Transportation Research Part D 96 (2021) 102848

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Urban main road capacity reduction: Adaptations, effects and consequences

Aud Tennøy [*], Oddrun Helen Hagen

Institute of Transport Economics, Department of Mobility, Gaustadalléen 21, 0349 Oslo, Norway

ARTICLE INFO

Keywords:
Road capacity reduction
Commuters
Adaptation
Effects
Consequences
Sustainable mobility

ABSTRACT

To support sustainable urban mobility strategies, reallocating road space from private vehicles to other uses may be a relevant intervention. Novel empirical knowledge could reduce barriers for implementing such interventions. A planned, 14-month capacity reduction of a main road tunnel in Oslo, Norway, carrying 70,000 vehicles a day, offered an excellent opportunity to document how commuters adapted, and what effects and consequences they experienced. Analyses of traffic data were combined with surveys and interviews with commuters. Congestion increased in the tunnel and on adjacent road-links, although road users adapted in ways resulting in significant traffic reduction through the tunnel. Some employees in an area near the tunnel experienced increased time-usage on their commute, and some adapted by changing transport mode, route, or trip-timing. However, results showed that they did not experience major negative consequences. Few commuters reported a need to shift routines in the household, and commuter satisfaction remained high.

1. Introduction

Increasing urban traffic volumes cause problems related to congestion, traffic safety, local pollution, greenhouse gas emissions, public health, and urban liveability, among other things, in cities around the world (European Environment Agency, 2018; UN Habitat, 2013; UN, 2017). City authorities struggle to reduce transport demand and traffic growth while also ensuring efficient mobility for passengers and goods. In Norway, the government has defined the 'zero-growth objective' to deal with this challenge. It states that increasing transport demand caused by the rapid population growth in the larger urban regions shall not cause growth in passenger road traffic (total vehicle kilometres travelled in the urban region; Ministry of Local Government and Modernisation, 2012, 2017; Ministry of Transport and Communications, 2013, 2017; see also Tønnesen et al., 2019). The overarching aim of the zero-growth objective is establishing more attractive and liveable cities, with vibrant and accessible city centres, and efficient and accessible mobility systems, where more of the transport is done by foot, bicycle, and public transport, and where the local and global pollution generated by the transport sector is reduced. The main strategies for achieving this aim are to develop transport systems and land use in ways that facilitate reduced transport demand, shorter trips, and modal shifts towards less car usage.

Reallocating urban road and street space from private cars to other uses may be a relevant intervention when aiming at modal shifts from private vehicles to different transport modes. However, it seems that authorities' exaggerated fear of negative effects and consequences related to road capacity reductions, such as increased congestion and time usage for road users, could be a key barrier to

* Corresponding author.
E-mail addresses: ate@toi.no (A. Tennøy), ohh@toi.no (O.H. Hagen).

https://doi.org/10.1016/j.trd.2021.102848

Available online 6 May 2021
1361-9209/© 2021 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

doing so (Cairns et al., 2002; Tennøy et al., 2016). A stronger knowledge base could reduce uncertainties and barriers to implementing such interventions. The aim of this paper is to contribute to the relatively scarce literature on adaptations to, effects and consequences of urban road capacity reductions with a thorough, longitudinal case study of a planned and temporary (14 continuous months) capacity reduction in a main road tunnel in Oslo, Norway.

Leaning on basic traffic theory, one would expect capacity reduction to result in increased traffic density, more unstable traffic and more congestion and delays for road users, especially in rush hours (Lieu, 1999; Treiber and Kesting, 2013). This could result in road users choosing other routes or travelling at other times, causing increased congestion elsewhere in the road transport system or at other times of the day. It could also affect public transport users, cyclists, and pedestrians if they were hindered by increased congestion or experienced more traffic while biking, walking, or waiting for the bus. Research on how absolute and relative qualities of and changes to transport systems affect travel behaviour indicates that this is too narrow an understanding. Previous studies have shown that people tend to travel longer and more frequently on average if travel is fast, safe, cheap, and comfortable than if the opposite is the case (Cairns et al., 2002; Downs, 2004; Goodwin, 1996; Mogridge, 1997; Noland and Lem, 2002). It is also well documented that changes in relative qualities between modes of transport, improving conditions for using one mode as compared to other modes, tend to result in more people choosing the improved mode (Altieri et al., 2020; Cairns et al., 2002; Downs, 2004; Engebretsen et al., 2017; Fishman et al., 2014; Goodwin, 1996; Forsyth and Krizek, 2010; Heinen et al., 2010; Mogridge, 1997; Noland and Lem, 2002; Pucher et al., 2010; Redman et al., 2013; Speck, 2012; Tennøy et al., 2019; Walker, 2012). Studies investigating the effects of *expanding* road capacity in congested urban road transport systems have documented how the mentioned mechanisms result in induced traffic—that is, overall traffic growth that would otherwise not have occurred—as more people choose to travel by private car and to travel longer distances when conditions for car usage improve (Cervero, 2003; Downs, 2004; Duranton and Turner, 2011; Goodwin, 1996; Litman, 2020; McCoy and Stephens, 2014; Mogridge, 1997; Noland and Lem, 2002; SACTRA, 1994; Tennøy et al., 2019; Twitchett, 2013).

The relatively few studies on the effects of *reducing* road capacity in congested urban road systems have found that road users adapt to this in ways that result in the opposite effects. In the largest and most comprehensive study on this topic, Cairns et al. (2002) collected and analysed 70 case studies where road capacity was reduced for different reasons in 11 countries over a period of three decades. The key findings were that traffic problems were usually far less severe than expected, overall traffic levels were significantly reduced in many cases and this could partly be explained by road users adapting to the situation in various ways. Supported by a survey of transport professionals, it was found that changes to routes, trip timing, modes of transport and trip frequency were understood as plausible behavioural responses to road capacity reductions. Studies of cases of temporary road capacity reductions because of road works have also shown that motorists adapted in ways that mitigated traffic deterioration compared with what was predicted (Brown et al., 2017; Taylor and Wachs, 2014; Tennøy et al., 2016; Torp and Eriksen, 2009). The existing literature is weak in terms of empirical studies of how users of the transport system report adapting to capacity reductions, and even more so when it comes to what direct effects and wider consequences they experience. Focussing on person transport, potential direct effects could be changes and variability in time usage and other issues directly following from changes in the traffic situation, for car drivers as well as for others (Cairns et al., 2002; Zhu et al., 2010). Wider consequences could, for instance, concern changes in distribution of tasks and responsibilities within the households (Cairns et al., 2002), or changes in commute satisfaction that could affect subjective wellbeing (Chatterjee et al., 2020).

Using a planned 14-month capacity reduction in a main road tunnel in Oslo, Norway, as case, this article contributes to the literature on adaptations to and effects and consequences of urban road capacity reductions with a thorough, empirical case study, and it contributes novel knowledge by incorporating commuters' experiences. The paper seeks to answer the following research questions: *What adaptations, effects and consequences could be observed in the transport system? How do affected commuters report having adapted, and what effects and consequences have they experienced?* The research was designed as a longitudinal case study, combining analyses of traffic data with surveys of commuters over four consecutive years and interviews with commuters in the two most relevant years.

The aim of the study is to contribute to the knowledge base informing planners and policymakers developing urban transport systems in ways that contribute to achieving their defined goals, such as more sustainable urban mobility. More empirical knowledge might reduce uncertainties related to the adaptations, effects, and consequences of road capacity reduction. This might be useful when considering permanent capacity reductions to reallocate road space to other uses or for other reasons, as well as in situations requiring temporary road capacity reductions. Although the case studied was a temporary capacity reduction, we believe the results are also relevant in discussions about permanent capacity reductions. As the tunnel capacity was reduced for 14 continuous months, and the study focusses on rather fixed commute trips, the adaptations, effects, and consequences are expected to be similar to what would be found if studying a permanent capacity reduction. Important exceptions are potential long-term impacts on commute patterns and land use development (Tennøy et al., 2019).

The paper is structured as follows: Section 2 describes the research design and data collection methods, including the case description. The results are then presented in section 3, followed by a discussion of the findings in section 4 and the concluding remarks in section 5. Results are presented in figures, and the underlying data can be found in tables in the appendices.

2. Research design, data and methodology

2.1. The case: Capacity changes in the Bryn tunnel

The research was designed as a single, longitudinal case study. The case was the capacity changes in the 270-metre-long Bryn tunnel, located on the outer ring road (Ring 3) in the Norwegian capital of Oslo (see Fig. 1). About 700 000 people live in Oslo municipality, while approximately 1 000 000 live in the city region and 1.6 million in the metropolitan area. This part of Ring 3 normally carries annual average daily traffic (AADT) of about 70 000 vehicles and distributes traffic between different parts of the city and the region (data from the Norwegian Public Roads Administration [NPRA]). The average amount of traffic per weekday in calendar weeks 5 and 6 of 2016, describing the normal traffic situation, was about 82 000 vehicles, of which 9900 vehicles (12 per cent) were longer than 5.6 m (mainly freight transport). Traffic is almost equal in both directions, including during rush hours. The tunnel is dual, with two lanes in each direction.

The tunnel capacity was reduced from four to two lanes for 14 continuous months, from 20 February 2016 to 29 April 2017, because of planned rehabilitation work necessitated by the EU tunnel safety directive (EU, 2004). One tube was closed at a time, and two-way traffic continued in the open tube. When the work was finished, both tubes opened for traffic, and the tunnel regained the same capacity as before. The Bryn tunnel was one out of ten tunnels in Oslo undergoing rehabilitation in 2015–2020. It was selected as the case for this study because it carries a heavy traffic load and because the road capacity would be halved for 14 continuous months. Other tunnels carried less traffic and/or experienced reduced capacity only at night, on weekends or holidays or for shorter continuous periods compared with the Bryn tunnel. Therefore, it was expected that the capacity reduction in the Bryn tunnel would cause more adaptations, effects and consequences compared with those in other tunnels.

The NPRA carried out a public information campaign, using several channels to encourage and advise travellers on how they could avoid congestion and contribute to reducing the negative impacts (Tønnesen et al., 2020). The campaign had a high level of outreach, with most commuters and truck drivers reporting they had received sufficient information regarding the situation, and only a few saying they had not received any information. The press and employers were the most important sources of information.

Key mitigation measures during the capacity reduction were speed limit reductions from 70 to 50 km/h, introduction of dedicated public transport lanes in the outer parts of the urban region, extension of a public transport lane through the most affected area, prohibition of electrical vehicles in dedicated public transport lanes and closing of an entry and exit lane near the tunnel. Works on the tunnel roof and on local roads affected the situation for these local roads in the vicinity. A metro line (Østensjøbanen), that had been closed for rehabilitation and substituted by buses, reopened with higher capacity and better standards in May 2016, and this probably influenced some findings in this study. Other changes in the transport system might also have affected the results.

