

Article

Trialing a Road Lane to Bicycle Path Redesign—Changes in Travel Behavior with a Focus on Users' Route and Mode Choice

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Abstract: Redistribution of space from private motorized vehicles to sustainable modes of transport is gaining popularity as an approach to alleviate transport problems in many cities around the world. This article investigates the impact of a trial Complete Streets project, in which road space is reallocated to bicyclists and pedestrians in Trondheim, Norway. The paper focuses on changes in the travel behavior of users of the street, with a focus on route and mode choice. In total, 719 people responded to a web-based travel survey, which also encompassed an integrated mapping Application Programming Interface (API). Amongst the findings of the survey is that the average length of the trial project that was utilized by cyclists on their most common journey through the neighborhood nearly doubled from 550 m to 929 m ($p < 0.0005$), suggesting that the intervention was highly attractive to bicyclists. Respondents were also asked whether they believe the trial project was positive for the local community, with the majority (87%) being positive or highly positive to the change. The intervention had a considerable impact on users' travel behavior in terms of both frequency and choice of active transportation modes, together with leading to a change in route preferences.

Keywords: bicycle; infrastructure; trial project; complete streets; mode choice; route choice; tactical urbanism

1. Introduction

With limitations in the space available for transport systems in growing cities, policy makers are increasingly seeking ways to encourage city residents to shift away from private motorized vehicles to more space-efficient public and active transport modes. One approach to facilitate this shift has been the redesign of streets in which space is reallocated from motorized vehicles to other users, an approach frequently referred to as Complete Streets, road diets, or lane reductions. Typically, motorized traffic lanes are substituted by a combination of facilities dedicated to public transport, bicycle users, pedestrians, or green space. Koorey and Lieswyn [1] provide an overview of alternative approaches for providing space to different modes of transport within a street cross-section.

Lane reduction projects are generally accepted as beneficial for traffic safety [2–5], and have few adverse impacts on automobile traffic flow [4,6–9]. On one street in San Francisco, the reduction in the number of traffic lanes from four to two and replacement with marked bicycle lanes was found to reduce car volumes by 10%, with the difference redistributed to parallel arterials [8]. Multiple studies have found that cycling volumes have increased in connection with road diets, which could be expected given the typical increase in space available for dedicated bicycle facilities [8–12]. Complete Streets, unlike road diets and lane reductions, do not necessarily imply that vehicle lanes must be

removed, but that the streetscape is altered for the benefit of all road users, which could include lane narrowing, landscaping, resurfacing, or the substitution of verge space with facilities for active transport [13].

Many studies refer to the effects of protected bicycle lanes or separate bicycle paths, which in urban contexts, often involve a road diet or street redesign, as discussed above. Monsere et al. [14] evaluated on-street protected bicycle lanes in five US cities and found that 10% of the cyclists intercepted on these facilities reported that they had previously used a different mode and 24% had changed their route to use the infrastructure. A similar study from Sydney, Australia, found that 40% of respondents surveyed on a newly implemented bicycle path had switched their transport mode to bicycle because of the facility [15]. The cyclists were found to have made a diversion from the shortest path of 351 m on average to take the bicycle path in use. Public response, not limited to cyclists, towards the redistribution of space from motorized vehicles to bicycles has been found to be generally positive [8,9,11].

In general, the majority of the academic literature reveals that bicyclists are willing to cycle longer on separated bicycle facilities in order to avoid major streets [16–20]. However, some studies find the opposite: one study of commuter cyclists in Guelph, Canada, showed a preference for main streets rather than direct off-road paths [21]. However, this was potentially affected by the presence of stairs on some off-road paths, suggesting that not all paths were designed with bicycles in mind.

In the Norwegian context, an early form of Complete Streets solution involving lane narrowing and streetscape alteration first began to be used in the 1970s to reduce traffic speed on major roads passing through small towns [22]. This involved the reconfiguration of a section of major road into a local street better suited to the local town environment, giving birth to the concept of “environmental streets” (*miljøgater* in Norwegian). However, the term was later adopted for road to street reconfigurations where a bypass road was provided nearby, thereby redistributing most of the through traffic. Environmental street projects are intended to have a site-appropriate design with the aim to: reduce traffic speed/volume, improve conditions for bicyclists and pedestrians, and develop attractive street environments that encourage social interaction [22].

