traffic volumes at different counting points, summing both directions in the morning rush (7:00–9:00). 'Local roads I' includes General Ruges vei and Tvetenveien. 'Local roads II' includes Plogveien, Enebakkveien and Østensjøveien 50. Discrete data are displayed as a continuous line for better readability.

[7] This may have various and complex causes, such as changes in the road toll system and prices, delays in changes back to the before-situation, real changes in travel behavior transport in Oslo, or othe causes.

It hence seems that some traffic disappeared in the period when the capacity in the Bryn tunnel was reduced. If these results are correct, it probably also means that the capacity reduction resulted in reduced GHG emissions.

Reduced local pollution

The National Public Roads Administration measured changes in local pollution in relevant areas before and during the capacity reduction. The analyses concluded that pollution was lower in the period with capacity reduction as compared to the normal situation, probably due to lower traffic volumes and speeds. Meteorology might have influenced on the results.

What effects and consequences did the capacity changes, and the adaptions to the changes, have for different groups of road users?

Main effects were increased delays and reduced predictability in the Bryn tunnel and on adjacent links. Some commuters stated that they had changed responsibilities or routines in the household as a consequence of this, and some experienced reduced commute satisfaction. Some truck drivers found that the situation created more stress and frustration and less predictable working days.

Commuters: Effects and consequences

The main effects of the capacity reduction in the Bryn tunnel for employees in businesses located in the Bryn area were longer travel time and poorer punctuality. 51 percent of car-drivers and 11 percent of public transport users stated that they spent more time on their commute when the capacity in the Bryn tunnel was reduced than in the before situation. On average, car-drivers estimated that they used approximately 9 minutes longer. These estimates agree well with our measurements of delays through traffic data.

When investigating consequences for commuters, we focused on changes in their commute satisfaction, and whether they had felt the need to reorganise tasks or routines within the household. Concerning the latter, we found that 12 percent of (all) respondents employed in businesses in the Bryn area report that the capacity reduction and/or their adaptation to the situation had led to changes in responsibilities, routines or other changes in the household. This included 5 percent answering that it had resulted in changes in responsibility/routines related to bringing children to and from kindergarten, school, etc.

Concerning commute satisfaction, all respondents were asked, in the annual surveys, how satisfied they were with their commute (before asking any questions about the Bryn tunnel). Results showed that the respondents overall were quite satisfied, with the proportions of respondents who answered 'satisfied' or 'very satisfied' varying from 72 percent (2016) to 78 percent (2017). The share that responded 'very satisfied' increased steadily over the years, from 26 percent in 2015 to 37 percent in 2018. The proportions who answered 'dissatisfied' or 'very dissatisfied' remained low, varying from 7 percent (2017) to 13 percent (2015 and 2016).

We also asked if respondents felt that their commute had become better or worse compared to the situation one year ago, se results in Figure S9. The shares that responded 'somewhat worse' or 'much worse' were higher in 2016 (24 percent in total) than in other years (varying from 8-17 percent). Interestingly, the proportion that responded 'somewhat better' and 'much better' was also higher in 2016 (22 percent in total) than in the other years (varying from 17-21 percent). We believe this is related to reopening of a relevant metro-line that had been closed for rehabilitation, and had come back in operation in April 2016.

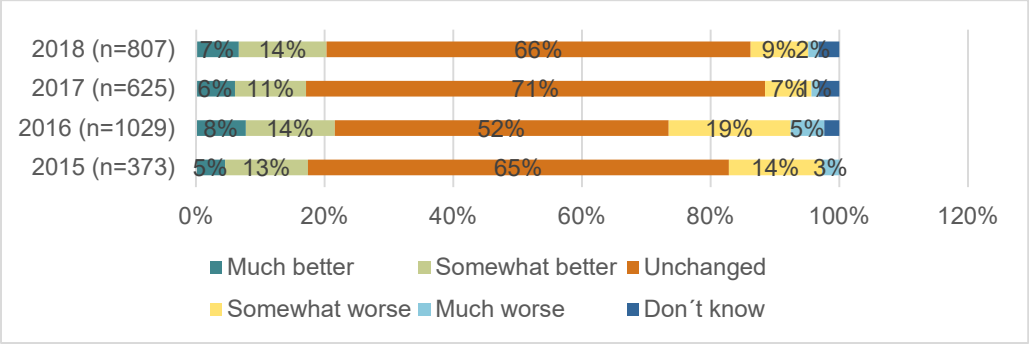

Figure S9: Answers to the question: 'Do you experience that your commute has become better or worse compared to the situation one year ago?'