2.2. Research design

Data were collected before, during and after the road capacity reduction in the Bryn tunnel. This allowed analysis of traffic data to study how road users adapted, first to the capacity being reduced, and then the expansion back to normal, and what effects this caused in the transport system. Further, it allowed us to investigate how commuters to the Bryn area adapted to the capacity changes and what effects and consequences they experienced. Choosing a case-study design enabled us to study this contemporary phenomenon in its real-life context and to investigate how different mechanisms played out in this situation (Yin, 2003). The choice of case was strategic

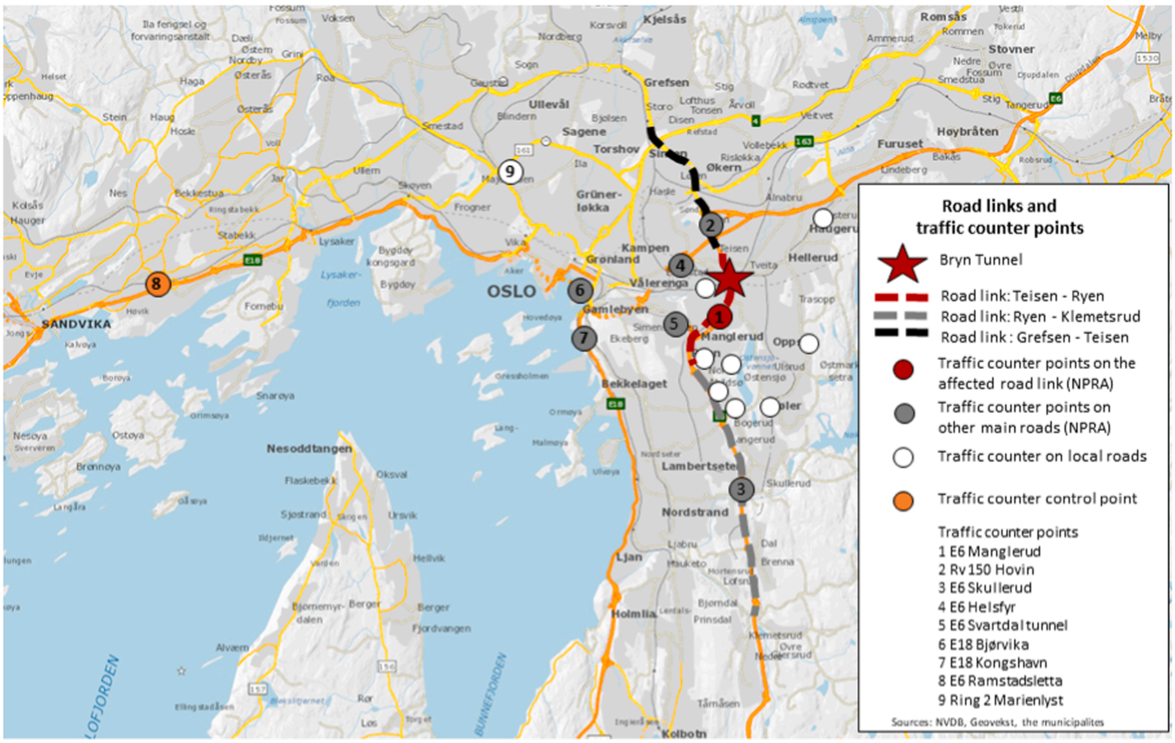

Fig. 1. Map showing the location of the Bryn tunnel on Ring 3, relevant traffic counters and road links where traffic speeds were measured.

(Flyvbjerg, 2006; Yin, 2003), as the capacity changes in the Bryn tunnel were understood as an extreme or unique case expected to bring about changes worth studying.

2.3. Data collection

Existing knowledge was used when designing the data collection and analyses, and a mixed-methods approach was applied, as recommended for case studies (Flyvbjerg, 2006; Stake, 1995; Yin, 2003). By analysing different types of data from different sources, the situation could be investigated from different perspectives, increasing the robustness of the results and conclusions. Key data and sources were as follows:

- Data on road traffic volumes and speeds from the NPRA and Oslo municipality;
- Data on commuter adaptations, effects and consequences from surveys and interviews conducted by involved researchers;
- Data on air pollution, collected by researchers at the Norwegian Institute of Air Research; and
- Data concerning the situation before capacity reduction and the rehabilitation project causing it, as well as precautionary, mitigation and information measures, from responsible agencies.

Traffic data were collected and analysed for two-week periods in the spring and autumn every year from 2015 to 2018, and surveys were conducted in the spring/summer in the same years. Interviews were carried out in the autumn seasons of 2016 and 2017. Data from the different years were compared when analysing adaptations to, effects and consequences of the tunnel capacity changes.

The traffic data were collected for the same analytically selected two-week period every year. In the spring, what weeks that were analysed the different years varied, to avoid including weeks with flexible holidays. The selected weeks are understood as stable with respect to traffic and weather (no snow) and/or relevant due to when the capacity changes occurred. The main arguments for analysing traffic data in some weeks instead of all weeks were that it allowed us to select weeks where data quality was good and where other major incidents did not affect the traffic significantly. We also found that this allowed for clearer and more understandable analyses. We mainly analysed traffic during rush hours because these are the most critical hours of the day, with the heaviest traffic, and because we wanted to focus on the effects and consequences for commuters. Historical data for traffic volumes from several of the most relevant traffic counters were not available before 2016, and some traffic counters were out of order in some periods. Data for traffic speeds were available for all relevant periods and road links.

Survey respondents were recruited through private and public businesses located within the borders of Oslo municipality and the eastern parts of the neighbouring municipality, Bærum (this part of Bærum is clearly a part of Oslo in a morphological sense). Geocoded information from the Central Register of Enterprises (Statistics Norway) was used to randomly draw a large number of companies representatively spread within the defined geographical area and to find their email addresses so we could contact them. Those agreeing to participate in the survey sent us email addresses of their employees so we could send the survey directly to them, forwarded an email with a survey link to their employees or made the survey link available on their intranet. Following from this, we do not and cannot know if the sample of respondents is representative of those invited to the surveys because we cannot know the characteristics of those invited. Further, we cannot know if respondents are representative of employees in companies in Oslo and eastern Bærum, as we cannot know the characteristics of the total population. This means that we could not control for systematic biases with respect to respondents. The locations of the workplaces of respondents are known, and the sample is representative in terms of the geographical distribution of workplaces. Characteristics of the respondents in the different years are listed in Appendix A. Surveys were conducted in May/June every year from 2015 to 2019. The number of respondents was relatively high, varying from $n = 4270$ (2015) to $n = 6768$ (2016).

The surveys consisted of a 'monitor part', asking the same questions every year of all respondents, and 'case parts' focussing on specific changes in the transport systems, addressing respondents working in geographical areas that were expected to be more affected by these changes than others. In this paper, we mainly use results from respondents working in the Bryn area, located close to the Bryn tunnel, who were expected to be more affected by the capacity changes. This expectation was realised. When asked in 2016 whether the respondents experienced that the capacity reduction in the Bryn tunnel had affected their commute, 19 per cent of the total sample and 44 per cent of the Bryn sample answered 'yes'. Respondents in the Bryn sample answered many questions concerning their adaptations to the Bryn tunnel capacity reduction and what effects and consequences they experienced. All commuters were included, regardless of what mode they normally used on their commute, as we believed the interventions could affect users of all transport modes in different ways. The number of respondents in the Bryn sample varied from $n = 373$ (2015) to $n = 1029$ (2016). Characteristics of the respondents included in the Bryn sample are listed in Appendix B.

Respondents were asked if they agreed to be contacted later for a follow-up interview, and around 30 per cent agreed to this. This allowed us to choose interviewees with different characteristics, adaptation strategies, travel behaviours and experiences. Twenty interviews were conducted in 2016, and another 20 took place in 2017. Interviewees were contacted by email and interviewed by telephone. The aim was to collect more nuanced and rich descriptions of adaptations, effects, and consequences than what could be expressed in the surveys.

We also collected and analysed data on bicycle traffic volumes and public transport passenger volumes, as well as delays for public transport and taxis, from relevant authorities. However, the data quality, availability and/or reliability were low, and we decided not to include these data and findings in the paper. Further, we attempted to measure changes using alternative big and new data in collaboration with relevant actors. This yielded much learning but no usable results. Data on how freight transport truck drivers adapted and what effects and consequences they experienced were also collected and analysed. Results are reported in another article (in review).

3. Findings

3.1. Effects of the capacity changes observed in the transport system

3.1.1. Effects observed in the Bryn tunnel and on adjacent road links

As shown by the traffic counter closest to the Bryn tunnel, E6 Manglerud, *traffic volumes* significantly decreased during the capacity reduction, by 26–34 per cent in rush hours (Fig. 2) and by 23 per cent per day (Fig. 3). Traffic increased to about the same levels as in the before-situation when the tunnel regained normal capacity. In Figs. 2–6 and 8, discrete data are displayed as continuous lines for better readability. Week 5,6 indicates weeks 5 and 6, while 19,21 indicates weeks 19 and 21, and so on.

Traffic in the nearby Rv 150 Hovin traffic counter showed similar figures, with a 23 per cent traffic decrease in morning rush hours and 31 per cent in afternoon rush hours. The traffic volume returned to about the same levels as before when the tunnel regained full capacity.

Analyses of traffic data showed that the decrease of vehicles longer than 5.6 m (representing mainly freight transport) was significantly lower than that for shorter vehicles. For this parameter, there was only a 4 per cent decrease during the day and 1 per cent during morning rush hours in the E6 Manglerud traffic counter (comparing weeks 5 and 6 in 2016 and 2017).

Similar traffic decreases as in the E6 Manglerud traffic counter were not found in the reference point E18 Ramstadsletta, located about 20 km from the Bryn tunnel and believed not to have been directly affected by the capacity reduction (see Fig. 1 for the location). 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 speeds on the part of Ring 3 including the Bryn tunnel, were significantly reduced in both the morning and afternoon rush hours in the capacity reduction period (see results for morning rush hours in Fig. 4 and for afternoon rush hours in Fig. 5), despite the substantial traffic decrease. Average measured speeds were close to or above the speed limit (70 km/h) before and after the capacity reduction period. The exception was the southbound traffic (‘out of the city’) in the afternoon rush with a measured average speed of about 30 km/h. Speed limits were reduced to 50 km/h during the capacity reduction, and the measured average speeds fell to 30–40 km/h. Southbound traffic in afternoon rush hours was again the exception; here, the average speed fell to about 20 km/h.

When comparing weeks 5 and 6 in 2016 and 2017, the results show that extra time used on the 3.3-kilometre-long Teisen–Ryen road link (including the Bryn tunnel) in 2017 varied from 2.5 min (morning rush hours, southbound) to 5.1 min (afternoon rush hours, southbound). When extra time used on the adjacent road links south and north of this road link were included, the results show that the extra time used for those driving this stretch of 13 km varied from 2.5 min (morning rush hours, southbound) to 12 min (afternoon rush hours, southbound).

Analyses of average speeds in the hours before and after rush hours showed speeds close to and higher than the speed limits (70 km/h) in the normal situation in the mornings, while the situation was more unstable and speeds lower in the afternoons (see Fig. 6 for speeds in rush directions). In the capacity reduction period, average measured speeds were mostly between 20 and 35 km/h in the hours before and after rush hours in the rush directions. The lowest speeds were found in the afternoons. In the mornings, the situation changed from one with mostly free-flowing traffic in the before-situation to a congested situation in the capacity reduction period.