Transport infrastructure interventions that require a change in the prioritization from motorized to mixed traffic often cause controversy amongst different stakeholders. As a result, environmental streets have frequently been implemented as trial projects in Norway since the 1990s. The usage of temporary street reconfigurations makes it possible to test the outcome before a political agreement has been reached concerning permanent reconstruction. In a report from the Norwegian Public Roads Administration (NPRA) where 16 trial environmental streets were evaluated, it was concluded that traffic speeds were reduced, improvements were observed in conditions for vulnerable road users, and the streets had become more pleasant and better suited to their location [23].

This paper focusses on changes in mode and route choice following a street redesign that took place in July 2017 in Trondheim, Norway, in which a separated bi-directional bicycle path replaced two lanes of car traffic. It was hypothesized that the reallocation of space to bicyclists and pedestrians would result in an increase in the number of these users along the trial project due to both modal shift and route substitution of existing trips to use the newly implemented facility.

Section 2 below introduces the case study and the methodology that was applied to collect and analyze data. The results are presented in Section 3, followed by the discussion in Section 4, which looks into the following aspects: mode choice, route choice, policy implications, and limitations. The concluding Section 5 outlines the main findings of the study and places them in a broader context.

2. Methodology

2.1. Case Description

The case study location is Trondheim in Norway, the fourth largest metropolitan area in Norway, with a population of 190,000 people [24]. The 2013/2014 National Travel Survey (NTS) shows that

private motorized vehicles are used for 50% of all journeys (8% as passenger), whilst 12% of trips are made by public transport [25]. With a cycling modal share of 9%, Trondheim has one of the highest rates of cycling among the largest Norwegian cities. However, rates vary considerably between summer (12%) and winter (4%) [25]. Relative to other Norwegian cities, the situation for cycling is characterized by reasonable separate infrastructure in a low-density grid outside the city center; however, with a discontinuous inner-city bicycle network [26]. Trips made on foot represent 28% of all journeys in Trondheim, whilst 1% are made by other forms of transport. Although the winters are mild in comparison to other cities at the same latitude (63°N), icy street conditions can typically be expected from late October to mid-April.

A trial Complete Streets project was implemented by the NPRA on a section of Innherredsveien (in blue in Figure 1) in July 2017. Planners intended for the street to continue to be a key corridor for local buses to the east of Trondheim, while at the same time providing a safe and attractive street environment for walking, cycling, street life, and local businesses. The importance of Innherredsveien as the major eastern arterial from the city center to the European E6 highway bypassing Trondheim (connecting the city with the airport) was diminished after the opening of the Strindheim Tunnel (labelled in Figure 1) in 2014. Thus, like some of the earlier environmental streets adopted in Norway in the 1990s, Innherredsveien has a bypass alternative.

