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Capacity reduction on urban main roads: How truck drivers adapted, and what effects and consequences they experienced

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ABSTRACT

Urban freight transport is an important issue in sustainable mobility discussions. It constitutes a significant proportion of urban traffic, and expected negative impacts for urban freight transport can be arguments against implementing restrictive measures targeting passenger traffic. The scarcity of empirical studies might lead to over- or underestimation of consequences for urban freight transport. This might slow shifts towards more sustainable mobility or cause unintended negative consequences. A long-planned 14-month capacity reduction in a main road tunnel in Oslo, Norway, causing significantly increased congestion, offered an excellent opportunity to study urban freight transport adaptations, effects and consequences. With truck drivers and logistics professionals as key informants, the study amplifies voices not often heard in research. Truck drivers adapted by avoiding the tunnel during rush hours only to a limited degree, and less than general traffic did. They reported limited flexibility, as routes and trip timing are strongly defined by customer contracts. The wider consequences for drivers were more stress and less predictable workdays. The findings might improve understandings of how truck drivers can and do adapt, and what consequences they experience. This will help authorities and freight companies plan for changes in urban transport systems aimed at sustainable mobility.

1. Introduction

As cities strive to reduce the negative impacts of transport while also ensuring efficient mobility, urban freight transport is an important issue for at least two reasons. One is that urban freight transport constitutes a substantial proportion of the traffic in cities and an even larger proportion of emissions (Browne et al., 2014; Lindholm and Blinge, 2014; Verlinde, 2015). Therefore, reducing urban freight traffic volumes might be part of the solution. Another reason is that interventions targeted at reducing passenger traffic volumes might have negative implications for urban freight transport, and this is sometimes used as an argument against implementing efficient sustainable mobility measures (Tennøy et al., 2019). For instance, previous research has clearly demonstrated that the absolute and relative qualities of the transport systems affect the competition between passenger traffic modes and that the allocation of space to different modes matters (Cairns et al., 2001; Downs, 2004; Forsyth and Krizek, 2010; McLeod et al., 2017; Noland and Lem, 2002; Pucher et al., 2010; Tennøy et al., 2019; Walker, 2012). Reallocating road space to other uses, such as designated public transport lanes, might therefor be an obvious solution. The response to such suggestions is often that it will increase congestion and related problems, especially for urban freight transport and other commercial transport, but these expectations are often exaggerated (Cairns et al., 2001; Tennøy et al., 2016).

Despite the importance of urban freight transport in sustainable mobility discussions, there are surprisingly few empirical studies on how freight transport adapts to general interventions in urban transport systems and the experienced effects and consequences (Ballantyne et al., 2013; Lindholm, 2013). This causes uncertainties in assessments and policymaking (Akgün et al., 2019; Holguín-Veras et al., 2017; Lindholm, 2013; Rai et al., 2017), where trade-offs between various positive and negative consequences are weighted against each other. It could cause unnecessary delays in the progress towards sustainable mobility if negative consequences for urban freight transport are overestimated in assessments, or it could cause unexpected and unwanted adaptations and consequences for urban freight transport if they are underestimated. The aim of this study is to contribute empirical knowledge to facilitate more knowledge-based discussions concerning these issues. This might help planners and policymakers accelerate shifts towards more sustainable mobility and avoid unintended negative consequences.

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A planned 14-month capacity reduction in a main road tunnel in Oslo, Norway, which was expected to cause significant increases in delays and variability in the traffic situation, offered an excellent opportunity to empirically investigate how urban freight transport adapted to the situation, and the experienced effects and consequences. This situation could be understood as representing cases where general road space is reallocated, for instance, to designated public transport lanes, as part of a sustainable mobility strategy. It could also be understood as a case of temporary disruption in the transport system caused by construction or maintenance work, as it also was. The situation allowed for mapping the situations before, during and after the intervention, as the tunnel regained its capacity after the rehabilitation works were completed.

From previous studies, we know that disruptions to road transport systems have economic and other consequences for logistics operators, suppliers, customers and the local and regional economies (Aydin et al., 2012; Ballantyne et al., 2013; Browne et al., 2014; Ivanov et al., 2008; Masiero and Maggi, 2012; Mesa-Arango et al., 2013). Most studies on this topic concern short-term and/or unannounced capacity reductions on interstate or regional highways (Aydin et al., 2012; Ivanov et al., 2008; Masiero and Maggi, 2012; Mesa-Arango et al., 2013), and few papers address urban situations. Research by Allen et al. (2000) and Browne et al. (2014), however, provides explanations and evidence for how urban freight companies can and do adapt to increased delays in specific parts of the transport system. These can be summarized as changing scheduling, trip timing, routes, delivery frequency and size, vehicle fleets or modes of transport. They can also negotiate contracts, reorganize routes or hire more drivers. Alternatively, they can continue operating as before. Most authors emphasize the limited flexibility of freight transport compared to passenger transport. Their adaptability depends, among other things, on customer contracts and public regulations defining delivery timeslots, which affect the opportunities to adjust trip timings to the traffic situation. The available route options might also vary.

Although truck drivers are the ones operating in the dense, complex and ever-changing urban transport systems, and several authors have highlighted the benefits of including different actors when studying urban freight transport (Akgün et al., 2019; Holguín-Veras et al., 2017; Rai et al., 2017; Stathopoulos et al., 2012), we found few studies using truck drivers as key informants (notable exceptions are Holguín-Veras et al., 2017; Mohan and Vaishnav, 2022). We decided to use truck drivers and logistics professionals in freight companies as key informants in this study, believing that they could offer different understandings and insights regarding flexibility and adaptation to interventions in the transport system, and the experienced effects and consequences compared to other actors. This includes how interventions affect their workdays and working environment. Their insights could also be vital when searching for solutions supporting sustainable and efficient urban mobility.

The literature discussed above led us to expect that truck drivers would adapt by changing routes or trip timings, reorganizing deliveries or operating as before. We also expected that they would adapt in ways involving avoiding the Bryn tunnel to a lesser degree than other road users due to their limited flexibility. Leaning on findings by Allen et al. (2000), Browne et al. (2014), Ivanov et al. (2008) and Mesa-Arango et al. (2013), we expected direct effects, like increased travel time, longer travel distance (for detours), reduced punctuality, missed or delayed deliveries and increased truck traffic on local roads. This could have consequences for truck drivers such as less predictable and convenient work hours and more stress. It could also cause consequences like an increased average vehicle operational cost and reduced profitability for the freight and distribution companies, as well as worsened conditions for residents, pedestrians and bicyclists along local roads if truck drivers rerouted to these roads.

Using a mixed-methods approach including analyses of traffic data, surveys of truck drivers and interviews with truck drivers and freight company logistics professionals, the research was designed to address the following questions: *How did truck drivers adapt to changes in the traffic situation caused by the capacity reduction in the Bryn tunnel, and what affected their adaptability? What were the direct effects and the wider consequences for the truck drivers? How do the truck drivers and logistics professionals think relevant actors could act to mitigate the negative effects and consequences?*

The paper is structured as follows. The next section presents the context of the study – namely, the tunnel capacity reduction in Oslo. Descriptions of the research design and data collection methods follow. Subsequently, the paper presents descriptive analyses of data collected through different sources. The results are then discussed across the different data sources to answer the research questions. Finally, the implications of the findings are reflected upon in the concluding remarks.

2. Capacity reduction in the bryn tunnel

This study investigates truck drivers' adaptation to changes in the traffic situation related to a capacity reduction in the Bryn tunnel and the effects and consequences they experienced. As illustrated in Fig. 1, the Bryn tunnel is located on the outer ring road (Ring 3) in the Norwegian capital of Oslo, with about 700,000 inhabitants in the municipality and about 1,000,000 inhabitants in the city region. Ring 3 distributes traffic between different parts of the city and the region. The tunnel is located on the part of Ring 3 with the heaviest traffic, and traffic volumes are almost equal in both directions, including during rush hours (Tennøy and Hagen, 2021; data from the Norwegian Public Roads Administration). The average traffic per weekday in calendar weeks 5 and 6 of 2016 was about 82,000 vehicles a day, and of these, about 9900 vehicles were longer than 5.6 m (understood as mainly freight-related transport). The tunnel is dual, with two lanes in each direction, and it is 270 m long.

Due to long-planned rehabilitation work, the capacity in the tunnel was reduced from four to two lanes from February 20, 2016 to April 29, 2017. One tube was closed at a time, and two-way traffic was permitted in the open tube. When the rehabilitation work was finished, both tubes were opened for traffic, and the tunnel regained the same capacity as before the rehabilitation.

The Bryn tunnel was one out of 10 tunnels in Oslo undergoing rehabilitation work between 2015 and 2020 due to requirements under the European Union (EU, 2004) tunnel safety directive. The capacity reduction in the tunnel was expected to cause more congestion and delays than that in other tunnels, as the traffic volumes were higher and as capacity would be reduced for 14 continuous months. We perceived this situation as an excellent opportunity for investigating how truck drivers adapted to changes in the traffic situation and the effects and consequences they experienced.