Hence, the capacity reduction did cause decreased average speeds and increased delays in rush hours in the Bryn tunnel and on this

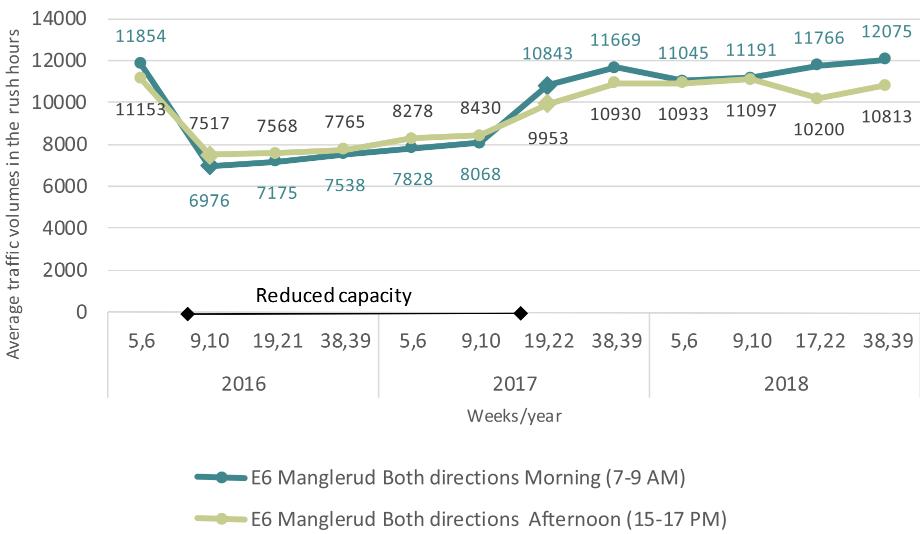

Fig. 2. Average traffic volumes from the E6 Manglerud traffic counter in the morning rush hours (7:00–9:00) and afternoon rush hours (15:00–17:00), summing both directions for the selected weeks. No data were available before week 5 in 2016. See Appendix C for the data table.

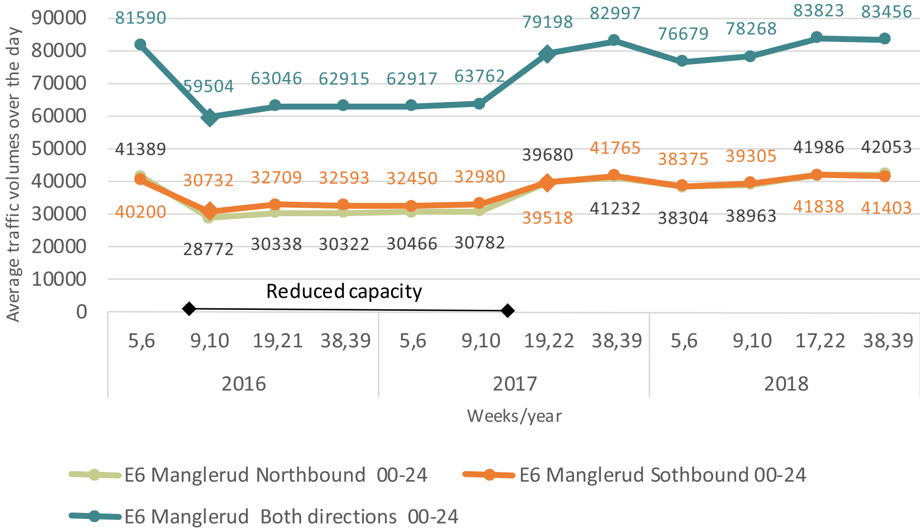

Fig. 3. Average traffic volumes over the day (00:00–24:00) for weekdays from the E6 Manglerud traffic counter, total for both directions and split into southbound and northbound traffic. No data were available before week 5 of 2016. See Appendix D for the data table.

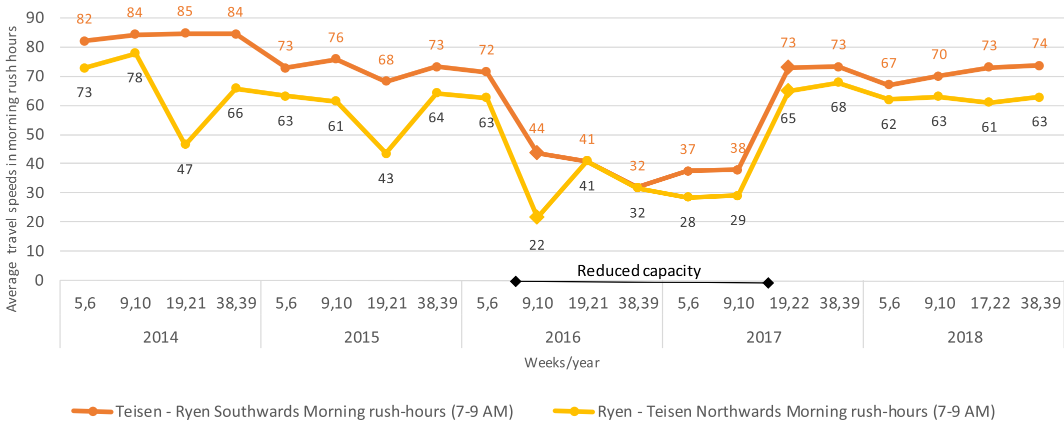

Fig. 4. Average speeds of the Teisen–Ryen road link, including the Bryn tunnel, in the morning rush hours (7:00–9:00) for selected weeks in 2014, 2015, 2016, 2017 and 2018. See Appendix E for the data table.

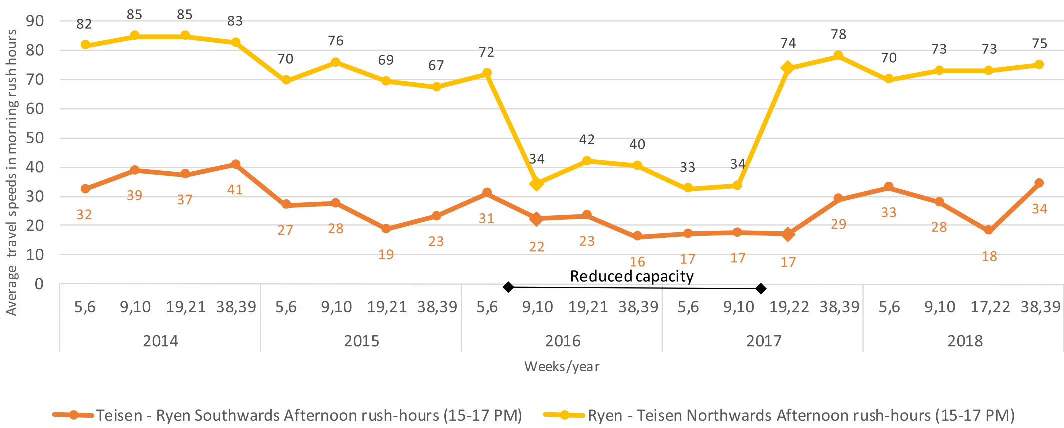

Fig. 5. Average speeds of the Teisen–Ryen road link, including the Bryn tunnel, in the afternoon rush hours (15:00–17:00) in selected weeks in 2014, 2015, 2016, 2017 and 2018. See Appendix F for the data table.

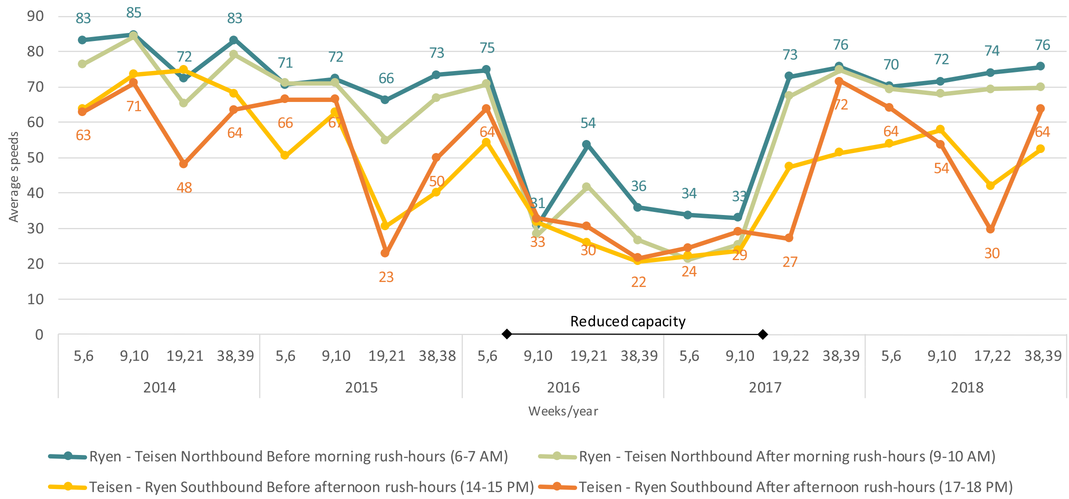

Fig. 6. Changes in average speeds in the hours before and after rush hour in the rush direction on the Teisen–Ryen road link, including the Bryn tunnel. See Appendix G for the data table.

part of Ring 3. The analyses also showed that the traffic situation was less predictable in the period when capacity was reduced.

Change of trip timing was a plausible way of adapting and could explain the increased delays through the tunnel in the hours before and after rush hours. If more people had decided to start their commute earlier or later than they normally do, and still drove through the tunnel, traffic in the Bryn tunnel would increase in the hours before and after rush hours. Instead, as measured in the E6 Manglerud traffic counter, there was a significant decrease in traffic volumes in these hours in the capacity reduction period as compared with the normal situation (see Fig. 7: the figure is meant to be read as a 'picture'; see Appendix H for the data table).

3.1.2. Effects observed in other parts of the main road system

Traffic data on alternative routes were analysed to see if road users had adapted by selecting other routes in the main road system to avoid the Bryn tunnel. When comparing the situation during the capacity reduction period with the before-situation, we found increased traffic on some of the alternative routes (see also Fig. 8). The strongest increase occurred on the most logical alternative route on the main road system, the Svartdal tunnel, by 12–37 per cent, while there was a 5 per cent increase at E6 Helsfyr in morning rush

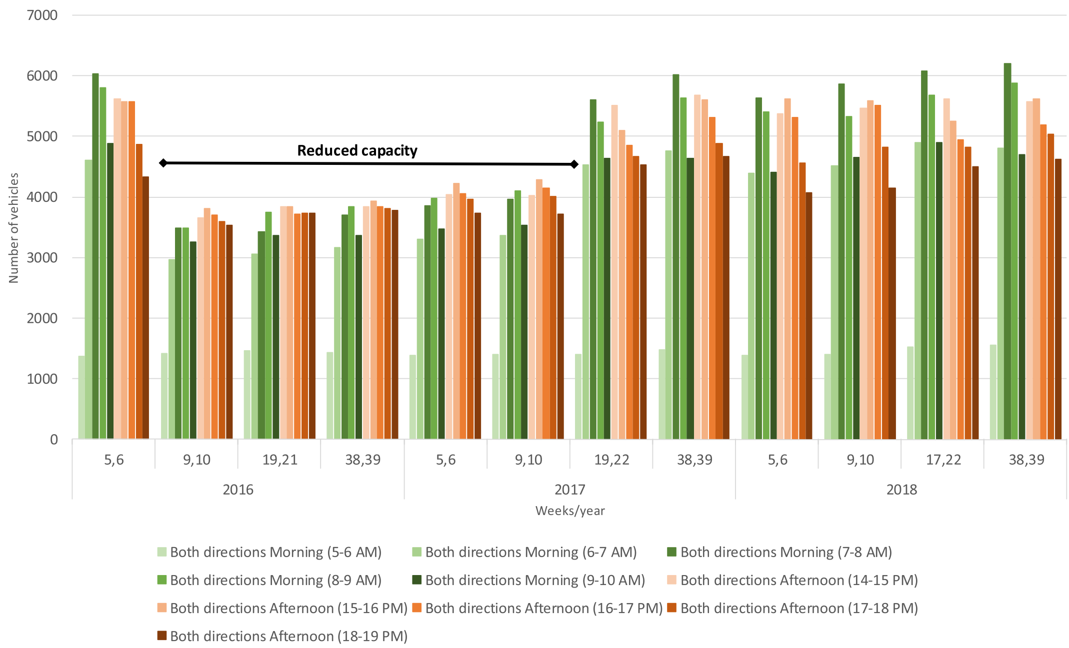

Fig. 7. Traffic volumes (vehicles per hour) in rush hours (7:00–9:00 and 15:00–17:00) and hours adjacent to rush hours (5:00–6:00, 6:00–7:00, 9:00–10:00, 14:00–15:00, 17:00–18:00 and 18:00–19:00) in the E6 Manglerud traffic counter, both directions. See Appendix H for the data table.

hours, indicating that these were the most important alternative routes. Only minor changes were observed in other relevant traffic counters in the main road system. A small traffic increase on Rv23 Oslofjord tunnel, leading traffic outside the Oslo road system, indicating that this was an alternative route for some.