It is, however, worth noting that 37 percent of respondents who worked in the Bryn area in 2016 responded, on a direct question concerning this, that their work journey had become worse or much worse due to the work in the Bryn tunnel. Car-drivers experienced this to a greater extent than public transport users and cyclists. Respondents in the age-group 35-54 years, as well as married/ cohabitants, experienced this to a greater extent than others. The percentage who experienced this increases with the number of children in the household, with income and with access to car. The proportion who experience it this way is reduced with increasing education. We found only insignificant differences between women and men.

The negative changes most (of those who stated that their work trip had become worse) stated to have experienced (in 2016) were more congestion and longer travel time, but also reduced punctuality, more car traffic/pollution where they walk or cycle and that it took longer time and was more congested in public transport. The positive changes reported (in 2017 and 2018) after the tunnel had regained normal capacity concerned largely the same issues, but in a positive direction, and fewer reported these changes.

Freight transport: Effects and consequences

The truckdrivers answering our surveys were generally dissatisfied with the traffic situation for freight transport in the Oslo area. The proportion who stated that they were dissatisfied or very dissatisfied ranged from 51 percent (2017) to 78 percent (2015). The percentage who stated that they were satisfied or very satisfied varied from 5 percent (2015) to 23 percent (2017).

The share of drivers who experienced a worsening of the traffic situation, compared to the situation one year before, peaked in 2016, with 67 percent experiencing a worsening of the situation. The proportion who responded that the traffic situation had improved from the previous year varied from 7 percent (2015) to 13 percent (2018). In 2016, when asked directly if their workdays had become better or worse due to the capacity reduction in the Bryn tunnel, 84 percent of truckdrivers responded that they felt that their working day had deteriorated. Eighty percent (in 2017) and 86 percent (in 2018) stated that their working day had improved much or very much as a result of the Bryn tunnel regaining normal capacity.

Drivers who responded that they experienced a change in their workdays received follow-up questions about what changes they experienced, and they could select multiple alternatives. The most commonly reported negative *effects* were more congestion (19 percent); increased time spent on routes (16 percent); and detours (14 percent). Fewer reported that it was more difficult to comply with time windows (3 percent); or that they had to distribute the goods on more vehicles (3 percent). The most commonly reported negative *consequences* were more stress and frustration (15 percent) and less predictable

workdays (10 percent). More inconvenient work hours, use of more vehicles, and more problems complying with mandatory rest periods were reported by fewer respondents. In interviews, longer workdays were also an issue. The drivers explained that this was mainly due to the more unpredictable traffic situation and the need to depart earlier. Some also said that the congested traffic led to more risk-taking behaviour among private drivers, causing traffic safety issues.

Most of the interviewed freight company transport planners reported that that reduced flexibility and efficiency resulted in increased costs and reduced profits. None reported, however, acquiring more vehicles or truckdrivers because of the change in the traffic situation, but drivers used more time on deliveries and routes. Several claimed that the situation for delivery zones in the city centre was a bigger problem than delays on the main roads, including the worsened situation caused by the rehabilitation works in the Bryn tunnel.

Among the suggestions on what the authorities can do in general to improve the situation for freight transport and delivery in Oslo, truckdrivers mentioned: Measures to reduce passenger car traffic, improve conditions for deliveries (especially spaces for loading and unloading in the city centre) and better information about the traffic situation. Among the proposals on what the authorities could have done to reduce the disadvantages associated with the capacity reduction in the Bryn tunnel, we find: Faster implementation of rehabilitation work, better information on road work and queues, giving freight transport access to the public transport lanes (instead of the electric vehicles), building new roads, take into account e.g. not to carry out vehicle inspection during periods of extra delays - such as when the Bryn tunnel had reduced capacity. We also found potential for improvement that the industry can initiate, such as changing routines at terminals, setting up routes to avoid the most congested situations, informing customers and drivers of delays, and plan for more time on routes when knowing there are increased delays and less predictability

Taxi traffic: Effects and consequences

The capacity reduction in the Bryn tunnel reduced driving speeds and increased tour lengths for taxi traffic only marginally. Drivers did not report that they had made significant changes to adapt to the situation in interviews. The largest taxi centre had not made any adjustments.