Another part of the project investigated how the capacity reduction affected traffic volumes in the Bryn tunnel in general, the average speed during rush hours and commuters' adaptations and experiences (Tennøy and Hagen, 2021). Relevant for this study focusing on truck drivers was that the total traffic volumes through the tunnel were significantly reduced during the capacity reduction period (by 26–34 per cent during rush hours and 23 per cent per day) and returned to about the same levels as before when the tunnel regained normal capacity. Traffic volumes increased on an alternative route on the main road system, but a significantly smaller traffic increase was evident compared to the traffic reductions in the Bryn tunnel. Apart from this, it seems that the effects of the Bryn tunnel capacity reduction were mainly limited to the road network close to the tunnel.

Despite the traffic reduction, the average speed on the part of Ring 3 including the Bryn tunnel was significantly reduced during both the morning and afternoon rush hours (see Figs. 2 and 3). In the before and after situations, average measured speeds were close to or above the speed limit (70 km/h), except from southbound traffic ('out of the city')

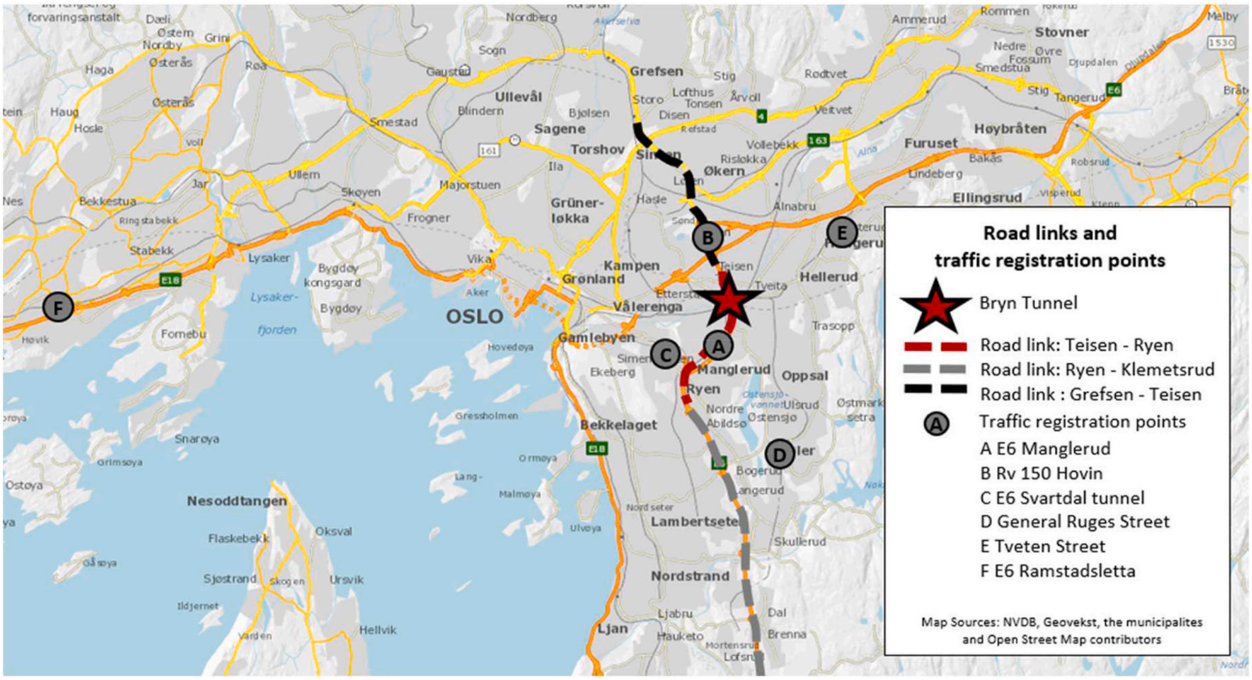

Fig. 1. Map showing the location of the Bryn tunnel on Ring 3 as well as traffic registration points and road links for speed measures. Traffic registration points A and B were used to measure traffic changes in the tunnel; points C, D and E to measure traffic changes on alternative routes; and point F to measure traffic changes at a control point assumed not to be affected by changes in the traffic situation related to the Bryn tunnel.

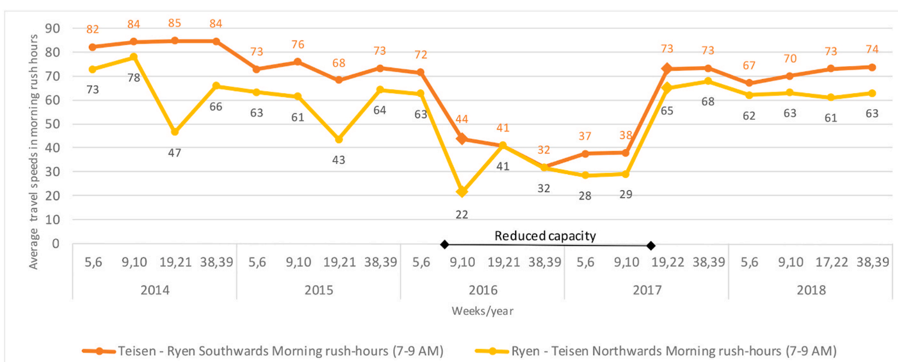

Fig. 2. Average speeds during weekday morning rush hours (7–9 AM) in two-week periods from 2014 to 2018 on the Teisen–Ryen road link. The link includes the Bryn tunnel. Facsimile from Tennøy and Hagen (2021). Data from the Norwegian Public Roads Administration.

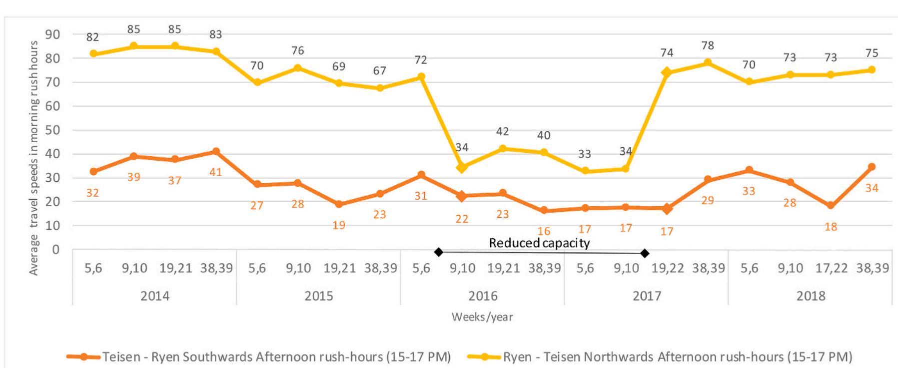

Fig. 3. Average speeds during weekday afternoon rush hours (3–5 PM) in two-week periods from 2014 to 2018 on the Teisen–Ryen road link. The link includes the Bryn tunnel. Facsimile from Tennøy and Hagen (2021). Data from the Norwegian Public Roads Administration.

during the afternoon rush. Here, average measured speeds were around 30 km/h. During the capacity reduction period, speed limits were reduced to 50 km/h, and the average measured speeds were 30–40 km/h. Again, the southbound traffic during the afternoon rush hours was the exception, where the average speed reduced to about 20 km/h. A comparison of weeks 5 and 6 in 2016 and 2017 revealed increased travel time on the 3.3 km long Teisen–Ryen road link in 2017, varying from an average of 2.3 min (morning, southbound) to 5.1 min (afternoon, southbound). When including the road links to the south and the north of Teisen–Ryen (13 km), the average extra time used varied from 2.3 min (morning rush, southbound) to 12 min (afternoon rush, southbound).

Analyses also showed greater variation in average travel speeds during rush hours in the directions opposite the rush directions (morning, southbound; afternoon, northbound) during the period with capacity reduction compared with the before and after situations (see Fig. 4 and data in Appendix E). In rush directions, the variations were similar or lower during the period with capacity reduction compared with the other situations. This indicates that the traffic was predictably slow in rush directions.

3. Research design, analyses and data collection

3.1. Research design

The research was designed as a single longitudinal case study focusing on affected truck drivers' adaptations to changes in the traffic situation following from capacity changes in the Bryn tunnel and the direct effects and wider consequences they experienced. A case study design allows investigators to study contemporary phenomena in their real-life contexts and answer 'how' and 'why' questions (Yin, 2003). The choice of case was strategic. The capacity reduction in the Bryn tunnel was understood as an extreme or unique case (Flyvbjerg, 2006; Yin, 2003) that would likely bring about conditions (increased congestion and delays) that would cause truck drivers to search for ways of adapting and experience effects and consequences. As recommended for case studies, a mixed-methods approach was applied (Flyvbjerg, 2006; Stake, 1995; Yin, 2003). This is also in accordance with recommendations by Holguín-Veras et al. (2017) and Mohan and Vaishnav (2022) demonstrating how combinations of qualitative and quantitative analyses can provide deeper insights for planning and policymaking.

The study was designed to capture how truck drivers who were affected by the changes could and did adapt and the effects and consequences they experienced, and not to investigate, for instance, the proportion of truck drivers affected in the Oslo region. Therefore, only truck drivers who regularly drove through the Bryn tunnel, and therefore were expected to experience changes in the traffic situation, were invited to participate in surveys and interviews.