Along with the findings showing a 26–34 per cent decrease in traffic volumes during rush hours in the Bryn tunnel, these results indicate that some motorists adapted to the capacity reduction by selecting alternative routes. The traffic increases on the alternative routes mentioned above are significantly lower in absolute figures compared with the traffic reduction through the Bryn tunnel.

The relatively strong traffic increase in the Svartdal tunnel resulted in somewhat reduced travel speeds in rush hours. We also found significantly increased delays on the north-south Karihaugen–Helsfyr link (southbound), intersecting with the part of Ring 3 where the Bryn tunnel is located. The traffic counter at E6 Helsfyr showed significantly reduced speeds in afternoon rush hours in the northbound direction. Apart from this, we did not find any significant changes in traffic volumes and speeds on the main road system.

3.1.3. Effects observed on local roads

Authorities worried that motorists would reroute to municipal and local roads, causing undesirable situations. In interviews and open answers to the survey, residents and other users of local roads in housing areas close to the Bryn tunnel reported increased delays and more congestion during parts of the capacity reduction period. Interviewees said they perceived this as a major disadvantage and a deterioration of the living environment. Analyses of traffic data for the six local roads with available data showed a total traffic increase of 6.8 per cent (a total of 626 vehicles on all roads, absolute numbers) in the morning rush hours and 4.5 per cent (a total of 460 vehicles) in the afternoon rush hours. Since the number of long vehicles on these local roads remained stable, it can be stated that the local roads were not used as bypass routes by vehicles longer than 5.6 m. Measurements via traffic counters did not show significant changes in average speeds (except for one road); however, measurements of time usage for a bus route through the area showed increased delays. There were road works on several local roads during the capacity reduction period, and our interpretation of the data is that the increased delays were mainly due to this. The increased congestion levels might have contributed to the residents and the local road users experiencing the traffic increase being stronger than it was. Nevertheless, the extra delays were perceived as negative.

According to interviews and open answers in the surveys, the road works and the changes in the traffic situation on local roads also caused disadvantages for pedestrians and cyclists. Bicyclists expressed that they were ‘forced’ onto the sidewalk, which was understood as disadvantageous for both pedestrians and cyclists. This problem was enhanced by insufficient bicycle infrastructure in parts of the network.

3.1.4. Effects on overall traffic volumes

Previous research has found ‘disappearing traffic’ resulting from capacity reductions (Cairns et al., 2002), and analyses were done

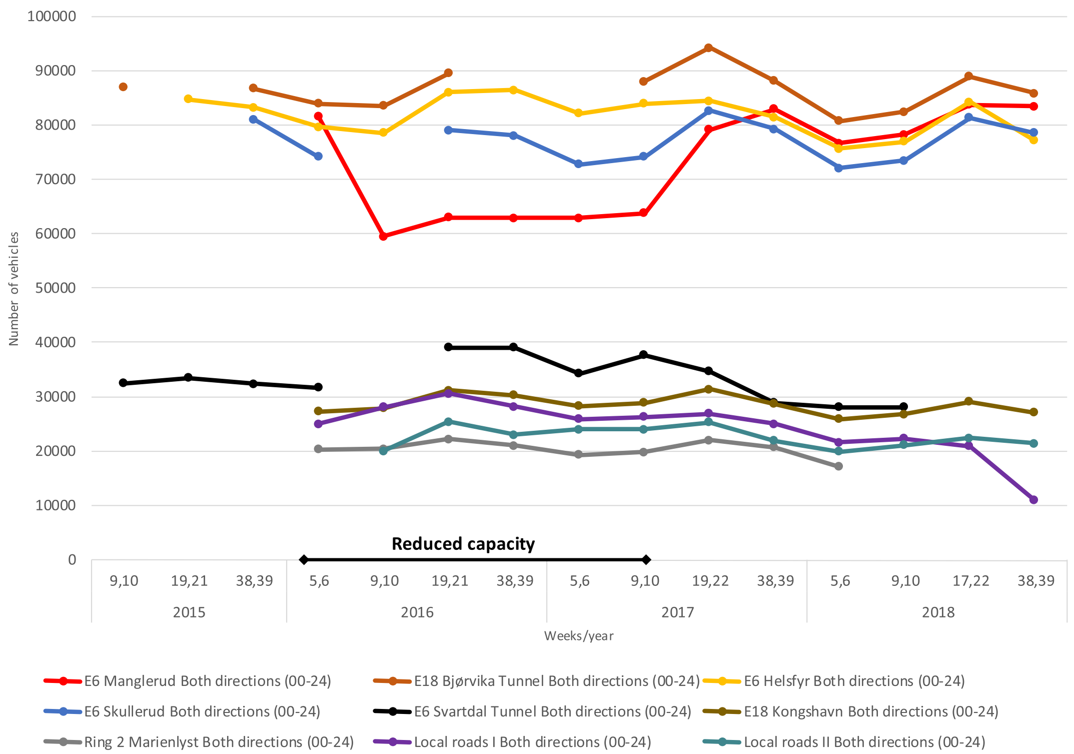

Fig. 8. Traffic volumes per workday (00:00–24:00) as measured at different traffic counters, summing both directions. Broken lines indicate missing data. See Appendix I for the data table.

to see if this was the case here. Traffic volumes from different traffic counters on routes understood to be alternatives to each other were summarised. This is not an easy task to accomplish, and some traffic might have been missed or double counted. We compared traffic in the selected traffic counters in weeks 5 and 6 of 2016 (before capacity reduction) to traffic volumes in the same weeks in 2017 (during capacity reduction), see Fig. 8. Total traffic volumes in these counters were reduced by 2800 vehicles (4.2 per cent) in the morning rush hours (7:00–9:00), by 1900 vehicles (2.9 per cent) in afternoon rush hours (15:00–17:00) and by 12 300 vehicles (2.2 per cent) per day. Hence, it seems that some traffic disappeared in the period when the capacity in the Bryn tunnel was reduced. The toll-ring tax system changed in October 2017, resulting in a drop in traffic through the Oslo toll ring by 4.7 per cent on weekdays (NPRA, 2018), as can also be observed in the 2018 data in Fig. 8. This is probably part of the explanation for why, after the tunnel regained normal capacity, the increased traffic volumes reached somewhat lower levels than found in the before-situation.

3.1.5. Summarising effects observed in the transport system

From what has been discussed above, the effects of the capacity reduction seem to be limited to the Bryn tunnel and road links adjacent to it and to an intersecting link, where analyses showed significantly increased delays. Road users adapted in ways that involved avoiding the tunnel in rush hours. As a result, the traffic volumes through the Bryn tunnel were significantly reduced, contributing to reducing delays and other disadvantages for road users in the capacity reduction period. The adaptations caused some changes in traffic volumes on alternative routes but did not result in significant increases in delays on these links overall. Traffic volumes in the road transport system seem to have been somewhat reduced during the capacity reduction period. When the tunnel regained normal capacity, traffic volumes and speeds returned to about the same levels as in the before-situation.

3.2. Effects on pollution

Since greenhouse gas emissions generated by transport are closely linked with traffic volumes (total vehicle kilometres), the reduction in total transport volumes probably means that greenhouse gas emissions were reduced during the capacity reduction period. Effects on local pollution (NO_2) was measured using passive sampling in periods before (20.01.2016–19.02.2016) and during (20.02.2016–21.03.2016) the capacity reduction in relevant areas. The analyses showed lower pollution concentrations in the Bryn area in the capacity reduction period compared to the before-situation (Tønnesen, 2016). The results from the Bryn area were in line with findings for comparable areas that were not directly affected by the capacity reduction, where pollution concentrations were also lower in the latter period. This could indicate that increased pollution caused by more congestion in the Bryn tunnel area, and reduced pollution caused by lower traffic volumes here, cancelled each other out. The overall reductions in the concentration of NO_2 across different areas are understood as resulting from meteorological and other exogenous factors.

3.3. How commuters adapted and what effects and consequences they experienced

3.3.1. Commuter adaptations

In the survey of employees working in businesses in the Bryn area, 24 per cent in 2016 (during capacity reduction) answered *both* that their commute had been affected by the capacity changes *and* that they had altered their commutes to adapt to the situation. The same rates were 6 per cent in 2017 (after the tunnel had regained full capacity) and 6 per cent in 2018 (more than a year after the tunnel had regained full capacity).

Of the 40 per cent answering that their commutes had been either positively or negatively affected by the capacity reduction in 2016, 41 per cent said they had not made any changes in their commutes to adapt to the situation. Further, 33 per cent had changed the starting time of their commute, 22 per cent had changed routes, 13 per cent had changed their mode of transport, 7 per cent had used their home offices more often and 7 per cent had made other changes (see Fig. 9). Among those reporting they drove a car on their latest commute (in 2016), fewer reported ‘no changes’ (34 per cent). Forty-three per cent of car drivers said they had changed the starting time of their commute, and 28 per cent reported that they had changed routes. The large majority of the respondents reported in 2017 and 2018 that they had not made any changes in their commute after the tunnel regained normal capacity (in April 2017).

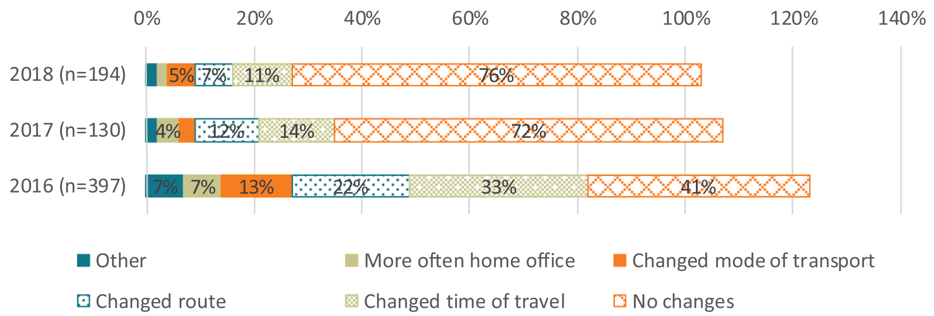

Fig. 9. Answers to the question, ‘What changes have you made in your commute to adapt to the capacity changes in the Bryn tunnel?’ Multiple answers were allowed. The question was asked only of those who answered that their commute had been affected by the capacity changes. See Appendix J for the data table.