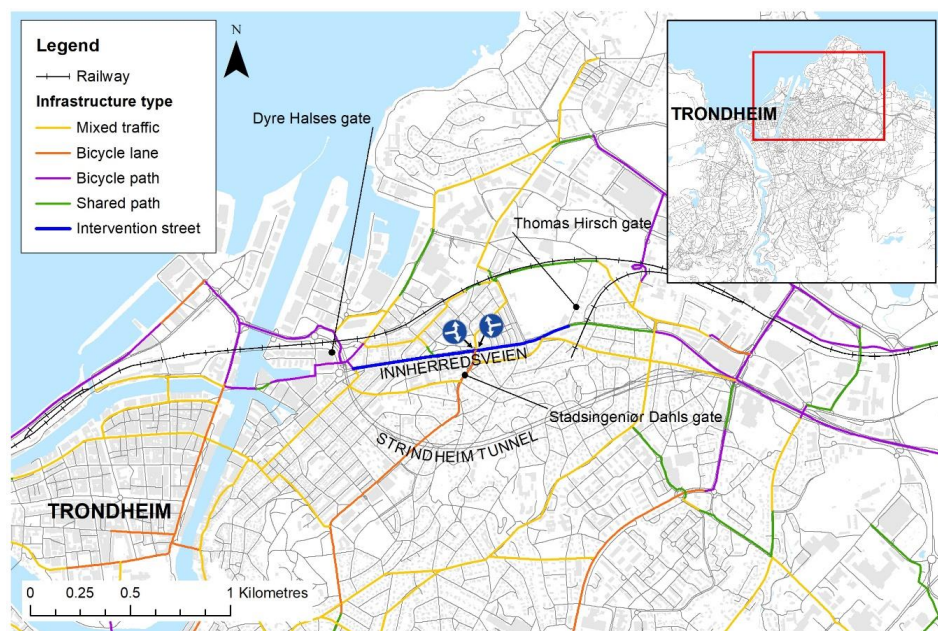


Figure 1. Location of the trial Complete Streets intervention, bypass tunnel, and existing official bicycle infrastructure network. As part of the intervention, it is forbidden to drive through the marked intersection in the middle of the intervention street.

Pre-intervention, there was no bicycle infrastructure on the section of the street where the trial project was implemented. The physical changes included a reduction in the number of traffic lanes from four to two and the implementation of a 1.8 km bidirectional bicycle path using the freed up road space, starting near to the crossing with Thomas Hirsch gate through to the roundabout with Dyre Halses gate. The project also involved the installation of signage midway along Innherredsveien at the intersection with Stadsingeniør Dahls gate (indicated in Figure 1), prohibiting the use of Innherredsveien for through-traffic. The speed limit was reduced from 50 to 40 km/h along the intervention section.

Two forms of physical separation were used: the installation of temporary concrete traffic barriers (along 35% of the section length) and the painting of wide diagonal stripes (65%) for lateral separation of bicycle and motorized traffic (Figure 2). Pedestrians and cyclists were the major beneficiaries for this reallocated space, but the waiting area for public transport users was also increased greatly on the

northern side of the road (since the two removed lanes were on this side of the road). There are three signalized intersections and one unsignalized intersection along the intervention stretch. On one of the intersections, the first traffic lights in Trondheim dedicated specifically to cyclists were installed.



Figure 2. The Complete Streets trial project used two forms of separation: painted horizontal lane markings and concrete barriers [27].

Different street configurations have been debated for Innherredsveien since the bypass tunnel construction commenced and three years following the tunnel's completion, the chosen reconfiguration option was implemented temporarily in order to ensure that it could be reversed. This was due to political disagreement about the project's potential to negatively impact bus travel times and increase car traffic on side streets.

2.2. Data Collection

The principal data collection method used in this study is a web-based travel survey encompassing both a questionnaire regarding demographics and transport behavior, together with an integrated mapping Application Programming Interface (API). The survey was built in and hosted by the website EmotionalMaps.eu. Technical information on the API and data collection approach can be found in a separate study [28]. It was a specific requirement for this paper that the geographic data collected through the API could be connected to the individuals' responses via a unique user ID.

The mapping part of the survey allowed the respondents to draw routes that they most commonly traversed and mark points of interest/concern before and after July 2017 when the infrastructural intervention occurred. This allowed the participants to reflect upon their experiences prior to the change, around one year earlier, with their stabilized post-intervention transport behavior. The questionnaire part of the survey included questions on users' demographics, most common travel behavior, use of the street, perceived safety concerns, opinion of the trial project, and feedback on alternative permanent solutions for the street.

To the authors' knowledge, a participant-recalled route choice approach using web-based/digitally drawn routes has not previously been applied to before-and-after evaluations of bicycle infrastructure interventions. In a review [29], Pritchard explored the available revealed preference methods for studying bicycle route choice, and found only two studies where a web-based mapping approach was used to study bicycle route selection [30,31]. However, neither study applied this methodology for the evaluation of bicycle infrastructure interventions.