3.2. Analyses

Qualitative and quantitative data were collected through four different sources and analysed in a strictly descriptive manner as described below. The researchers used these results when doing data source triangulation, as described by Stake (1995) and Yin (2003). In this process, the defined research questions were answered by critically discussing and comparing results from analyses of data from different sources. If answers to the same question from different sources coincided, this would strengthen the robustness of the finding. In cases where the results deviated, researchers discussed how this discrepancy could be interpreted and understood and which data sources were more comprehensive and robust. The combination of quantitative and qualitative data helped the researchers arrive at richer descriptions and explanations when answering the research questions. The answers to the research questions resulting from this process were discussed against findings from other studies made in other contexts (from the literature review) to arrive at more analytical generalizations, defining the situations for which the findings might be relevant. As we found no other studies focusing on the same issues and actors investigated here, this part of the analysis necessarily became weaker than desired. Therefore, the conclusions are weaker than they otherwise would have been, and so is the basis for generalization.

3.3. Data collection

Four sources of data were used: (i) traffic data from the Norwegian Public Roads Administration, (ii) surveys administered to truck drivers, (iii) semi-structured interviews with truck drivers and (iv) semi-structured interviews with freight company logistics professionals. Truck drivers were recruited to the interviews through processes independent from the recruitment of respondents to the surveys. Data were collected before, during and after the capacity reduction. See the overview of data collection methods and periods in Table 1.

Traffic data were collected to analyse the following: (i) whether truck drivers adapted to changes in the traffic situation by avoiding the Bryn tunnel throughout the day and during morning rush hours; (ii) if they

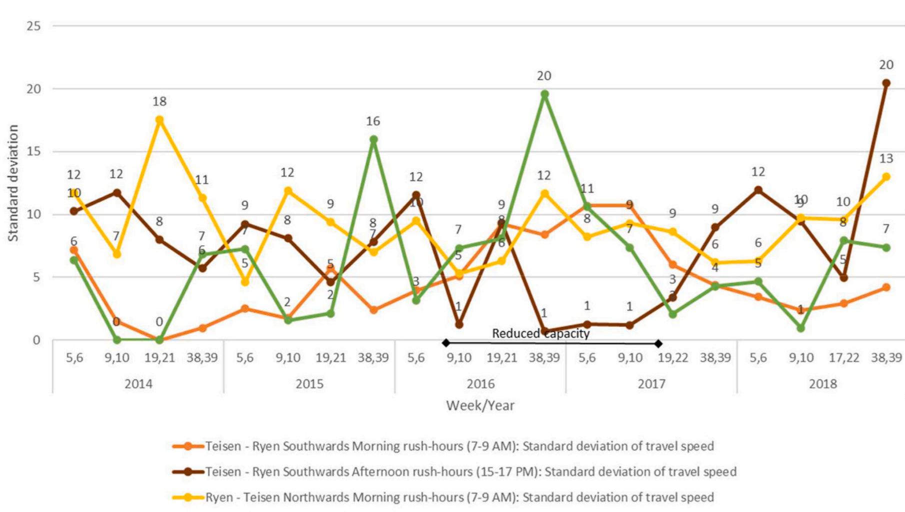

Fig. 4. Standard deviations of average hourly travel speeds during weekday morning rush hours (7–9 AM) and weekday afternoon rush hours (3–5 PM) in two-week periods from 2014 to 2018 on the Teisen–Ryen road link. The link includes the Bryn tunnel. Data from the Norwegian Public Roads Administration.

Table 1
Overview, data collection periods and methods.

Data collection period	Number of respondents	Situation
Traffic data from the national and local road authorities		
Weeks 5 and 6, 2016	–	Before capacity reduction
Weeks 5 and 6, 2017	–	During capacity reduction
Weeks 5 and 6, 2018	–	After capacity reduction
Surveys to truck drivers		
May 2015	$N_{Total} = 41$[a]	Before capacity reduction
June 2016	$N_{Total} = 55$, $n_{Bryn} = 32$[a]	During capacity reduction
May–June 2017	$N_{Total} = 75$, $n_{Bryn} = 39$[a]	After capacity reduction
Interviews with truck drivers		
March 2016	N = 19	During capacity reduction
September 2016	N = 11 (of the 19 in March 2016)	During capacity reduction
June and August 2017	N = 7 (of the 11 in September 2016)	After capacity reduction
Interviews with logistics professionals at freight companies		
April 2017	N = 8	During capacity reduction

[a] N_{Total} refers to the total number of respondents driving in Oslo at least one day per week; n_{Bryn} refers to the number of respondents saying they often or sometimes drove through the Bryn tunnel. In 2015, the respondents were not asked whether they drove through the Bryn tunnel.

adapted this way to a higher or lower degree than other road users did, (iii) whether they adapted by choosing an alternative route on the main road system; and (iv) if they adapted by using alternative routes along local roads. The selection of alternative routes to study was supported by broader analyses of changes in traffic volumes in the main road system (Tennøy and Hagen, 2021). Local and national authorities conduct continuous traffic registrations, providing an objective source of data for traffic volumes on roads. The traffic registration system distinguishes between vehicles of different lengths. The total number of vehicles (all traffic) as well as the number of vehicles longer than 5.6 m (mainly freight transport) were extracted from six analytically selected traffic registration points (see Fig. 1 for the location of these registration points):

- Traffic registration points directly connected to the Bryn tunnel, A: E6 Manglerud and B: Rv 150 Hovin
- Traffic registration point on the most natural alternative route on the main road system, C: E6 Svartdal tunnel
- Traffic registration points on alternative local (municipal) roads, D: General Ruges Street and E: Tveten Street
- Traffic registration point in a part of the main road system assumed not to be directly affected by the capacity reduction in the Bryn tunnel (control point), F: E18 Ramstadsletta

Average traffic per day (12 a.m.–12 a.m.) and during morning rush hours (7–9 a.m.) were analysed for weeks 5 and 6 in 2016, 2017 and 2018 (see Table 1). The category 'vehicles equal to or longer than 5.6 m' includes other long vehicles in addition to freight vehicles, reducing the accuracy of the analyses.

The average numbers of vehicles longer than 5.6 m in the situations before, during and after capacity reduction at the two registration points close to the Bryn tunnel were compared to reveal whether the number of long vehicles passing through the tunnel changed. This would indicate whether truck drivers adapted to the situation by avoiding the tunnel during morning rush hours and during the day in the period with capacity reduction. Comparisons with changes in total traffic volumes could uncover whether truck drivers adapted in this way to the same degree that other road users did. Similar analyses were conducted for three registration points thought to be alternative routes to determine whether truck drivers used alternative routes and to the same degree as other road users. The control point (F) was included to identify general changes in the traffic situation to facilitate assessment of whether observed changes in the tunnel were related to general changes or to the capacity reduction in the Bryn tunnel.

Surveys of truck drivers were conducted in 2015, 2016 and 2017 (see Table 1) with the aim of gathering information from a high number of truck drivers and capture main tendencies. The number of respondents turned out to be lower than expected and desired, as we return to below. The questions concerned the effects and consequences of capacity changes in the Bryn tunnel and characteristics of the truck drivers (see Appendix A for an overview of questions asked in the 2016 survey and Appendix B for some characteristics of the truck drivers completing the survey). The recruited drivers' key characteristics were that most worked in distribution transport (and not in long-distance transport), drove medium-sized delivery vans or trucks (up to 7500 kg) and drove in Oslo five days a week.

Recruiting truck drivers to answer the surveys was challenging, as has been reported in other studies recruiting professional drivers; see, for instance, Nævestad et al. (2019). Although the researchers made real efforts and cooperated with relevant actors, the number of respondents remained low. On the basis of discussions with the Delivery Industry's Centre for Development and Competence (DICDC, a partner in the research project) and its contacts in the industry, we decided to distribute the 2015 survey via the four most relevant truck drivers' unions. The survey was distributed to 500 truck drivers, and 59 responded. Forty-one of these drove in Oslo at least one day per week and were included in the sample. To increase the response rate, the 2016 survey was distributed through DICDC's network in the industry in addition to the unions. This survey was distributed in Norwegian and English, both electronically and on paper. After a week, only eight truck drivers had completed the survey. To increase the response rate, we decided to contact truck drivers directly at work while they were loading and unloading. Truck drivers were contacted at different sites and at different times of the day. When they were too busy to spend 10–15 min completing the survey, the research assistants followed the drivers and asked questions while they were working or distributed the survey to the drivers' email addresses. Sixty truck drivers completed the 2016 survey, 55 of whom were driving in Oslo at least one day per week and were included in the sample. Contacting truck drivers directly was selected as the only method for recruiting respondents for the 2017 survey. Via the same procedure as in 2016, 77 drivers completed the survey, 75 of whom were driving in Oslo at least one day per week and were included in the sample. In hindsight, we believe that asking drivers for their phone numbers and administering the survey by phone while they were driving could have increased the number of respondents. In all surveys, participants who left contact information took part in a lottery where they could win a gift card of 1000 NOK.

We do not know if the samples of survey respondents are representative of truck drivers in Oslo. We knew that we would not be able to find information describing the total population of truck drivers operating in the area, among other reasons, due to the widespread use of temporary employment among truck drivers. For this reason, and to keep the surveys short, we did not collect demographic data in the surveys. Due to the above-described way respondents were recruited, the characteristics of truck drivers who were invited to participate but declined are also unknown. Therefore, we do not know whether there are any systematic patterns concerning who participated and who did not. This was known when designing the study, which was not aimed at statistical generalization.