It is interesting to compare the results from the surveys with what was observed in the transport system. Starting with the option most had ticked in the survey, *changed starting time of their commute*, and comparing this to the measurements of changes in traffic volumes through the tunnel (Fig. 7), the findings do not support each other. This discrepancy spurred further investigation. With support in the interviews, we understand the answer from survey respondents as essentially meaning that they started their commute somewhat earlier to compensate for increased time spent because of extra delays.

Rerouting was the second most frequently ticked response to how commuters had adapted. This is in line with what was found in the analyses of traffic data, showing reduced traffic volumes through the Bryn tunnel and increased traffic volumes on alternative main road routes (although the increase turned out to be less than the decrease through the tunnel).

In the survey, 13 per cent of those stating their commute was affected by the Bryn tunnel capacity reduction indicated that they had *changed mode of transport* on their commute to adapt to the situation (Fig. 9). They were also asked what mode of transport they had used for the longest part of their latest commute. Comparison of results from surveys conducted in 2015–2018 revealed greater changes in the modal split among employees working in the Bryn area than Fig. 9 indicates. The results showed a significant decrease in respondents answering that they had driven a car on their latest commute, from 39 per cent in 2015 to 29 per cent in 2016 (see Fig. 10). The decrease continued to 27 per cent in 2017 and 21 per cent in 2018. The share answering that they had travelled by bicycle and public transport increased. The discrepancies between the results presented in Figs. 9 and 10 could be a result of commuters changing modes on their commutes because of other changes in the transport system. A metro line serving the area, which had been closed for rehabilitation and substituted by bus for a year, reopened a few weeks before the 2016 survey; moreover, conditions for bicycling in Oslo improved in the period, and the tax system in the toll ring was changed in October 2017. The mode changes observed in Fig. 10 are probably also influenced by these circumstances. Analyses of our total survey sample (Oslo and eastern Bærum) showed similar but weaker tendencies towards decreasing car-usage across the city. These findings are in accordance with previously published analyses showing a trend over the years of lower proportions of trips in general made as car drivers by Oslo municipality inhabitants (Hjorthol et al., 2014; NPRA, 2019).

The respondents were asked how often they had *worked from home* the previous week. The number of respondents answering ‘none’ decreased from 89 per cent in 2015 to 82 per cent in 2016 and to 76 per cent in 2017, whereas it increased to 81 per cent in 2018. This is in line with the 7 per cent who answered ‘working from the home office more often’ when asked directly about what adaptations they had made to the capacity reduction in 2016 (Fig. 9). Interviewees described a less strict policy from their employers with respect to using the home office in the period as a measure to reduce the negative consequences of the capacity reduction, and this was appreciated by the interviewees.

3.3.2. *Effects experienced by commuters*

The 40 per cent of the respondents answering that their commutes had been either positively or negatively affected by the capacity reduction in 2016 were asked what negative effects they experienced. ‘More congestion when driving’ (58 per cent) and ‘increased travel time’ (57 per cent) were the most frequent answers, followed by ‘reduced punctuality’ (27 per cent), ‘more car traffic where I bicycle or walk’ (21 per cent), ‘increased travel time by public transport’ (15 per cent) and ‘more crowding on public transport’ (12 per cent). Few respondents reported positive effects. In the 2017 and 2018 surveys, around 50 per cent reported that reopening of the Bryn tunnel with full capacity had resulted in reduced congestion in the road network and reduced time usage on commutes; they also reported improvements relating to the other factors. Some reported increased travel time after the reopening of the tunnel.

Unsurprisingly, those commuting as car drivers or car passengers reported more often than others that their commute had been affected by the capacity changes. Analyses of data from the 2016 survey showed only small gender differences with respect to answers, while those in the 35–54 age group and those who were married or living with a partner reported more negative effects than others did. The tendency towards having experienced negative effects increased with the number of children in the household, lower education, higher income and access to cars.

Asked directly about time usage, 51 per cent of car drivers and 11 per cent of public transport users answered that they spent more time on their commutes during the capacity reduction period as compared to the normal situation. Car drivers estimated, on average, increased time usage of about nine minutes. According to our interpretation, these estimates are somewhat larger compared with what

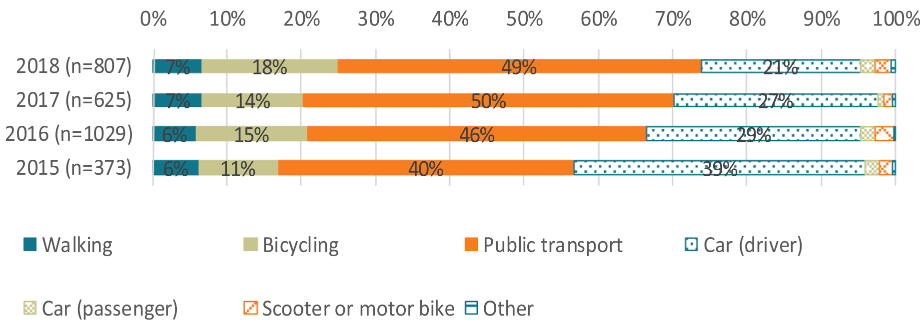

Fig. 10. Answers to the question, ‘Which mode of transport did you use for the longest part of your last commute?’ See Appendix K for the data table.

the traffic data analyses show.

Interviewees explained that the traffic situation was more unpredictable during the capacity reduction, and they experienced more congestion and delays. Some car users said the situation was better than expected. Cyclists reported messier, more unsafe, and denser traffic situations, whereas those travelling by public transport expressed that their commutes were not affected much. The general impression from the interviews done after the tunnel had regained full capacity was that the situation had improved.

3.3.3. Consequences experienced by commuters

Investigations of consequences for commuters concentrated on changes in commute satisfaction and whether respondents had needed to reorganise routines or responsibilities within the household. It was found that 12 per cent of all respondents in 2016 answered that the capacity reduction and/or adaptations to it had caused changes in routines or responsibilities in their household. Changes in routines related to accompanying children were reported by 5 per cent of respondents. Amongst those stating that their commutes were affected by the capacity reduction, 20 per cent reported changes in the household for this reason, while the figure was 5 per cent for those stating that their commutes had not been affected.

Concerning commute satisfaction, respondents were asked in the yearly surveys how satisfied they were with their commute. This question was asked before the specific questions related to the capacity changes in the Bryn tunnel. Overall, respondents reported high commute satisfaction, with high proportions indicating they were 'satisfied' or 'very satisfied'. The proportions decreased from 73 per cent in 2015 to 72 per cent in 2016, increased to 78 per cent in 2017 and sank to 76 per cent in 2018 (see Fig. 11). There was a steady increase in proportions, indicating respondents were 'very satisfied' with their commutes, from 26 per cent in 2015 to 37 per cent in 2018. Few said they were 'dissatisfied' or 'very dissatisfied' with their commute, and this varied from 7 per cent in 2017 to 13 per cent in 2015 and 2016.

Car drivers were less satisfied with their commute than others were, with the proportion agreeing that they were (very) satisfied varying from 60 per cent in 2016 to 73 per cent in 2017 (see Fig. 12). The number of car drivers stating they were (very) dissatisfied was quite low, varying from 10 per cent (2017) to 21 per cent (2016). Only around 4 per cent indicated being very dissatisfied, and this was also the case during the capacity reduction in 2016.

When asking whether respondents experienced that their commute had become better or worse compared with the situation a year prior, 2016 (when capacity was reduced) stood out as a special year (see Fig. 13). In this year, the proportion answering that their commute had become somewhat or much worse was higher than in the other years (24 per cent in 2016 and varying between 8 and 17 per cent in the other years), as was the proportion answering that their commute had become better or much better (22 per cent, compared with 17–21 per cent in the other years). With support from the interviews, we understand the higher number of commuters stating that their commute had become worse as mainly related to the capacity reduction; we understand the higher share of commuters stating their commute had improved as mainly related to reopening of the metro-line serving the area in April 2016.

This result indicates that the capacity reduction in the Bryn tunnel had some negative impact on commute satisfaction among employees in businesses located in the Bryn area, and unsurprisingly, this seems to have mainly concerned those commuting as car drivers.

4. Discussion

Studying adaptations to and effects and consequences of changes in urban transport systems means studying a complex reality, where numerous and different actors affect and are affected by the situation through many disparate mechanisms. This article has focussed on what effects and consequences could be observed in the road transport system when the capacity of the Bryn tunnel, located on the main road system in Oslo and carrying AADT 70, 000, was halved for 14 months, with two out of four lanes closed for rehabilitation. Further, it has considered how commuters to an area close to the tunnel adapted to the situation and what effects and consequences they experienced.

In summary, it was found that halving the capacity of this heavily trafficked tunnel went relatively well, and the negative effects and consequences were less severe than expected. This was partly because road users adapted to the situation in ways that reduced traffic through the tunnel significantly, by 26–34 per cent in rush hours and by 23 per cent per day. This contributed to reducing the negative effects and consequences and to limiting them to the road system close to the tunnel. Almost half of the commuters to workplaces in the nearby Bryn area who answered the survey, reported being affected by the capacity reduction, and 59 per cent of these respondents said they adapted by altering their commute in different ways. The most frequently reported adaptations were changes in trip timing, route, and transport mode. Increased time usage on commutes and more congestion and crowding were the most frequently reported effects. However, most respondents did not report having been affected and to have adapted. Based on the information from surveys and interviews, the consequences for commuters could not be interpreted as severe. Commuter satisfaction remained high, and few said they had made changes in the routines or responsibilities of the household because of the capacity reduction. The findings are in line with results from previous research on similar cases in Norway and elsewhere (Brown et al., 2017; Cairns et al., 2002; Taylor and Wachs, 2014; Tennøy et al., 2016; Torp and Eriksen, 2009). As discussed in section 1, we believe the results from this study of a temporary capacity reduction are also relevant when discussing permanent capacity reductions because of the long period of reduced capacity (14 months) and the focus on the rather fixed commute trips.

We see the research design as a major strength of the study. The research was designed as a longitudinal case study, with data collection before, during and after the capacity reduction period; moreover, data were collected from different sources and through different methods. When data from different sources pointed in the same direction, this was understood as strengthening the findings. When this was not the case, it spurred deeper analyses and sometimes a search for answers through other sources. We believe this

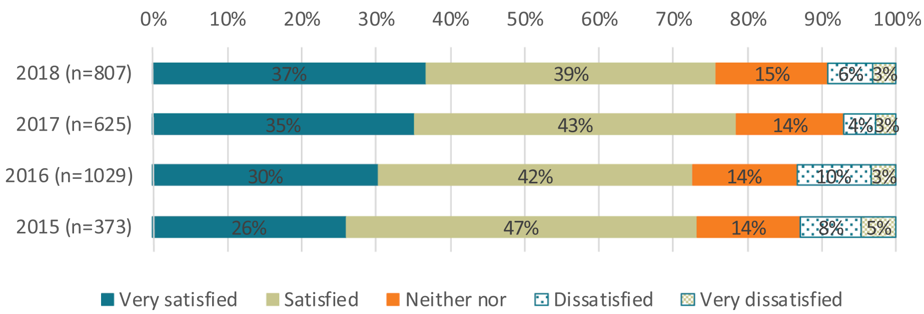

Fig. 11. Answers to the question, 'How satisfied are you with your commute at this time of the year?' See Appendix L for the data table.