The taxi drivers stated in the survey that their working day was poorer as a result of the works in the Bryn tunnel, and they were more dissatisfied with the traffic situation in the Oslo area in 2016 than in 2015. In the qualitative interviews, however, the drivers clearly stated that the reduction in capacity was not a major obstacle to their accessibility. Taxis are allowed in public transport lanes, and the delays were perceived to be so moderate that those we interviewed did not pay much attention to them.

Did the information measures work as intended? What could improve?

The NPRA implemented an information strategy with several elements: Interest analysis, local information (written), dialogue with schools and FAU[8], advertising and editorials in traditional media, posts on their websites, posts and advertisements on social media, competitions and campaigns. The information reached the public, and we have not suggested any improvements.

[8] FAU: Parents Council Working Committee in schools.

The surveys and interviews among commuters, truckdrivers and taxi drivers showed that the NPRA managed to disseminate the information. Most commuters (61 percent), truckdrivers (75 percent) and taxi drivers (54 percent) responded that they had received sufficient information. Only 3 percent of the commuters, 6 percent of the truckdrivers and 5 percent of the taxi drivers replied that they had not received information about the capacity reduction. The most important sources of information were as follows: employers; newspaper, radio and television editorials; newspaper advertisements; and colleagues, friends and acquaintances.

Figure S10: Example of ads from the Norwegian Public Roads Administration. Source: Norwegian Public Roads Administration.

Social media were indicated as an important source of information by a smaller share of respondents. Nevertheless, the NPRA's use of the Facebook page 'Bryn tunnel' is an interesting development. They used it to communicate with users and answer questions, and this communication replaced some of the communication they normally would have engaged in by email and phone. Hence, we conclude that the information measures worked as intended: The information reached large shares of the intended audience.

Did the mitigation measures work as intended? What can improve?

Several mitigation measures were implemented to reduce the inconveniences for road users and residents due to the capacity reduction in the Bryn tunnel: Reduced speed limits, closing ramps, congestion warnings, signs informing about alternative routes, temporary public transport lanes, restrictions on electric vehicles in public transport lanes, closing of local roads during rush hours and temporary commuter parking.

We did not conduct thorough investigations as to whether all these measures have worked as intended. In the survey of employees of Bryn-area businesses, 12 percent agreed that temporary public transport lanes and restrictions on electric vehicles in public transport lanes contributed to reducing the inconveniences for road users to a high or very high degree, while 3 percent answered the same for temporary commuter parking. Sixty to 70 percent of respondents did not know or felt that the question was not relevant for them.

The NPRA had prepared action plans A and B for mitigation measures. Plan B was to be implemented if the measures in Plan A were not sufficient, but the authority decided not to implement Plan B. This suggests that the mitigation measures functioned as intended. The mitigation measures were adjusted somewhat along the way, and these experiences will be useful in similar situations in the future. In surveys and interviews, many argued that they

believed that the work could and should have been completed faster, for example by using double or continuous shifts.

So what? What can we learn from case Bryn tunnel?

A major finding is thus that halving the road capacity on one of Norway's most heavily trafficked roads did not have major negative consequences, and less severe consequences than expected. Few evidences of severe consequences were found. We concluded that this went quite well, as the capacity reduction did not cause chaos, crisis or intolerable situations.

How, then, can this knowledge be useful in developing the more efficient and environmentally friendly urban transport systems of the future? As we understand this, it involves developing cities and urban transport systems in ways ensuring effective accessibility, while significantly reducing local and global environmental impacts from transport, and making cities more attractive and vibrant. This includes reaching the zero growth-objective.

We believe that the findings might help expanding the understanding of what are possible and relevant interventions when developing cities and their transport systems, and this might accelerate implementation of measures that contribute to achieving prioritized goals. If one, for instance, see reallocation of car lanes to public transport lanes as 'not possible', it might also be 'not possible' to improve public transport speed and competitiveness, and making urban transport systems more efficient. In such discussions, it is problematic if those who are set to solving the problem have a too narrow and restricted understanding of what alternatives and interventions are possible and relevant.