Repeated interviews with truck drivers provided more in-depth information about adaptations, effects, and consequences and whether and how they changed over time. In total, 19 truck drivers were recruited through one large goods supplier carrying out its own transport demand and one transport and logistics company; they were interviewed in March 2016. Two truck drivers were also truck owners. The semi-structured interviews covered questions concerning whether and how the drivers adapted to the change in the traffic situation, the effects and consequences they experienced and their ideas on what other actors could do to mitigate negative impacts (see interview guide in Appendix C). Most interviews were conducted face to face, but some were carried out by phone when drivers were too busy to do the interview at the site. The truck drivers were asked if they could be contacted for new interviews at later stages and 14 agreed to this. When contacted in September 2016, three truck drivers declined a second interview—one because he had changed routes and his experience was no longer relevant and two for no specified reason. The remaining 11 truck drivers were interviewed by phone. Using the same interview guide as in March, the focus was on changes compared with the case in March. At this time, the drivers had had more time to experience and adapt to the capacity reduction. The 11 interviewees were contacted for new interviews in June 2017, after the tunnel had regained normal capacity. These interviews aimed at gaining insight into whether any adaptations to the capacity reduction had been kept and whether previous negative effects and consequences had been reduced. Seven truck drivers agreed to participate in the additional phone interview. Those who declined did not give specific explanations. Our understanding was that some did not see any reason for taking part because the problematic period was now over. Ideally, all interviewees would have taken part throughout the study. However, losing interviewees along the way was expected, and it was partly why we started out with a relatively high number of interviewees.

When analysing the interview data, the aim was to extract more in-depth information and reflections concerning how truck drivers adapted to the capacity reduction and why, how the changes affected their workdays (or not), corresponding consequences and suggestions on how various actors could contribute to reducing any negative impacts. Key information was sorted in tables, for instance, regarding whether and how the interviewees adapted. Next, information on what kinds of adaptations the different interviewees employed and their explanations of how and why they made these adaptations were extracted. To summarize the findings, we chose to place emphasis on presenting descriptions of experiences reported by the interviewees rather than on what kinds of responses were more common.

Interviews with eight logistics professionals working for six different freight and distribution companies were conducted in April 2017, a few weeks before the Bryn tunnel was reopened at full capacity. These interviews provided information about the adaptations logistics professionals and companies made to reduce any negative effects and consequences for the firms and drivers, as well as whether any changes made would persist after the situation returned to normal (see interview guide in Appendix D). Using our network, we contacted 16 logistics professionals or firms by phone and/or email and invited them to participate in the study. Eight agreed, and we received no explanations as to why the others declined. Analyses of the interviews with logistics professionals were carried out much like the interviews with truck drivers, as described above.

4. Findings

4.1. Results from analyses of traffic data

Traffic data were analysed to identify whether freight transport adapted to changes in the traffic situation by avoiding the Bryn tunnel, whether they adapted by driving other routes and if they adapted in these ways to the same extent as other traffic did. The average numbers of all vehicles and of vehicles equal to or longer than 5.6 m were collected at six analytically selected traffic registration points presented in Table 2 (per workday) and Table 3 (during morning rush hours on workdays), together with figures for long vehicles' share of the total traffic. Relative changes in general traffic and in the number of long vehicles across different situations are presented in Tables 4 and 5. All tables include traffic in both directions and the situations before, during and after the capacity reduction. The registration points represent the Bryn tunnel (A and B), alternative routes (C, D and E) and a control point (F).

Starting with the traffic registration points representing traffic in the Bryn tunnel, the average daily number of vehicles equal to or longer than 5.6 m decreased by 4 per cent (386 vehicles) over the day when comparing the situations before and during the capacity reduction at registration point A and by 13 per cent (1523 vehicles) at registration point B. The total numbers of vehicles (all lengths) decreased by 23 and 20 per cent, respectively. During morning rush hours, the numbers of long vehicles decreased by 1 per cent (16 vehicles) at registration point A and 14 per cent (216 vehicles) at registration point B, while the total traffic volumes decreased by 34 and 23 per cent. This resulted in increased shares of long vehicles. After the tunnel regained full capacity, the number of long vehicles increased relatively more during the day (9 and 21 per cent) and during morning rush hours (5 and 22 per cent) compared to the decrease when capacity was reduced. Traffic data collected at the control point (F), controlling for changes in the general traffic situation, showed a clearly different pattern from the registration points representing the Bryn tunnel. Our interpretation is therefore that the changes in traffic volumes in the Bryn tunnel were related to the changes in the traffic situation. Understood this way, the results indicate that only a minority of all drivers adapted to the capacity reduction by avoiding the Bryn tunnel, and drivers of long vehicles adapted this way to a lesser degree than other drivers did.

The tables also show that the numbers of long vehicles on the most logical alternative route in the main road system (registration point C) increased by 41 per cent (838 vehicles) per day and 29 per cent (70 vehicles) during morning rush hours when comparing the situations before and during the capacity reduction. Total traffic at registration point C increased relatively less—by 8 per cent per day and 0 per cent during morning rush hours. After the tunnel regained full capacity, the number of long vehicles decreased by 17 per cent during the day and by 0 per cent during morning rush hours. These changes deviated strongly

Table 2
Average numbers of vehicles (all vehicles and vehicles equal to or longer than 5.6 m) and shares of long vehicles per day in the situations before, during and after the capacity reduction in the Bryn tunnel. The shaded rows show data from traffic registration points representing the Bryn tunnel.

Traffic registration points	Weeks 5 and 6 (2016: Before)			Weeks 5 and 6 (2017: During)			Weeks 5 and 6 (2018: After)		
	All vehicles	≥5.6 m	Share	All vehicles	≥5.6 m	Share	All vehicles	≥5.6 m	Share
A: E6 Manglerud	81,589	9918	12%	62,917	9532	15%	76,679	10,407	14%
B: Rv 150 Hovin	89,372	11,879	13%	71,609	10,356	14%	85,798	12,577	15%
C: E6 Svartdal tunnel	31,678	2043	6%	34,215	2880	8%	28,109	2404	9%
D: General Ruges Street	10,929	968	9%	11,238	901	8%	9235	721	8%
E: Tveten Street	14,020	569	4%	14,639	589	4%	12,366	506	4%
F: E18 Ramstadsletta	85,599	8414	10%	87,093	9167	11%	84,596	9568	11%

Source: Traffic registration points run by the Norwegian Public Roads Administration and the City of Oslo.

Table 3
Average numbers of vehicles (all vehicles and vehicles equal to or longer than 5.6 m) and shares of long vehicles during morning rush hours (7–9 AM) in the situations before, during and after the capacity reduction in the Bryn tunnel. The shaded rows show data from traffic registration points representing the Bryn tunnel.

Traffic registration points	Weeks 5 and 6 (2016: Before)			Weeks 5 and 6 (2017: During)			Weeks 5 and 6 (2018: After)		
	All vehicles	≥5.6 m	Share	All vehicles	≥5.6 m	Share	All vehicles	≥5.6 m	Share
A: E6 Manglerud	11,854	1184	10%	7828	1168	15%	11,045	1225	11%
B: Rv 150 Hovin	13,987	1505	11%	10,779	1289	12%	13,173	1569	12%
C: E6 Svartdal tunnel	4981	244	5%	4981	314	6%	4611	314	7%
D: General Ruges Street	1541	146	9%	1574	141	9%	1229	95	8%
E: Tveten Street	2025	96	5%	2179	93	4%	1723	72	4%
F: E18 Ramstadsletta	10,640	901	8%	10,901	925	8%	11,022	912	8%

Source: Traffic registration points run by the Norwegian Public Roads Administration and the City of Oslo.

Table 4
Relative changes between the different situations (all vehicles and vehicles equal to or longer than 5.6 m) per day. The shaded rows show data from traffic registration points representing the Bryn tunnel.

Traffic registration points	Before (weeks 5 and 6, 2016) – During (weeks 5 and 6, 2017)		During (weeks 5 and 6, 2017) – After (weeks 5 and 6, 2018)		Before (weeks 5 and 6, 2016) – After (weeks 5 and 6 2018)	
	All vehicles (%)	≥5.6 m (%)	All vehicles (%)	≥5.6 m (%)	All vehicles (%)	≥5.6 m (%)
A: E6 Manglerud	−23	−4	22	9	−6	5
B: Rv 150 Hovin	−20	−13	20	21	−4	6
C: E6 Svartdal tunnel	8	41	−18	−17	−11	18
D: General Ruges street	3	−7	−18	−20	−15	−25
E: Tveten street	4	4	−16	−14	−12	−11
F: E18 Ramstadsletta	2	9	−3	4	−1	14

Source: Traffic registration points run by the Norwegian Public Roads Administration.

Table 5
Relative changes between the different situations (all vehicles and vehicles equal to or longer than 5.6 m) during morning rush hours (7–9 AM). The shaded rows show data from traffic registration points representing the Bryn tunnel.