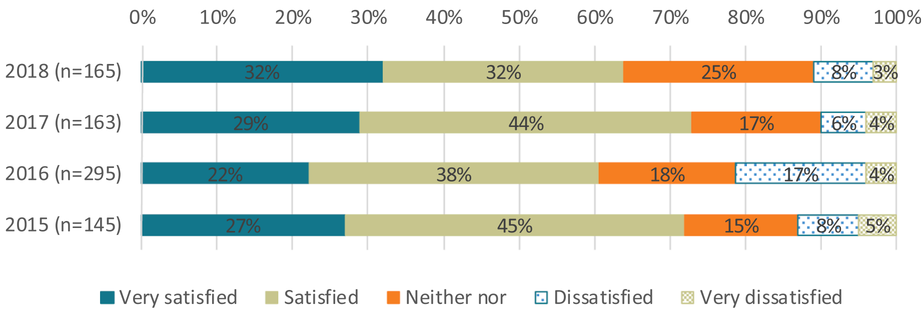

Fig. 12. Car drivers' answers to the question, 'How satisfied are you with your commute at this time of the year?' See Appendix M for the data table.

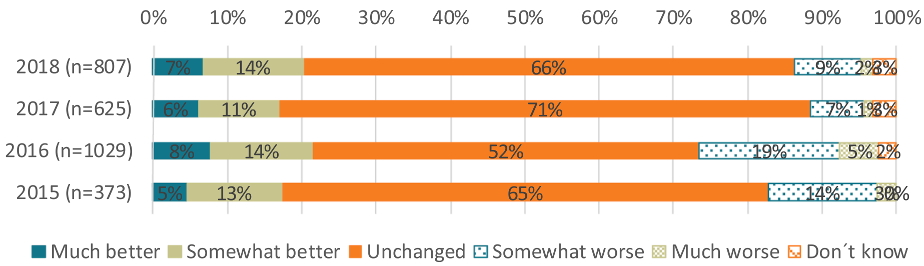

Fig. 13. Answers to the question, 'Do you find that your commute has become better or worse compared with the situation one year ago?' See Appendix N for the data table.

design makes the findings and conclusions more robust. We also see it as a strength that the capacity reduction case studied was not a politically decided intervention to achieve certain goals because the less political context reduced the incitements for biased answers in surveys and interviews. A metro line serving the Bryn area was reopened after rehabilitation during the tunnel capacity reduction period. Hence, the case could be understood as one where commuters to the Bryn area experienced both that road capacity was reduced, and public transport services improved.

Data for bicycle traffic and public transport passengers were also collected and analysed. The quality of these data was weak, and results from their analyses could not be included as findings. We consider this a weakness of the study. However, the results did point in the same directions as the reported findings.

5. Concluding remarks

The results from this and previous studies documenting the adaptability and flexibility of urban transport system users might be helpful for those seeking to achieve sustainable urban mobility goals, such as the Norwegian zero-growth objective. More empirical knowledge from studies of real-life cases may reduce uncertainties and facilitate shifts in how planners, policymakers and decision makers frame problems and assess potential solutions (Schön and Rein, 1994; Tennøy, 2010).

First, the results could help expand the understanding of what interventions are feasible and relevant and widen '*the boundaries of the "thinkable*"', as Witzell (2020:3) puts it. This is of great relevance. If, for instance, planners and policymakers believe that the reallocation of road space to dedicated public transport lanes will cause more negative effects and consequences than would otherwise be the case, they might decide against such a measure. In this way, they could miss opportunities to improve public transport competitiveness and speed, and hence, to develop more efficient and sustainable transport systems. The same is the case for other solutions requiring reduction or reallocation of ordinary road space, for instance, to facilitate dedicated freight transport lanes or bicycle lanes or to reduce traffic through an area.

Second, the findings question the necessity of 'replacement capacity' when road capacity is suggested to be reduced or reallocated for other uses. This may enhance the chances that interventions providing more sustainable and efficient urban transport systems will be implemented, as well as that they can be implemented faster and without unnecessary and large costs.

Third, the findings illustrating travel behaviour adaptability support previous studies documenting how urban road capacity expansions in pressured urban transport systems could be counterproductive because they cause increased traffic, and eventually, more people stuck in congestion (Downs, 2004; see also section 1). Taking this knowledge into account could help authorities shift their investments from projects *reducing* the chances of achieving sustainability goals, such as expanding road capacity, to projects enhancing the chances of achieving these goals.

Fourth, the findings could be understood as input to ongoing discussions concerning assumptions and methods used in analyses of interventions in transport systems that strongly influence the development of future urban transport systems (e.g., Wardman and Toner, 2018). The value of lost or saved time is a substantial element in cost–benefit analyses of transport systems interventions. If the amount of time lost or saved or the value of time (VOT) is estimated incorrectly, this could have major implications for what decisions are made. As part of the project, the Norwegian regional transport model was used to analyse the effects of the Bryn capacity reduction, and the results were compared to measured data for traffic volumes and speeds. The key findings were that the model predicted traffic volumes relatively precisely but severely overestimated time usage, especially in rush hours (Tørset et al., 2020). One could also discuss whether the VOT used in such cases is reasonable. Using figures from the latest Norwegian VOT study (Flügel et al., 2020), and assuming nine minutes extra used on each car commuting trip through the tunnel and six of the minutes of the commute spent in heavy instead of moderate congestion, the extra cost for each car-commuter is NOK 40 per trip and NOK 80 per workday. This adds up to NOK 18 400 per car commuter per year. If calculating the costs for the approximately 7700 vehicles passing through the Bryn tunnel in the morning rush hours in the capacity-reduction period, it represents a total of NOK 142 million per year. Other variables would also have been included in a real cost–benefit analysis, but this rough estimate is sufficient for the point discussed here. In the Bryn study, 60 per cent of those commuting by car were very satisfied or satisfied with their commute when the capacity was reduced (compared with 64–73 per cent giving the same response when the capacity was normal), and 21 per cent were dissatisfied or very dissatisfied (compared with 10–13 per cent in the other years). Few reported that the situation had caused changes in routines or responsibilities in the household. An interesting discussion concerns whether it is reasonable to value the measured effects and consequences to NOK 142 million per year (about EUR 15.3 million). Wardman and Toner (2018) call for more critical discussions of current practices against findings from empirical research. Used as input to such discussions, the results of this study and other studies (see Xie and Levinson, 2011, who have reached different conclusions) could contribute to calibrating and improving the ways interventions in the transport system are assessed. This could have a major impact on transport systems development and the degree of goal achievement.

Finally, the documentation of adaptations to and effects and consequences of capacity reduction in the Bryn tunnel, as well as how information and mitigating measures worked out (Tønnesen et al., 2020), may be helpful for authorities in cities in Norway and other countries aiming to reduce disadvantages associated with temporary capacity reductions. These situations occur regularly because of construction, rehabilitation and maintenance work, and the frequency increases as larger parts of urban transport systems are built as maintenance-intensive tunnels.

Developing more efficient and sustainable cities and urban transport systems is a complex task involving numerous uncertainties, and a solid knowledge base is needed. This includes empirical knowledge of adaptations to and effects and consequences of various transport system interventions. We believe that the findings and discussions presented here are valuable inputs that could expand the way in which relevant actors think about how urban transport systems and cities can be developed to become more sustainable and efficient. This could accelerate the implementation of measures that contribute to achieving prioritised goals and retard the implementation of counterproductive measures.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors are grateful for valuable comments and suggestions from the four anonymous reviewers, that helped us improving the paper. We wish to thank the BYTRANS project partners and the BYTRANS project group for collaboration and inputs, especially Iratxe Landa-Mata, Susanne Nordbakke and Kåre H. Skollerud, who contributed to the data collection and analyses. We also wish to thank the participants in the International Transport Forum Roundtable on 'Zero Car Growth', taking place in Paris in December 2019, for valuable discussions and inputs. This work was financed by the Research Council of Norway, grant number 257152, the Municipality of Oslo, the Norwegian Public Roads Administration, Akershus County Council, the Norwegian State Railways, and the Norwegian Automobile Federation.

Appendix A. Characteristics of respondents to the survey, total sample, 2015–2018

	All survey respondents			
Year	**2015**	**2016**	**2017**	**2018**
Number of respondents	**N = 4270**	**N = 6768**	**N = 6018**	**N = 5457**
Gender				
Male	45%	48%	43%	42%
Female	54%	51%	55%	55%
Other/will not say	1%	1%	2%	3%
Age				
18–24 years	1%	1%	1%	1%
25–34 years	19%	17%	19%	17%
35–44 years	26%	25%	24%	22%
45–54 years	29%	27%	25%	26%
55–66 years	23%	22%	21%	21%
67–74 years	2%	2%	2%	2%
No answer	0%	6%	9%	12%
Children in household under the age of 18				
No children	56%	57%	59%	53%
One child	16%	16%	16%	15%
Two or more children	28%	27%	25%	25%
No answer	0%	1%	0%	7%
Marital status				
Married/partner	75%	75%	73%	71%
Single	22%	22%	23%	22%
Other/no answer	3%	3%	4%	7%
Education level				
Primary school	2%	1%	1%	1%
High school	11%	11%	10%	9%
College/university, short	32%	28%	27%	26%
College/university, long	52%	58%	60%	61%
Other/no answer	4%	2%	2%	3%
Income (NKR)				
Less than 299 000 NKR	2%	2%	1%	2%
300 000 – 399 000	4%	4%	3%	2%
400 000 – 499 000	21%	17%	17%	14%
500 000 – 599 000	24%	22%	24%	24%
600 000 – 699 000	18%	18%	18%	20%
700 000 – 799 000	9%	10%	10%	10%
800 000 – 899 000	6%	7%	7%	7%
900 000 – 999 000	4%	4%	4%	5%
More than 1 000 000	6%	8%	7%	9%
Do not know/no answer	6%	8%	8%	8%
Car ownership				
No	–	17%	18%	19%
Yes, car sharing or similar	–	3%	4%	3%
Yes	–	81%	78%	78%
Number of cars in household (only asked those answering yes on car ownership)				
No car	–	0%	0%	0%
One car	–	63%	65%	65%
Two or more cars	–	37%	35%	35%
No answer	–	–	–	–
Driver License				
Yes	–	7%	8%	8%
No	–	93%	92%	92%

Appendix B. Characteristics of the respondents to the survey, Bryn sample, 2015–2018

	Bryn-sample			
Year	**2015**	**2016**	**2017**	**2018**
Number of respondents	**N = 373**	**N = 1029**	**N = 625**	**N = 807**
Gender				

(*continued on next page*)

(*continued*)

	Bryn-sample			
Year	**2015**	**2016**	**2017**	**2018**
Male	48%	55%	51%	43%
Female	52%	45%	48%	54%
Other/no answer	0%	1%	1%	3%
Age				
18–24 years	1%	0%	0%	0%
25–34 years	20%	14%	15%	13%
35–44 years	31%	27%	22%	21%
45–54 years	21%	27%	29%	28%
55–66 years	16%	21%	21%	22%
67–74 years	1%	1%	2%	1%
No answer	–	9%	11%	14%
Children in household under the age of 18				
No children	52%	54%	53%	52%
One child	16%	16%	15%	13%
Two or more children	32%	30%	28%	27%
No answer	–	–	4%	8%
Marital status				
Married/partner	77%	77%	76%	72%
Single	21%	20%	21%	21%
Other/no answer	2%	3%	3%	7%
Education level				
Primary school	1%	2%	1%	0%
High school	13%	9%	8%	8%
College/university, short	38%	32%	25%	29%
College/university, long	46%	55%	63%	60%
Other/no answer	3%	2%	3%	3%
Income (NKR)				
Less than 299 000 NKR	0%	1%	1%	1%
300 000 – 399 000	4%	3%	1%	1%
400 000 – 499 000	24%	15%	10%	9%
500 000 – 599 000	34%	23%	21%	22%
600 000 – 699 000	20%	20%	24%	27%
700 000 – 799 000	8%	12%	16%	11%
800 000 – 899 000	3%	7%	9%	8%
900 000 – 999 000	1%	4%	4%	5%
More than 1 000 000	1%	8%	6%	8%
Do not know/no answer	5%	8%	9%	8%
Car ownership				
No	–	12%	13%	11%
Yes, car sharing or similar	–	3%	2%	2%
Yes	–	85%	85%	87%
Number of cars in household (only asked those answering yes on car ownership)				
No car	–	0%	0%	0%
One car	–	61%	50%	50%
Two or more cars	–	39%	35%	37%
No answer	–	–	15%	13%
Driver License				
Yes	–	5%	5%	4%
No	–	95%	95%	96%

Appendix C. Traffic volumes, rush-hours, E6 Manglerud (Fig. 2)

Average traffic volumes from the E6 Manglerud traffic counter in the morning rush-hours (7:00–9:00) and afternoon rush-hours (15:00–17:00), summing both directions for the selected weeks.