The results can also be input to ongoing discussions about assumptions and methods related to analyses of effects and consequences of interventions in transport systems. Our results showed that the proportion of motorists who were very satisfied or satisfied with their commute was 50 percent in 2016 (compared with 64-73 percent in the other years), and the proportion who were dissatisfied or very dissatisfied was 21 percent in 2016 (against 10-13 percent in the other years). Rough estimates showed that increased time spent (estimated at 9 minutes) and more of the travel time spent in strong rather than moderate congestion in rush hour (estimated at 6 minutes) for motorists who continued to drive through the Bryn tunnel during the capacity reduction, would have been calculated at a cost of approx. NOK 40 per trip or NOK 80 per day if using data from the latest Norwegian value of time (VOT) study. If this is multiplied by 7700 vehicles passing the tunnel in morning rush hours, and by 230 workdays per year, the costs will be estimated to approximately NOK 142 million per year. This is a large figure, and it is interesting to discuss whether the cost seems reasonable when we compare it with the changes in perceived commute satisfaction. In discussions related to assumptions and methods within socio-economic analysis, more critical discussions are sought against findings from empirical research. The empirical studies we have done in connection with the Bryn tunnel case can be useful input for such discussions, for example about VOT. The same applies to whether transport models calculate the effects of capacity changes on traffic volumes, congestion and delays correctly. This has been investigated as part of the BYTRANS project, and preliminary results show that the regional transport model (RTM) calculates larger delays and increases in delays than what we measured in the system although modelled traffic flow was more correctly estimated. It is important to discuss and calibrate such methods, models and assumptions. In cost-benefit analyses of interventions, changes in time spent, calculated using transport models, and the value of lost or saved time, defined through VOT studies, are very heavy posts. If the transport models calculate

greater changes in delays than those that actually occur, and the value of lost or saved time is overestimated, this could have major implications when calculating benefits and costs of transport systems interventions. This may result in not prioritizing the projects that provide the most benefit to society, measured for example as more efficient and environmentally friendly urban transport systems. More empirical research related to the effects and consequences of changes in transport systems, such as what we have done here, can contribute to a critical discussion of the current assumptions, methods and models, which can further contribute to better analyzes and a greater degree of goal achievement.

In discussions concerning implementation of interventions causing reduced car accessibility, it is often claimed that 'replacement capacity' needs to be in place first. This might cause delays, that suggestions are rejected, or that the interventions contribute less to achieving sustainability goals. Our findings question the necessity of 'replacement capacity', as they show that many road users adapt in ways helping reducing the pressure, as delays in urban road systems increase. This might improve the chances that interventions providing more efficient and environmentally friendly urban transport systems are implemented, that they can be implemented more quickly, and without unnecessary and large costs.

There are plans for construction of new roads and expansion of road capacity on existing ones in most Norwegian cities. This is often justified by the aim to reduce congestion and delays. The results of our investigations show, as also found in a number of previous studies, that road users adapt to changes in urban transport systems. This supports the well-documented knowledge that increased road capacity in pressured urban road systems causes more people to choose the private car, increased traffic volumes and, eventually, more people stuck in congestion. Taking this knowledge into account could help authorities to not investing in measures and projects *reducing* the chances of achieving their defined goals, such as expanding road capacity, and instead invest in measures and projects that help achieving more effective and environmentally friendly urban transport systems.

Freight transport accessibility is often major concern in discussions concerning development of more efficient and sustainable transport systems, and an argument for increasing road capacity - or not reducing it. Our studies into effects and consequences for freight and delivery transport, and especially for truckdrivers, has provided new insights that can be used when searching for better solutions. We have not found much research concerning these issues, in particular where the truckdrivers' voices are heard. Their proposals, such as allowing freight traffic in the public transport lanes instead of electric vehicles, should be considered.

Increasing parts of the urban road systems in Norwegian cities are built in maintenance intensive tunnels. Hence, situations like the one studied here will occur more frequently in the future. The documentation of effects and consequences of capacity reduction in the Bryn tunnel, as well as how information and mitigating measures worked out,