Traffic registration points	Before (weeks 5 and 6, 2016) – During (weeks 5 and 6, 2017)		During (weeks 5 and 6, 2017) – After (weeks 5 and 6, 2018)		Before (weeks 5 and 6, 2016) – After (weeks 5 and 6 2018)	
	All vehicles (%)	≥5.6 m (%)	All vehicles (%)	≥5.6 m (%)	All vehicles (%)	≥5.6 m (%)
A: E6 Manglerud	−34	−1	41	5	−7	4
B: Rv 150 Hovin	−23	−14	22	22	−6	4
C: E6 Svartdal tunnel	0	29	−7	0	−7	29
D: General Ruges street	2	−3	−22	−33	−20	−35
E: Tveten street	8	−3	−21	−23	−15	−25
F: E18 Ramstadsletta	2	3	1	−1	4	1

Source: Traffic registration points run by the Norwegian Public Roads Administration.

from what was measured at the control point (F). Our interpretation is therefore that the changes in traffic volumes at registration point C were related to changes in the traffic situation in the Bryn tunnel. Understood this way, the results indicate that some drivers of long vehicles adapted to the changes in the Bryn tunnel by driving this alternative route, and some of those drivers continued to use this same route.

The numbers and shares of long vehicles registered on the municipal roads (registration points D and E) decreased or remained stable when comparing the situations before and during the tunnel capacity reduction. The numbers decreased further after the Bryn tunnel regained full capacity. Total traffic volumes at these registration points varied in similar ways.

4.2. Results from truck driver surveys

In the 2016 and 2017 surveys, truck drivers who drove through the Bryn tunnel once a week or more were asked if they had experienced a change in their workday due to the rehabilitation work in the tunnel

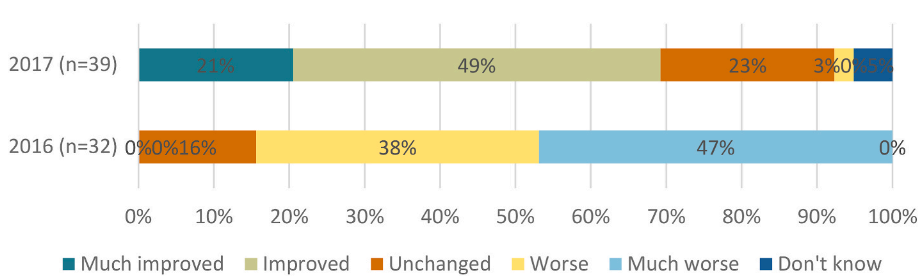

Fig. 5. Truck drivers' answers to the questions 'Do you find that your workday has become better or worse as a result of the work in the Bryn tunnel (compared with before the capacity reduction)?' (2016) and 'Do you find that your workday has become better or worse as a result of the completion of the work in the Bryn tunnel (compared to when capacity was reduced)?' (2017). Percentages of drivers. n = 32 (2016) and n = 39 (2017).

(Fig. 5). During the rehabilitation work (2016), most (27 out of 32 drivers) stated that this worsened their workday. After the rehabilitation work was completed (2017), most experienced an improvement in their workday (27 out of 39 drivers).

This understanding is supported by the responses from all truck drivers who answered the surveys in 2015, 2016 and 2017 to the more general question concerning whether they experienced a worsening or improvement of the traffic situation in the Oslo area compared with the same time the previous year (results in Fig. 6). The share of drivers who experienced a worsening of the traffic situation peaked in 2016, with 67 per cent experiencing at least a worsening of the situation.

In 2016 and 2017, drivers who responded that they experienced a change in their workday due to the construction work in the Bryn tunnel received follow-up questions about what effects and consequences they experienced. Both surveys included two separate questions with predetermined alternatives for the drivers to choose from. The alternatives were the same in both questions, with the exception that they were phrased positively in one and negatively in the other. In each question, the truck drivers could select multiple alternatives, resulting in more 'votes' than respondents. The alternative 'no changes' was mutually exclusive, and the alternative 'Use more vehicles' was presented negatively only.

Fig. 7 shows the results from the 2016 survey. Only one driver reported experiencing no negative changes. The most reported negative effects were more congestion (19 per cent), increased time used on the route (16 per cent) and more detours due to reduced accessibility (14 per cent). The most frequently reported consequences were more stress and frustration (15 per cent) and less predictable workdays (10 per cent). Inconvenient work hours, the use of more vehicles to deliver the same amount of goods and problems complying with mandatory rest periods were found to be of less concern. A few respondents also reported positive changes.

In 2017, after the tunnel regained full capacity, the picture changed; see Fig. 8. Only 2 of 28 drivers did not report any positive changes. The most frequently reported positive effects were less time used on the route (33 per cent) and less congestion (21 per cent). The most frequently reported consequence was less stress and frustration (13 per cent). Five drivers reported negative changes after the tunnel regained full capacity.

In 2016, 17 of the 32 drivers using the Bryn tunnel contributed suggestions on what relevant actors could do to ease the situation for truck drivers. The suggestions were mainly related to allowing delivery trucks in public transport lanes, improving parking for deliveries, reducing passenger traffic via various measures, providing alternative routes, increasing the total road capacity and increasing efforts to finish the rehabilitation work sooner.

4.3. Results from interviews with truck drivers

Out of 19 truck drivers interviewed in March 2016, 10 said they made changes to adapt to the capacity reduction in the Bryn tunnel and nine did not. The main adaptations reported were using alternative routes to avoid the tunnel during the most congested rush hours, changing the departure time to be on the road ahead of or behind traffic and changing distribution routes so that deliveries involving driving through the tunnel were made at less congested times. Of those who reported no adaptations, five drivers operated in the affected area but normally did not drive through the Bryn tunnel on their route, while four did. Of these four, one driver reported that he wanted to make adaptations but could not due to route restrictions. A few drivers reported that they experienced reduced congestion. These drivers entered the main road system 'behind' the problematic area, where traffic flowed better than normal, as the capacity reduction made the tunnel a bottleneck.

During the follow-up interviews in September 2016, all 11 interviewees who had made adaptations in March 2016 said they were maintaining these. Two drivers had made additional changes to ease the situation. One stated that he sometimes changed the delivery order, while the other did smaller, local adaptations, like making a specific lane choice at a certain link. One driver who had employed no adaptations in March reported in September that he chose an alternative route to avoid the Bryn tunnel during morning rush hours. After the rehabilitation work was finished in 2017, all seven interviewed truck drivers experienced decreased delays and travel time through the tunnel. They had mainly returned to their old routines.

The effects and consequences reported in the in-depth interviews can be grouped into three categories. *First,* the traffic situation disruption caused by the capacity reduction in the Bryn tunnel increased uncertainty. Some days, traffic could be normal, while on other days, there could be severe congestion and long delays. One small accident could result in lengthy delays. On average, the drivers reported an extra delay of 10–20 min during rush hours and large variability. *Second,* some drivers experienced longer workdays. This was not only a direct effect of increased congestion but also a result of existing routines that were not adapted to the problematic situation. For instance, the Norwegian Public Roads Administration conducted vehicle controls as normal, which resulted in delayed departures from terminals and increased the probability of being stuck in traffic. One interviewee reported that some terminals also had routines entailing that truck drivers who were delayed in traffic could miss their designated slot at the terminal, increasing the truck drivers' workday even further. Drivers experienced workdays of up to 2 h longer, as delays in the Bryn tunnel led to missed slots for loading/unloading at the terminals. *Third*, there were effects and consequences related to safety. One driver explained that many private car drivers took high risks to reach a preferred position, either in front of or behind a freight vehicle. Another said there should be more traffic signs informing drivers about the reduced capacity and congestion. The sudden reduction in traffic speed came as a surprise to some and resulted in dangerous situations.

When asked if their employers made any adaptations to ease the situation, 11 drivers stated that they did not know about any

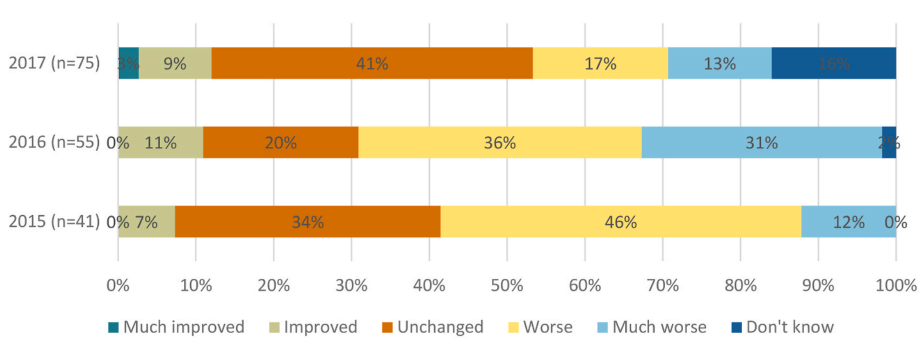

Fig. 6. Truck drivers' answers to the question 'Have you experienced a worsening or improvement of Oslo traffic compared to the same time last year?' Percentages of drivers. n = 41 (2015), n = 55 (2016) and n = 75 (2017).