Year	Weeks/Time	Morning (7–9 AM)	Afternoon (15–17 PM)
2016	5,6	11,854	11,153
	9,10	6976	7517
	19,21	7175	7568

(*continued on next page*)

(*continued*)

Year	Weeks/Time	Morning (7–9 AM)	Afternoon (15–17 PM)
	38,39	7538	7765
2017	5,6	7828	8278
	9,10	8068	8430
	19,22	10,843	9953
	38,39	11,669	10,930
2018	5,6	11,045	10,933
	9,10	11,191	11,097
	17,22	11,766	10,200
	38,39	12,075	10,813

Appendix D. Traffic volumes, workdays, E6 Manglerud (Fig. 3)

Average traffic volumes over the day (00:00–24:00) for weekdays from the E6 Manglerud traffic counter total for both directions and split in southbound and northbound traffic.

	Direction	**Northbound**	**Sothbound**	**Both directions**
Year	**Weeks/Time**	**00–24**	**00–24**	**00–24**
2016	**5,6**	41,389	40,200	81,590
	9,10	28,772	30,732	59,504
	19,21	30,338	32,709	63,046
	38,39	30,322	32,593	62,915
2017	**5,6**	30,466	32,450	62,917
	9,10	30,782	32,980	63,762
	19,22	39,680	39,518	79,198
	38,39	41,232	41,765	82,997
2018	**5,6**	38,304	38,375	76,679
	9,10	38,963	39,305	78,268
	17,22	41,986	41,838	83,823
	38,39	42,053	41,403	83,456

Appendix E. Average speeds, morning rush-hours, Teisen–Ryen (Fig. 4)

Average speeds (km/hrs) of the Teisen–Ryen road link including the Bryn tunnel in the morning rush-hours (7:00–9:00) in selected weeks in 2014, 2015, 2016, 2017 and 2018.

	Direction	**Southwards**	**Northwards**
Year	**Weeks/Time**	**Morning (7–9 AM)**	**Morning (7–9 AM)**
2014	**5,6**	82	73
	9,10	84	78
	19,21	85	47
	38,39	84	66
2015	**5,6**	73	63
	9,10	76	61
	19,21	68	43
	38,39	73	64
2016	**5,6**	72	63
	9,10	44	22
	19,21	41	41
	38,39	32	32
2017	**5,6**	37	28
	9,10	38	29
	19,22	73	65
	38,39	73	68
2018	**5,6**	67	62
	9,10	70	63
	17,22	73	61
	38,39	74	63

Appendix F. Average speeds, afternoon rush-hours, Teisen–Ryen (Fig. 5)

Average speeds (km/hrs) of the Teisen–Ryen road link including the Bryn tunnel in the afternoon rush-hours (15:00–17:00) in selected weeks in 2014, 2015, 2016, 2017 and 2018.

	Direction	Southwards	Northwards
Year	**Weeks/Time**	**Afternoon (15–17 PM)**	**Afternoon (15–17 PM)**
2014	**5,6**	32	82
	9,10	39	85
	19,21	37	85
	38,39	41	83
2015	**5,6**	27	70
	9,10	28	76
	19,21	19	69
	38,39	23	67
2016	**5,6**	31	72
	9,10	22	34
	19,21	23	42
	38,39	16	40
2017	**5,6**	17	33
	9,10	17	34
	19,22	17	74
	38,39	29	78
2018	**5,6**	33	70
	9,10	28	73
	17,22	18	73
	38,39	34	75

Appendix G. Average speeds, before/after rush-hours, Teisen–Ryen (Fig. 6)

Average speeds in rush-directions in the hours before and after rush-hours on the Teisen–Ryen road link including the Bryn tunnel (directional)

	Direction	Northbound	Northbound	Southbound	Southbound
Year	**Weeks/ Time**	**Before morning rush-hours (6–7 AM)**	**After morning rush-hours (9–10 AM)**	**Before afternoon rush-hours (14–15 PM)**	**After afternoon rush-hours (17–18 PM)**
2014	**5,6**	83	77	64	63
	9,10	85	84	74	71
	19,21	72	65	75	48
	38,39	83	79	68	64
2015	**5,6**	71	71	51	66
	9,10	72	71	63	67
	19,21	66	55	31	23
	38,38	73	67	40	50
2016	**5,6**	75	71	54	64
	9,10	31	28	32	33
	19,21	54	42	26	30
	38,39	36	27	21	22
2017	**5,6**	34	21	22	24
	9,10	33	25	24	29
	19,22	73	67	47	27
	38,39	76	75	51	72
2018	**5,6**	70	69	54	64
	9,10	72	68	58	54
	17,22	74	69	42	30
	38,39	76	70	53	64

Appendix H. Traffic volumes, rush-hours and adjacent hours, E6 Manglerud (Fig. 7)

Traffic volumes (vehicles per hour) in rush-hours (7:00–9:00 and 15:00–17:00) 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 counter, summing both directions

Year	Weeks/ Time	Morning (5–6 AM)	Morning (6–7 AM)	Morning (7–8 AM)	Morning (8–9 AM)	Morning (9–10 AM)	Afternoon (14–15 PM)	Afternoon (15–16 PM)	Afternoon (16–17 PM)	Afternoon (17–18 PM)	Afternoon (18–19 PM)
2016	**5,6**	1375	4607	6043	5811	4879	5614	5576	5577	4866	4332
	9,10	1421	2960	3487	3489	3261	3654	3816	3702	3595	3527
	19,21	1467	3058	3423	3753	3367	3848	3845	3724	3739	3727
	38,39	1438	3173	3696	3842	3372	3836	3928	3836	3810	3774
2017	**5,6**	1383	3311	3851	3977	3470	4038	4217	4061	3960	3737
	9,10	1402	3362	3969	4099	3538	4031	4279	4151	4016	3711
	19,22	1400	4531	5611	5232	4633	5506	5095	4858	4671	4524
	38,39	1481	4761	6025	5644	4642	5686	5610	5320	4881	4667
2018	**5,6**	1392	4396	5640	5405	4410	5383	5626	5308	4561	4073
	9,10	1400	4521	5860	5331	4660	5473	5590	5508	4828	4153
	17,22	1516	4899	6081	5685	4898	5621	5259	4941	4829	4505
	38,39	1548	4811	6199	5876	4694	5573	5623	5190	5039	4621

Appendix I:. Traffic volumes, per workday, different traffic counters (Fig. 8)

Traffic volumes per workday (00–24) measured at mentioned traffic counters, summing both directions. Empty cells indicate missing data. Calculations of total change of traffic volumes are made by subtracting traffic volumes in weeks 5 and 6 in 2016 from the traffic volumes og weeks 5 and 6 in 2017 and summarizing these. The exceptions are traffic counter E18 Bjørvika tunnel, where we needed to use weeks 9 and 10 instead of 5 and 6, due to missing data in weeks 5 and 6 2017, and local roads II where we had no data from the before-situation and substituted this by figures showing differences between the capacity-reduction period and the after-situation (weeks 5 and 6 in 2017 and 2018).

Year	Weeks	E6 Manglerud	E18 Bjørvika Tunnel	E6 Helsfyr	E6 Skullerud	E6 Svartdal Tunnel	E18 Kongshavn	Ring 2 Marienlyst	Local roads I	Local roads II
2015	**5,6**	–	81,907	–	–	31,898	–	–	–	–
	9,10	–	**87,094**	–	–	32,450	–	–	–	–
	19,21	–	–	84,802	–	33,460	–	–	–	–
	38,39	–	86,778	83,247	81,089	32,399	–	–	–	–
2016	**5,6**	**81,590**	84,008	**79,699**	**74,157**	**31,678**	**27,222**	**20,240**	**24,949**	–
	9,10	59,504	**83,572**	78,571	–	–	27,844	20,340	28,039	19,949
	19,21	63,046	89,616	86,048	79,112	39,089	31,174	22,210	30,554	25,407
	38,39	62,915	–	86,482	78,041	39,072	30,277	20,953	28,193	22,965
2017	**5,6**	**62,917**	–	**82,210**	**72,814**	**34,215**	**28,309**	**19,283**	**25,877**	**23,958**
	9,10	63,762	88,110	84,021	74,212	37,649	28,895	19,806	26,305	24,003
	19,22	79,198	94,227	84,504	82,728	34,636	31,334	21,996	26,847	25,291
	38,39	82,997	88,199	81,470	79,311	28,896	28,700	20,703	25,010	21,837
2018	**5,6**	76,679	80,827	75,733	72,082	28,109	25,883	17,050	21,601	**19,830**
	9,10	78,268	82,530	76,984	73,523	28,018	26,713	–	22,291	21,040
	17,22	83,823	89,011	84,246	81,408	–	29,074	–	20,864	22,338
	38,39	83,456	85,888	77,199	78,588	–	27,104	–	10,894	21,338

Appendix J. Answers to survey, Fig. 9

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

	2016 (n = 397)	2017 (n = 130)	2018 (n = 194)

(continued on next page)

(*continued*)

	2016 (n = 397)	2017 (n = 130)	2018 (n = 194)
Other	7%	2%	2%
More often home office	7%	4%	2%
Changed mode of transport	13%	3%	5%
Changed route	22%	12%	7%
Changed time of travel	33%	14%	11%
No changes	41%	72%	76%

Appendix K. Answers to survey, Fig. 10

Bryn sample respondents' answers to the question 'Which mode of transport did you use the last time you travelled to work and met where you normally meet?'

	2015 (n = 373)	2016 (n = 1029)	2017 (n = 625)	2018 (n = 807)
Walking	6%	6%	7%	7%
Bicycling	11%	15%	14%	18%
Public transport	40%	46%	50%	49%
Car (driver)	39%	29%	27%	21%
Car (passenger)	2%	2%	1%	2%
Scooter or motor bike	2%	2%	1%	2%
Other	0%	0%	0%	0%

Appendix L. Answers to survey, Fig. 11

Bryn sample respondents' answers to the question 'How satisfied are you with your commute at this time of the year?'

	2015 (n = 373)	2016 (n = 1029)	2017 (n = 625)	2018 (n = 807)
Very satisfied	26%	30%	35%	37%
Satisfied	47%	42%	43%	39%
Neither nor	14%	14%	14%	15%
Dissatisfied	8%	10%	4%	6%
Very dissatisfied	5%	3%	3%	3%

Appendix M. Answers to survey, Fig. 12

Car-drivers' answers to the question 'How satisfied are you with your commute at this time of the year?