The survey was intended for people who had used the street both before and after the changes were made. Recruitment was targeted towards residents in the neighborhood surrounding the intervention street through the distribution of 5000 flyers containing a link to the online survey in June

2018. Approximately 2000 of these flyers were distributed manually to easily accessible mailboxes, cyclists, and pedestrians in the intervention area, businesses, parked cars at a nearby shopping center, and a school. The remaining 3000 were delivered by the Norwegian postal and delivery company Bring to addresses with less accessible mailboxes (particularly apartments).

Alternative forms of recruitment included distribution via various social media websites connected to the area of interest, together with the intranet of the nearby university college.

The initiative's impacts on traffic were evaluated on behalf of the NPRA who commissioned the project, through the collection of information on motorized traffic volumes, average running speeds for public transport on the street, manual observations, and video footage of cyclist and pedestrian activity. A report of the findings was prepared by the consultancy Rambøll [32], without the involvement of the authors of the current study.

2.3. Analysis

2.3.1. Geographic Information Systems (GIS)

A type of revealed preference methodology called participant-recalled route choice was employed, where participants of the survey were instructed to draw the route through the neighborhood that they used most often both before and after Innherredsveien was reconfigured [29]. These routes were subsequently filtered such that only one route per user per time period (before and after) was included. In cases where participants drew multiple routes, the route closest to the intervention was retained for analysis. Routes with a poor spatial quality that could not be reliably matched to the street network were filtered out. This procedure meant that 606 routes drawn by 385 respondents remained for map-matching. Map-matching was performed in ArcMAP 10.6 by creating a 50 m buffer around the selected original routes and executing a shortest path search from origin to destination on the transport network contained within the buffer. The transport network available was dependent on the mode of transport (such that cyclists could not be routed along the road tunnel for instance).

The route choice changes were only considered for a subset of participants who drew a satisfactory route in both time periods (211 panel respondents). The total length traversed by every route along the 1.8 km intervention section of Innherredsveien was then calculated. This allows an approximation of the change in route choice due to the trial project by comparing the intervention length utilized in the two periods.

2.3.2. Statistical Tests

A binary logistic regression model was run to ascertain the effects of users' characteristics on whether they increased their frequency of cycling. It included gender, occupation, mode before, purpose before, and time of day as predictor variables.

Paired-samples t-tests were run to consider whether the distance travelled on Innherredsveien by the bicyclists during their most usual trip significantly increased after the trial project was implemented. A cumulative odds ordinal logistic regression with proportional odds was run to determine the effect of respondents' occupation and transport mode used before the intervention on their agreement with the statement that the project has been positive for the neighborhood (from "Strongly disagree" to "Strongly agree" in a Likert scale style manner). However, the assumption of proportional odds was violated, as assessed by a full likelihood ratio test comparing the fit of the proportional odds model to a model with varying location parameters $\chi^2(20) = 44.541$, $p = 0.001$. Therefore, the responses to this question were rearranged in two alternatives ("Agree" and "Disagree") so that a binary logistic regression model could be applied instead.

Chi-square tests were used to test whether there is a difference in the distribution of the explanatory variables used in the logistic regression models. The same test was also applied to find out whether the change in the distribution of the mode of the most usual trip was statistically significantly different.

The statistical models were run using IBM SPSS Statistics version 25 [33].

3. Results

3.1. Overview

In total, 719 people who have used Innherredsveien after the trial project was implemented responded to the electronic survey during the period it was available online—from the 11th of June to the 15th of August, 2018. The descriptive statistics for the sample are shown in Table 1. It can be seen that more than half of the respondents are male and the majority of them are employed (76.8%). It should be mentioned that the survey sample is not representative of the population of Trondheim. For instance, whilst over 40% of the sample stated that their most usual journeys pre-intervention were made by bicycle, trip-level National Travel Survey (NTS) data from 2014 suggests that only 11.1% of the trips that either started or ended in the basic statistical unit areas adjacent to the intervention were made by bicycle ($n = 396$ trips) [25]. This percentage is only indicative, however, as the trips reported in the NTS concern all trip purposes, while the current study asked respondents about their most usual trip in the vicinity of the trial project. The age variable was categorized in this way in order to achieve statistically significant differences between the sub-groups of cyclists who increased their frequency of cycling in the after period and the sample population of respondents. More about these categories and the increase in cycling can be found in Table 2.