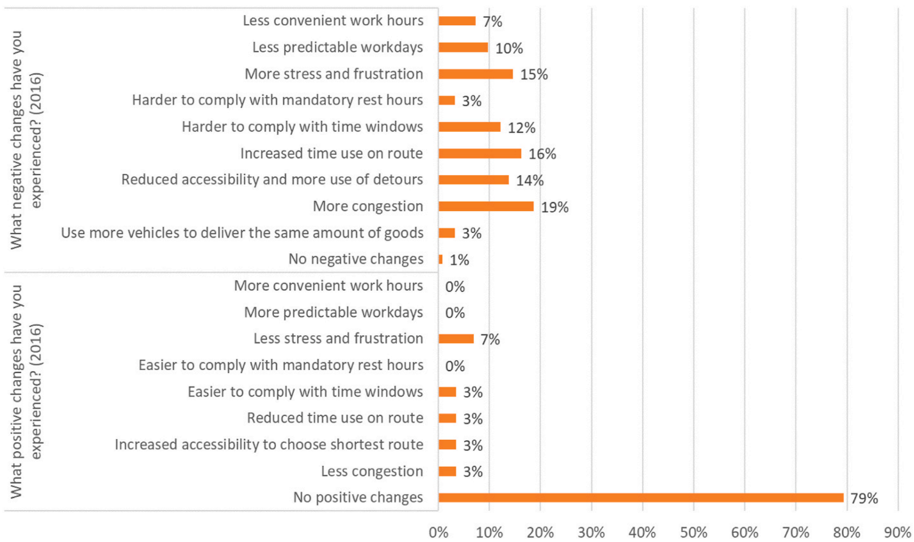

Fig. 7. Truck drivers' responses to the question 'What negative and positive changes have you experienced compared to the situation before the capacity reduction in the Bryn tunnel?' Drivers could choose multiple alternatives. n = 27 (2016, during the capacity reduction).

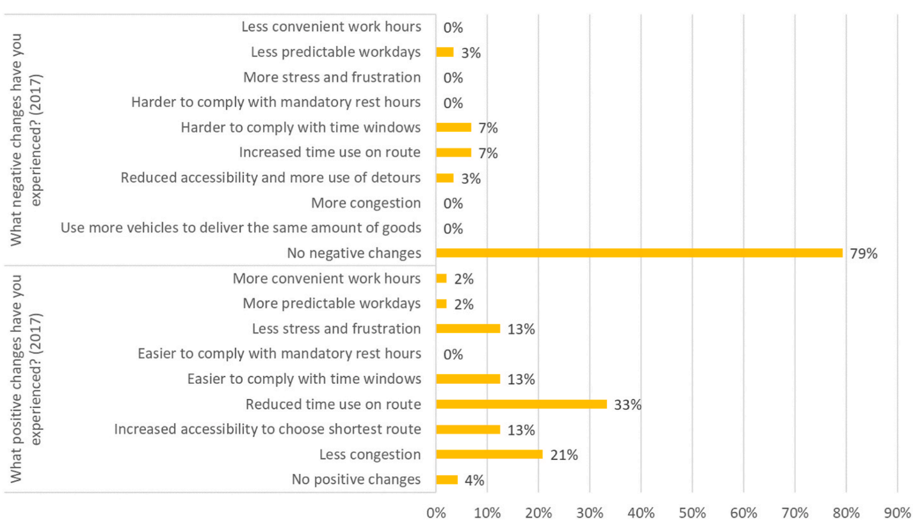

Fig. 8. Truck drivers' responses to the question 'What negative and positive changes have you experienced compared to the situation when the capacity in the Bryn tunnel was reduced?' Drivers could choose multiple alternatives. n = 28 (2017, after the tunnel regained normal capacity).

organizational adaptations to the situation. The other drivers explained that the companies and/or logistics professionals helped by planning for increased time used on routes, reorganizing routes to avoid the tunnel, informing drivers and customers about extraordinary traffic issues and ensuring better utilization of existing vehicles. This reveals potential for mitigating measures that are in the hands of the freight companies. From the descriptions above, it also seems that changes in routines at some terminals, where truck drivers in the current situation risk losing their time slots and experience long wait times if they are delayed, is another action the freight industry could take to reduce stress and time used for deliveries.

Concerning what relevant authorities could do to reduce the disadvantages of tunnel rehabilitation, truck drivers' answers could be grouped into three categories: progress in rehabilitation work to finish it sooner, better information and signage in connection to roadwork and queues, and various measures to reduce passenger traffic and improve accessibility for freight transport. This included restrictions on the use of bus lanes for electric passenger vehicles (which, together with taxis, are allowed in bus lanes in Norway) and, instead, allowing freight traffic in the bus lanes or allocating lanes for freight vehicles. Thus, the suggestions were in accordance with those from the 2016 survey.

4.4. Results from interviews with logistics professionals

Five out of eight logistics professionals interviewed in April 2017 reported making changes to adapt to the capacity reduction in the Bryn tunnel, including rerouting, changing departure times and guiding truck drivers out of the most congested areas at the most congested times. Two logistics professionals planned, but did not implement, changes, while one had already been avoiding the Bryn tunnel prior to the capacity reduction. One logistics professional said his drivers reported congestion and increased time used on routes, but they did not advocate the need for drastic changes. Several logistics professionals highlighted that freight transport is determined by the customers (freight shippers or receivers), providing little room for adaptations, and one said the customers had accepted changes in contracts due to the situation. The logistics professionals reported that reduced flexibility and efficiency due to congestion increased costs and reduced incomes. None reported acquiring more vehicles or truck drivers 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 greater problem than delays on the main roads, including the worsened situation caused by the rehabilitation work in the tunnel. Concerning suggestions for mitigating measures, the logistics professionals also highlighted enhanced efforts to finish the rehabilitation work sooner. Some wanted more information about the ongoing rehabilitation work, but most logistics professionals were satisfied with the information they had received.

5. Discussion

Having analysed data gathered from different sources (traffic data, truck driver surveys, interviews with truck drivers and logistics professionals), the findings can be critically discussed against each other and against findings in previous studies to answer the research questions defined in section 1 (Stake, 1995; Yin, 2003). *The first research question* concerned how and to what degree truck drivers could and did adapt to changes in the traffic situation, and what affected their adaptability. Analyses of traffic data indicated that only a minority of drivers of long vehicles adapted to the capacity reduction by avoiding the Bryn tunnel. This is in line with findings from the interviews, where only some truck drivers reported taking actions to adapt to the situation. Those reporting adaptations, said they tried to avoid the Bryn tunnel during rush hours by using alternative roads, reorganizing delivery routes and starting earlier or later to avoid congestion. Logistics professionals reported similar strategies. Traffic data showed, however, that relative reductions in the number of long vehicles in the Bryn tunnel were similar during morning rush hours and during the day (see Tables 4 and 5). Further, the relative increase of long vehicles on the alternative route on the main road system (registration point C) was higher during the day than during morning rush hours. This could indicate that drivers wanted to avoid the tunnel during rush hours but were not able to, or that they did not find alternatives they perceived as better than to continue operating as normal. Supporting this, truck drivers and logistics professionals alike claimed limited flexibility due to strict customer contracts and lack of route options or other ways of adapting. These findings are in line with results from previous studies (Allen et al., 2000; Browne et al., 2003). Results from the traffic data analyses also showed that the relative reduction in the number of long vehicles in the tunnel was significantly lower than that of all vehicles during morning rush hours as well as during the day. A study on how commuters adapted to the same situation found a higher degree of adaptation and that changes in trip timings, routes and transport modes were most common (Tennøy and Hagen, 2021). These results support claims in existing literature, that freight traffic has fewer adaptation alternatives and less flexibility than other road users.

The second research question concerned the effects and consequences for truck drivers and their workdays. The most frequent effects reported in the surveys were increased delays when passing the tunnel, increased time used on routes and the need to detour. This was supported by findings from analyses of traffic data showing significant reductions in the average speed during rush hours and an average increase in travel time on the road stretch, including the tunnel varying between 2.3 and 5.1 min depending on the direction and time of day (section 2). Truck drivers said in interviews that the traffic situation had become more unpredictable, and this was partly supported by analyses of traffic data (Fig. 4). Logistics professionals confirmed that travel time had increased, and predictability had decreased. These findings are in line with previous studies (Allen et al., 2000; Browne et al., 2014; Ivanov et al., 2008; Mesa-Arango et al., 2013). In the surveys, the most frequently reported negative consequences for the truck drivers and their workdays were increased stress and frustration (15 per cent) and less predictable workdays (10 per cent). In interviews, congestion and the unpredictable traffic situation were connected to the need for earlier departure to comply with time restrictions on the route and, consequently, longer workdays. Some also noted that the congested traffic led to more risk-taking behaviour among private drivers, causing traffic safety issues. Logistics professionals reported reduced efficiency and increased costs, but none had needed to acquire more vehicles or truck drivers. We could not find similar studies with which to compare these findings. Analyses of traffic data from registration points on local roads understood as alternatives to the Bryn tunnel (D and E) showed reduced or stable numbers of long vehicles, when comparing the situations before and during the capacity reduction in the Bryn tunnel, and a further and stronger reduction after the tunnel regained normal capacity. The expected and undesirable situation with increased long vehicle traffic on these local roads due to the main road tunnel capacity reduction, therefore, did not occur.