	2015 (n = 145)	2016 (n = 295)	2017 (n = 163)	2018 (n = 165)
Very satisfied	27%	22%	29%	32%
Satisfied	45%	38%	44%	32%
Neither nor	15%	18%	17%	25%
Dissatisfied	8%	17%	6%	8%
Very dissatisfied	5%	4%	4%	3%

Appendix N. Answers to survey, Fig. 13

Bryn sample respondents' answers to the question: 'Do you experience that your commute has become better or worse compared to the situation one year ago?'

	2015 (n = 373)	2016 (n = 1029)	2017 (n = 625)	2018 (n = 807)
Much better	5%	8%	6%	7%
Somewhat better	13%	14%	11%	14%
Unchanged	65%	52%	71%	66%
Somewhat worse	14%	19%	7%	9%

(*continued on next page*)

(*continued*)

	2015 (n = 373)	2016 (n = 1029)	2017 (n = 625)	2018 (n = 807)
Much worse	3%	5%	1%	2%
Dońt know	0%	2%	3%	3%

References

Altieri, M., Silva, C., Terabe, S., 2020. Give public transport a chance: A comparative analysis of competitive travel time in public transit modal share. J. Transp. Geogr. 87, 102817.
Brown, A.E., Taylor, B.D., Wachs, M., 2017. The boy who cried wolf? Media messaging and traveler responses to "carmageddon" in Los Angeles. Public Works Manage. Policy 22 (3), 275–293.
Cairns, S., Atkins, S., Goodwin, P., 2002. Disappearing traffic? The story so far. Municipal Engineer 1, 13–22. https://doi.org/10.1680/muen.151.1.13.38856.
Cervero, R., 2003. Road expansion, urban growth, and induced travel: A path analysis. Journal of American Planning Association 69 (2), 145–163.
Chatterjee, K., Chng, S., Clark, B., Davis, A., DeVos, J., Ettema, D., Handy, S., Martin, M., Reardon, L., 2020. Commuting and wellbeing: A critical overview of the literature with implications for policy and future research. Transport Reviews 40 (1), 5–34.
Downs, A., 2004. Still Stuck in Traffic. Coping with Peak-hour Traffic Congestion. Brookings Institution Press, Washington, DC.
Duranton, G., Turner, M.A., 2011. The fundamental law of road congestion: Evidence from U.S. cities. American Economic Review 101, 2616–2652.
Engebretsen, Ø., Christiansen, P., Strand, A., 2017. Bergen light rail – Effects on travel behaviour. J. Transp. Geogr. 62, 111–121.
European Environment Agency, 2018. Trends and projections in Europe 2018. Tracking progress towards Europe's climate and energy targets. EEA Report No. 16/218, EEA, Copenhagen, Denmark.
European Union, 2004. EU directive 2004/54 Safety requirements for tunnels in the trans-European road network.
Fishman, E., Washington, S., Haworth, N., 2014. Bike share's impact on car use: Evidence from the United States, Great Britain, and Australia. Transportation Research Part D: Transport and Environment 31, 13–20. https://doi.org/10.1016/j.trd.2014.05.013.
Flügel, St., Halse, A.H., Hulleberg, N., Jordbakke, G.N., Veisten, K., Sundfør, H.B., Kouwenhoven, M., 2020. Value of travel time and related factors. Technical report, the Norwegian valuation study 2018–2020. TØI report 1767/2020, Institute of Transport Economics, Oslo, Norway.
Flyvbjerg, B., 2006. Five Misunderstandings About Case-Study Research. Qualitative Inquiry 12, 219–245.
Forsyth, A., Krizek, K., 2010. Promoting Walking and Bicycling: Assessing the Evidence to Assist Planners. Built Environment 36, 429–446.
Goodwin, P.B., 1996. Empirical evidence on induced traffic. A review and synthesis. Transportation 23, 35–54.
Heinen, E., van Wee, B., Kees, M., 2010. Commuting by bicycle: An overview of the literature. Transport Reviews 30 (1), 59–96.
Hjorthol, R., Engebretsen, Ø, Uteng, T.P., 2014. Den nasjonale reisevaneundersøkelsen 2013/14 – nøkkelrapport [2013/14 National travel survey—key results]. TØI-report 1383/2014. Institute of Transport Economics, Oslo, Norway.
Lieu, H., 1999. Traffic-flow theory. Public Roads 62 (4), 45–48.
Litman, T., 2020. Generated traffic and induced travel. Implications for transport planning. Version dated 1 July, 2020. Victoria Transport Policy Institute, Victoria.
McCoy, E.J., Stephens, D.A., 2014. Quantifying causal effects of road network capacity expansions on traffic volume and density via a mixed model propensity score estimator. J. Am. Stat. Assoc. 109 (507), 1440–1449. https://doi.org/10.1080/01621459.2014.956871.
Ministry of Local Government and Modernisation, 2012. Meld. St. 21 (2011–2012). Norsk klimapolitikk [White paper 21 (2011–2012). Norwegian climate politics]. https://www.regjeringen.no/no/dokumenter/meld-st-21-2011-2012/id679374/.
Ministry of Local Government and Modernisation, 2017. Meld. St. 18 (2016–2017). Bekeraftige byar og sterke distrikt [White paper 18 (2016–2012). Urban sustainability and rural strength]. https://www.regjeringen.no/no/dokumenter/meld.-st.-18-20162017/id2539348/.
Ministry of Transport and Communications, 2013. Meld. St. 26 (2012–2013) Nasjonal transportplan 2014–2023 [White paper 26 (2012–2013) National Transport Plan 2014–2023]. https://www.regjeringen.no/no/dokumenter/meld-st-26-20122013/id722102/.
Ministry of Transport and Communications, 2017. Meld. St. 33 (2016–2017) Nasjonal transportplan 2018–2029 [White paper 33 (2016-2017) National Transport Plan 2018–2029]. https://www.regjeringen.no/no/dokumenter/meld.-st.-33-20162017/id2546287/.
Mogridge, M.J.H., 1997. The self-defeating nature of urban road capacity policy. A review of theories, disputes and available evidence. Transp. Policy 4 (1), 5–23.
Noland, R.B., Lem, L.L., 2002. A review of the evidence for induced travel and changes in transportation and environmental policy in the US and the UK. Transportation Research Part D: Transport and Environment 7 (1), 1–26.
Norwegian Public Roads Administration, 2019. Nasjonalt regnskap for bærekraftig mobilitet [National accounts for sustainable mobility]. Norwegian Public Roads Administration, Oslo, Norway.
Norwegian Public Roads Administration, 2018. Trafikkutvikling per oktober 2018 etter innføring av trinn 1 i Oslopakke 3. Oppummering fra Oslopakke 3-sekretariatet [Traffic development per October 2018, after implementation of step 1 in Oslo-package 3. Summary by the Oslo-package 3 secretariat]. Norwegian Public Roads Administration, Oslo, Norway.
Pucher, J., Dill, J., Handy, S., 2010. Infrastructure, programs, and policies to increase bicycling: An international review. Prev. Med. 50, 106–125.
Redman, L., Friman, M., Gärling, T., Hartig, T., 2013. Quality attributes of public transport that attract car users: A research review. Transp. Policy 25, 119–127. https://doi.org/10.1016/j.tranpol.2012.11.005.
Schön, D., Rein, M., 1994. Frame Reflection. Toward the Resolution of Intractable Policy Controversies. Basic Books, New York.
Speck, J., 2012. Walkable City. How Downtown Can Save America, One Step at a Time. North Point Press, New York.
Stake, R.E., 1995. The Art of Case Study Research. Sage Publications, Thousand Oaks, London and New Delhi.
Standing Advisory Committee on Trunk Road Assessment (SACTRA), 1994. Trunk Roads and the Generation of Traffic. Department of Environment, Transport and the Regions. HMSO, London.
Taylor, B.D., Wachs, M., 2014. Carmageddon in Los Angeles: The sizzle and the fizzle. ACCESS Magazine 1, 44.
Tennøy, A., 2010. Why we fail to reduce urban road-traffic volumes: Does it matter how planners frame the problem? Transp. Policy 17, 216–233. http://dx.doi/10.1016/j.tranpol.2010.01.011.
Tennøy, A., Tønnesen, A., Gundersen, F., 2019. The effects of urban road capacity expansions – experiences from two Norwegian cases. Transportation Research Part D: Transport and Environment 69, 90–106. https://doi.org/10.1016/j.trd.2019.01.024.
Tennøy, A., Wangsness, P.B., Aarhaug, J., Gregersen, F.A., 2016. Experiences with capacity reductions on urban main roads – Rethinking allocation of urban road capacity? Transp. Res. Procedia 19, 4–17.
Tønnesen, A., Hagen, O.H., Tennøy, A., 2020. Use of public information for road-capacity reductions: A study of mediating strategies during tunnel rehabilitation in Oslo. Transportation. https://doi.org/10.1007/s11116-020-10128-6.
Tønnesen, A., Krogstad, J.R., Christiansen, P., 2019. National goals and tools to fulfil them - A study of opportunities and pitfalls in Norwegian metagovernance of urban mobility. Transp. Policy 81, 35–44.
Tønnesen, D., 2016. Passiv prøvetaking ved Brynstunnelen [Passiv sampling, the Bryn tunnel]. DAT/O-116068.
Torp, A., Eriksen, T., 2009. Trafikkregistreringer før og etter trafikkomlegging i Bjørvika/E18 Festningstunnelen [Traffic registrations before and after interventions in Bjørvika/ E18 Festning tunnel]. PROSAM note. PROSAM, Oslo, Norway.

Tørset, T., Kwong, C.K., Lu, C., Aakre, A., 2020. BYTRANS: How do the models explain changes in road capacity in urban transport? A review of data sources. Case: Bryn tunnel. TØI-report 1797/2020. Institute of Transport Economics, Oslo, Norway.
Treiber, M., Kesting, A., 2013. Traffic Flow Dynamics. Springer Verlag Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-32460-4.
Twitchett, C., 2013. Ignoring Induced Traffic – An Empirical Study of Induced Traffic. Master's thesis. Aalborg University, Aalborg, Denmark.
UN Habitat, 2013. Planning and Design for Sustainable Urban Mobility. Global Report on Human Settlements 2013. Routledge, New York, NY.
UN, 2017. New Urban Agenda (H. I. Secretariat Ed.). UN Habitat, Quito, Ecuador.
Walker, J., 2012. Human Transit. How Clearer Thinking about Public Transit Can Enrich Our Communities and Our Lives. Island Press, Washington, Covelo, London.
Wardman, M., Toner, J., 2018. Is generalised costs justified in travel demand analysis? Transportation 47, 75–108. https://doi.org/10.1007/s11116-017-9850-7.
Witzell, J., 2020. Assessments tensions: How climate mitigation futures are marginalized in long-term transport planning. Transportation Research Part D: Transport and Environment 87, 1–12. https://doi.org/10.1016/j.trd.2020.102503.
Xie, F., Levinson, D., 2011. Evaluating the effects of the I-35W bridge collapse on road-users in the twin cities metropolitan region. Transportation Planning and Technology 34 (7), 691–703.
Yin, K.R., 2003. Case Study Research. Sage Publications, Thousand Oaks, CA, Design and Methods.
Zhu, S., Levinson, Liu, H.X, Harder, K., 2010. The traffic and behavioral effects of the I-35W Mississippi River bridge collapse. Transportation Research Part A: Policy and Practice 44(10), 771-784.