Table 1. Descriptive statistics for the survey sample.

| Variable | Category | Frequency | % |
|-------------------------------------|----------------------|-----------|------|
| Gender | Male | 415 | 57.7 |
| | Female | 304 | 42.3 |
| | Total | 719 | 100 |
| Age | ≤29 | 243 | 33 |
| | 30–34 | 123 | 17 |
| | 35–54 | 274 | 39 |
| | ≥55 | 79 | 11 |
| | Total | 719 | 100 |
| Occupation | Employed | 552 | 76.8 |
| | Student | 116 | 16.1 |
| | Non-employed | 50 | 7 |
| | Total | 718 | 100 |
| Mode of most usual trip “before” | Walking | 144 | 20.9 |
| | Cycling | 287 | 41.6 |
| | Public transport | 147 | 21.3 |
| | Car/Motorcycle/Moped | 112 | 16.2 |
| | Total | 690 | 100 |
| Mode of most usual trip “after” | Walking | 155 | 22.5 |
| | Cycling | 369 | 53.5 |
| | Public transport | 96 | 13.9 |
| | Car/Motorcycle/Moped | 70 | 10.1 |
| | Total | 690 | 100 |
| Purpose of most usual trip “before” | Work | 300 | 43.5 |
| | School | 64 | 9.3 |
| | Personal | 326 | 47.2 |
| | Total | 690 | 100 |
| Purpose of most usual trip “after” | Work | 341 | 49.4 |
| | School | 44 | 6.4 |
| | Personal | 305 | 44.2 |
| | Total | 690 | 100 |

3.2. Mode Choice

Data for the mode choice of the most usual trip on the trial project both before and after the intervention was available for 690 (96%) of the 719 respondents, as the remaining respondents had not used the street prior to the intervention. Survey respondents were asked to report on the mode they used for their most usual trips in the vicinity of Innherredsveien before and after the implementation of the trial project. Cycling was found to be the most common mode pre-implementation (41.6%), followed by public transport users (21.3%) and pedestrians (20.9%), whilst motorists (including a very small number of motorcycle users) represented 16.2% of the sample (Figure 3). In the after period, the dominance of cycling increased to 53.5%, whilst the use of motorized modes of transport decreased to 10.1%. The distribution of the modes used for the most usual trip before the implementation was found to be significantly different from the distribution post-intervention using a chi-square test ($p = 0.0014$).

Figure 3 visualizes the modal shifts (again for the most common trip made in the neighborhood) for the sample population ($n = 690$). The four largest modal changes (each over four percent of the sample population) are public transport to bicycle (6.7%), motorized modes to bicycle (4.5%), public transport to walking (4.3%), and walking to bicycle (4.2%). Figure 3 also visualizes the mode loyalty, or the retention rate of the different modes of transport users, with cyclists' being highest (92% of existing cyclists continued cycling post-intervention), followed by pedestrians (66%), car/motorcycle users (51%), and public transport users (44%). It should be noted that the numbers are only indicative of mode share changes of the street.

Amongst the 690 respondents for whom mode information was available, 15.4% (106) reported that they had changed the mode of their most usual trip to cycling. Of these 106 users, 29.2% (31) had previously used a motorized vehicle, 43.3% (46) had used transit, and 27.4% (29) walked for their most usual trip.