The third research question concerned how relevant actors could act to mitigate negative effects and consequences of the main road capacity reduction. Interviews revealed that some freight companies and logistics professionals took actions to facilitate adaptation and reduce negative consequences, while others did not. This displays a potential for action among freight companies. Truck drivers also pointed at how changes in routines at terminals could help. They reported that rigid routines at terminals, where drivers risked long wait times if they were delayed and missed their designated time slots, caused unnecessary increases in time used for deliveries. These examples indicate that actors within the freight industry could take actions to improve adaptability, reduce stress for truck drivers and improve efficiency. Turning to what public authorities could do, besides speeding up the roadwork, most suggestions concerned ways of improving accessibility for freight traffic by reducing private traffic, giving freight transport vehicles ‘on duty’ access to public transport lanes instead of private electrical vehicles (that are allowed in public transport lanes in the current situation), expanding roads or constructing bypass routes.

In summary, only a minority of truck drivers adapted to the traffic situation changes in ways involving avoiding the Bryn tunnel during rush hours or during the day. Some adapted by changing routes, trip timings or the organization of delivery routes, but most continued operating as before. Results support the understanding that freight traffic and truck drivers have limited flexibility and fewer alternatives than other road users. Another key finding is that halving the capacity on a heavily trafficked urban main road did not cause unbearable negative effects or consequences for truck drivers or freight companies. Travel time increased but normally only by a few minutes during rush hours. The traffic situation also became less predictable. Truck traffic on local roads did not increase. Truck drivers reported that the situation affected their workday negatively. More stress and frustration were reported by 15 per cent of the drivers and less predictable workdays by 10 per cent. The logistics professionals said it was not necessary to hire more truck drivers or to buy more trucks. Interviewees suggested actions freight industry actors could take to reduce negative impacts of changes in the transport system and improve flexibility, punctuality and efficiency. These might be relevant inputs for the freight industry. Some of the suggestions to public authorities, such as expanding urban road capacity, are not in accordance with sustainable mobility goals. Others, like various measures to reduce passenger road transport, and perhaps allowing urban freight transport in dedicated public transport lanes instead of electric passenger vehicles, could be in accordance with such goals.

This longitudinal single case study was not designed to be statistically generalizable to other cities. The low number of respondents in the surveys is a weakness. We believe, however, that similar results would have been found if the study had been carried out in other cities with similar characteristics as Oslo (city size, road network, availability of alternative routes, congestion levels, etc.), located in countries with similar organization of the freight and distribution industry and regulations of working conditions for truck drivers. The results might also be interesting beyond these contexts, as they contribute a better understanding of the fine-grained interactions between truck drivers and the complex urban transport environment they negotiate in their daily practice.

6. Concluding remarks

Potential conflicts between sustainable mobility goals and concerns related to urban freight transport might delay the progress towards sustainable mobility or cause unwanted negative consequences for urban freight transport. A scarcity of empirical studies on how changes in the general transport system affect truck drivers and the freight industry causes uncertainties in assessments and policymaking. The empirical case study presented in this paper contributes to the existing literature with findings from a case of urban main road capacity reduction in Oslo. This study combining surveys and interviews with truck drivers and logistics professionals with analyses of traffic data was designed to analyse and describe how truck drivers adapted, what effects and consequences they experienced and how different actors could act to reduce negative impacts. It was found that most truck drivers did not make changes to adapt to the situation and that they had limited options and less flexibility than other road users. The main effects were increased travel time and reduced traffic predictability. Some drivers reported consequences such as more stress and less predictable workdays. It was not necessary to hire more truck drivers or to buy more trucks. Truck traffic did not increase on local roads.

When discussing potential policy implications of the results, the case could be understood as representing situations where road space is reallocated to other uses as part of a sustainable mobility policy. In this perspective, an interpretation of the results could be that halving the capacity on a heavily trafficked main road caused only moderate negative consequences for truck drivers, freight companies and local roads, and less so than many expected. This would support claims that negative consequences for urban freight transport of road space reallocation targeted at reducing passenger traffic volumes are exaggerated and expand the understanding of what policy measures are feasible and relevant. For instance, it could affect how relevant actors assess road capacity reductions or the reallocation of urban road space to other uses, like dedicated public transport lanes or bicycle infrastructure. This could result in more efficient sustainable mobility policies. The results also support the understanding that freight traffic and truck drivers have limited flexibility and fewer alternatives than other road users to adapt to traffic disruptions and general congestion in urban transport systems. Interviewees suggested allowing freight vehicles in dedicated public transport lanes to reduce the challenges they face. This could be a feasible policy measure if it does not cause delays for public transport, and this needs to be studied and discussed more thoroughly. They also suggested actions freight industry actors could take to improve the situation. If challenges for freight transport could be addressed in these ways, it could also reduce resistance to restrictive measures aimed at reducing passenger car traffic and achieving more sustainable urban mobility.

The results from this investigation of one single case in its specific context obviously cannot be generalized to all other cities and situations. Seen together with other studies, they could however facilitate more knowledge-based assessments and discussions, helping public authorities to develop more efficient policies that accelerate shifts towards sustainable mobility and avoid unintended negative consequences. They might also leave authorities and freight industry actors better equipped when planning for temporal changes in urban transport systems due to necessary construction works.

A contribution of this paper is that results from studies using truck drivers and logistics professionals as key informants are in line with what has been found in other studies using other methods and informants. The voices of truck drivers and logistics professionals operating in urban environments are seldom heard in research literature. Using these actors as key informants, the study contributed more nuanced and context-related knowledge of how they perceive their workdays and working conditions and how they respond to and are affected by changes in the transport system. Descriptions of the challenges faced when using truck drivers as informants, thorough descriptions of the data collection process and suggestions for improvements can be helpful for other researchers using truck drivers as informants in future research. Hopefully, this can contribute to more researchers involving this under-researched group in their studies.

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Municipality of Oslo.
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Akershus County Council.
Norwegian Automobile Federation.

Role of funding sources

These and other public authorities have been partners in the project and contributed in different ways. They have facilitated access to data, and they have been relevant discussions partners. The Norwegian Research Council have not been involved in any other ways that as a funding source.

The researchers involved have been fully responsible for the research design, collection and analyses of data, interpretation of findings and communication of results. The funding sources have not interfered in this.

Submission declaration

This work has not been published previously in any scientific journal, and it is not under consideration for publication in any other scientific journal.

The results themselves have been published, through other channels than scientific journals. Some results have been published in a scientific conference, but not in the version submitted here. The results have also been communicated to planning practice actors in Norway on several occasions, as they were important input to authorities' handling of ongoing changes in the transport system in Oslo. For the same reason, the results have been presented in publicly accessible Institute of Transport Economics research reports, together with results concerning information measures, commuters' adaptations and experiences, etc. These reports are written in Norwegian, and they have English summaries.

Author statement

Tennøy: Supervision, Project administration, Funding acquisition, Conceptualization, Methodology, Formal analysis, Writing original draft, Writing - review and editing.

Caspersen: Methodology, Conceptualization, Investigation, Formal analysis, Data-curating, Writing original draft, Writing - review and editing.

Ørving: Investigation, Formal analysis, Data-curating, Writing original draft, Writing - review and editing.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

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Appendix A. Truck driver Survey 2016

Questions that are not relevant for the analyses and discussions in the paper have been removed by the authors. The text is translated from Norwegian.

Welcome to the survey for truck and van drivers in the Oslo area! Your opinions and experiences from freight transport in the Oslo area will be valuable contributions to our research on how freight transport is affected by and adapts to changes in the Oslo transport system. Participation is completely voluntary, and all data will be anonymous, i.e. your answers can not be traced back to you.

The survey will take about 15 min. We appreciate it if you take the survey as soon as possible, preferably before Tuesday June 14, 2016. When completing the survey, you can choose to join a lottery for a 1000 NOK gift certificate.

In advance: thank you for completing the survey!

Question 1: Do you normally transport goods in the Oslo area at least one day per week?

- Yes - mostly distribution transport
- Yes - mostly long-haul transport
- No (exit)

If your answer was “no” in Question 1 the rest of the questions in this survey will not be relevant for you, and you do not have to complete the survey. Thank you for your participation.

Question 2: On how many days per week do you normally transport goods in the Oslo area?

- Scale from 1 to 7

Question 3: What kind of vehicle do you normally drive?

- Delivery van
- Medium truck (if chosen, also choose the size of the vehicle)
    - Less than 3,5 metric ton
    - Between 3,5 and 7,5 metric ton
    - More than 7,5 metric ton
- Heavy truck
- Semi-trailer truck

Question 4: How easy/difficult is it to arrive within the time windows for delivery/pick-up?

- Very easy
- Easy
- Neither
- Difficult
- Very difficult
- Unsure/Not relevant

Question 5: How easy/difficult is it to comply with driving and rest periods?

- Very easy
- Easy
- Neither
- Difficult
- Very difficult
- Unsure/Not relevant

Question 6: How satisfied are you with the traffic situation in Oslo for freight transport?

- Very satisfied
- Satisfied
- Neither
- Dissatisfied
- Very dissatisfied
- Unsure/Not relevant

Question 7: Do you think the traffic situation in the Oslo area has become worse or better for freight transport compared to same time last year?

- Much better
- Slightly better
- Unchanged
- Slightly worse
- Much worse
- Unsure/Not relevant

10 tunnels on the main road system will be rehabilitated between 2015 and 2020. The Bryn tunnel is currently partially closed and has reduced capacity compared to the normal situation.

We would like to hear your experiences from how the tunnel rehabilitation period has affected freight transport.

Question 16: Do you normally transport goods through the Bryn tunnel?

- Yes, often
- Yes, sometimes
- No (please proceed to question 22)

Question 17: Do you feel you received sufficient information about the Bryn tunnel rehabilitation before the rehabilitation work started?

- Yes, I received sufficient information
- I received some information, but not sufficient
- No, I did not receive any information (please proceed to question 19)
- Unsure/Not relevant (please proceed to question 19)

Question 18: Where did you receive your information from? Check up to three of the most important sources of information.

- Employer (e.g. e-mail, intranet)
- Colleagues, friends, or acquaintances
- Newspaper ads
- Radio ads
- News segments on TV, radio or in news papers
- Vegvesen.no
- Roadside information billboards
- Other information from The Norwegian Public Roads Administration
- (flyers, e-mail, or meetings)
- Facebook page for the Bryn tunnel
- Other social media
- Do not remember
- Other experiences? Please fill in:

Question 19: Do you feel that your workdays have become better or worse because of the rehabilitation work at the Bryn tunnel (compared to the situation before partial closing)?

- Much better
- Better
- Same as before (please proceed to question 22)
- Worse
- Much worse
- Unsure/Not relevant (please proceed to question 22)

Question 20: What positive changes have you experienced, compared to the situation before partial closing of the Bryn tunnel? Multiple options possible.

- None (mutually exclusive alternative)
- Less congestion on the road
- Shorter time on a regular route
- Preferred roads are now more accessible so I can choose better routes
- Easier to arrive within the time windows for delivery/pick-up
- Easier to comply with driving and rest periods
- Less stress/frustration
- A more predictable workday
- Fewer hours on inconvenient parts of the day
- Other experiences? Please fill in:

Question 21: What negative changes have you experienced, compared to the situation before partial closing of the Bryn tunnel? Multiple options possible.

- None (mutually exclusive alternative)
- More congestion on the road
- Longer time on a regular route
- Preferred roads are now less accessible, so I have to make detours
- Harder to arrive within the time windows for delivery/pick-up
- Less cargo per trip since goods must be spread across more cars to arrive within time windows
- More violations of driving and rest periods
- More stress/frustration
- Less predictable workdays
- More hours on inconvenient parts of the day
- Other experiences? Please fill in:

Question 22: Do you have any specific suggestions to the government on what can be done to reduce the disadvantages the tunnel rehabilitations may have for freight transport?

If you wish to be in a lottery for a 1000 NOK gift certificate, please write down your e-mail address or phone number:

Appendix B. Truck driver Survey Characteristics

Questions and answers	2015	2016		2017	
	Total	Total	Bryn	Total	Bryn
Do you usually drive in Oslo?					
Yes	41				
Distribution	-*	51	32	71	38
Long distance	–	4	0	3	1
No answer				1	
No (exit)	18	5		2	
What type of vehicle do you drive?					
Delivery van	–	18	12	43	21
Medium truck	–	29	19	31	18
Heavy truck	–	5		1	
Semi-trailer truck	–	3	1		
How many times per week do you drive in Oslo?					
1–4	6	9	4	10	8
5	35	44	27	58	25
6–7		2	1	7	6

* "-" means that the question was not asked in that particular survey.

Appendix C. Interview Guide for Truck Drivers

- What kind of freight vehicle do you usually drive?
- Does your normal distribution the route go through the Bryn tunnel?
- How satisfied are you with the traffic situation in Oslo for freight transport?
- Do you do anything differently at the start of a shift now than you did before/during the tunnel rehabilitation? Why/where/how?
- Do you do anything differently during the transport proper than you did before/during the tunnel rehabilitation? Why/where/how?
- Do you do anything differently at the end of the shift than you did before/during the tunnel rehabilitation? Why/where/how?
- What are the consequences of rehabilitating/reopening the tunnel for your workdays?
- Do you experience better or worse delivery precision? Is it easier or more difficult to schedule deliveries considering time?
- Do you know if your transport company has made any adjustments to ease any possible challenges related to the tunnel rehabilitation?
- What is the most important thing Oslo municipality and the Norwegian Public Roads Administration can do to manage the tunnel rehabilitation in the best possible way?
- What is the most important thing Oslo municipality and the Norwegian Public Roads Administration can do for Oslo to become a better city to transport goods in?

Appendix D. Interview Guide for Logistics professionals

- What type of freight do you plan for and for what areas?
- How many of your vehicles drive through the Bryn tunnel?
- How satisfied are you with the traffic situation in Oslo for freight transport?
- Have you customized the start of the shift to accommodate the rehabilitation work in the tunnel? If so, why, where, and how?
- Have you customized the shift to accommodate the rehabilitation work in the tunnel? If so, why, where, and how?
- Have you customized the end of the shift to accommodate the rehabilitation work in the tunnel? If so, why, where, and how?
- What are the consequences of the rehabilitation work in the tunnel for your workday?
- Are you familiar with any changes at the company level to ease potential challenges with the rehabilitation work?
- What are the most important actions the Municipality of Oslo and the Norwegian Public Roads Administration can implement to manage the tunnel rehabilitation in the best way possible?

- What are the most important actions the Municipality of Oslo and the Norwegian Public Roads Administration can do to make Oslo a better city to transport goods in?

Appendix E. Variation in travel time uncertainties

Data from the Norwegian Public Roads Administration, concerning speed on road links, were used to analyse variations in travel time uncertainties. Travel time uncertainties are here represented by the standard deviation of the hourly average travel speed on the road link Teisen – Ryen (which includes the Bryn tunnel) during morning rush-hours (7–9 AM) and afternoon rush-hours (3–5 PM) in analytically selected two-week periods of 2014–2018, as well as minimum and maximum hourly speed. See tables E1 (southward traffic) and E2 (northward traffic).

Table E1
Average hourly travel speed, standard deviation of hourly travel speed, minimum and maximum hourly travel speed in chosen weeks of 2014–2018 for morning (7–9 AM) and evening (3–5 PM) rush-hours for the road link Teisen – Ryen Southwards. Shaded rows indicate the period with capacity reduction.

Year	Week	Morning rush-hours (7–9 AM)				Afternoon rush-hours (3–5 PM)			Max travel speed
		Average travel speed	Standard deviation	Min travel speed	Max travel speed	Average travel speed	Standard deviation	Min travel speed	
2014	5,6	82	7	62	85	32	10	16	53
	9,10	84	1	80	85	39	12	26	61
	19,21	85	–	85	85	37	8	25	48
	38,39	84	1	82	85	41	6	32	48
2015	5,6	73	2	69	77	27	9	20	51
	9,10	76	2	72	78	28	8	16	41
	19,21	68	6	58	75	19	5	12	25
	38,39	73	2	68	76	23	8	15	41
2016	5,6	72	4	64	76	31	12	19	56
	9,10	44	5	38	52	22	1	20	24
	19,21	41	9	29	57	23	9	11	38
	38,39	32	8	26	52	16	1	15	18
2017	5,6	37	11	25	54	17	1	16	20
	9,10	38	11	26	55	17	1	16	20
	19,21	73	6	57	77	17	3	10	22
	38,39	73	4	63	79	29	9	19	45
2018	5,6	67	3	59	71	33	12	21	58
	9,10	70	2	65	72	28	9	19	52
	19,21	73	3	69	76	18	5	11	28
	38,39	74	4	64	79	34	20	15	75

Table E2
Average hourly travel speed, standard deviation of hourly travel speed, minimum and maximum hourly travel speed in chosen weeks of 2014–2018 for morning (7–9 AM) and evening (3–5 PM) rush-hours for the road link Ryen – Teisen Northwards. Shaded rows indicate the period with capacity reduction.

Year	Week	Morning rush-hours (7–9 AM)				Afternoon rush-hours (3–5 PM)			Max travel speed
		Average travel speed	Standard deviation	Min travel speed	Max travel speed	Average travel speed	Standard deviation	Min travel speed	
2014	5,6	73	12	55	85	82	6	65	85
	9,10	78	7	67	85	85	–	85	85
	19,21	47	18	21	76	85	–	85	85
	38,39	66	11	46	78	83	7	63	85
2015	5,6	63	5	55	69	70	7	55	75
	9,10	61	12	35	71	76	2	73	78
	19,21	43	9	33	61	69	2	66	72
	38,39	64	7	47	71	67	16	33	77
2016	5,6	63	10	42	72	72	3	65	76
	9,10	22	5	15	31	34	7	24	48
	19,21	41	6	34	55	42	8	29	58
	38,39	32	12	17	49	40	20	23	75
2017	5,6	28	8	20	44	33	11	19	48
	9,10	29	9	18	42	34	7	24	45
	19,21	65	9	47	73	74	2	70	77
	38,39	68	6	58	76	78	4	72	83
2018	5,6	62	6	48	69	70	5	57	73
	9,10	63	10	39	72	73	1	71	74
	19,21	61	10	41	72	73	8	52	81
	38,39	63	13	37	81	75	7	55	83

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