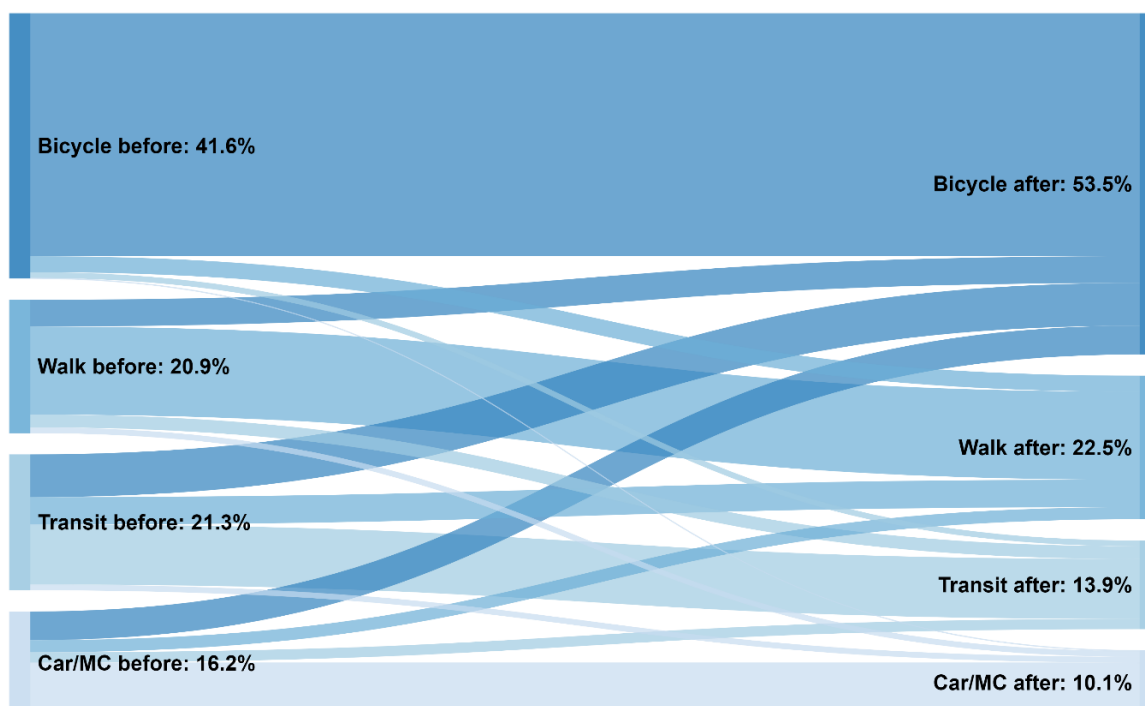


Figure 3. Sankey diagram showing the modal share of survey participants before and after the Complete Streets reconfiguration of Innherredsveien ($n = 690$).

It is worth mentioning that before the intervention took place, there was no bicycle infrastructure on the section of the street where the trial project was implemented, and amongst the 231 cyclists who used Innherredsveien, 65% (151) used the sidewalk, whilst 35% (80) had been cycling on the street.

Amongst all 719 respondents, 577 (80.3%) stated that they use either a normal or a pedal-electric bicycle at least once a month during the warmer half of the year. These respondents were asked about the extent to which their frequency of cycling has been influenced by the implementation of the trial infrastructure project. A total of 272 respondents or 37.8% of the sample increased their frequency of cycling, whilst those who reported a decrease in their frequency of cycling made up only 1.4% of the sample (10). Ten out of the 272 respondents who have increased their frequency of cycling (or 1.4% of all survey respondents) stated that they began to use a bicycle as a direct result of the trial project.

The changes observed amongst survey respondents were also reflected in increases in bicycle traffic volume collected in connection with the NPRA evaluation report. In the report, camera-recorded traffic counts revealed that the number of bicycles had increased at all three observed intersections. From east to west, each intersection's peak hour bicycle volumes (averaged from two hours traffic counting in both the morning and afternoon on two successive days) increased by 95% (592 to 1154), 103% (584 to 1184), and 122% (390 to 866), respectively, from June to September 2017 [32].

A logistic regression model was run, with the intent to estimate the effects of users' characteristics on their frequency of cycling. The model fitted the data poorly and could not explain the variation of the dependent variable (cycling frequency) using the chosen independent variables. No improvement in the overall percentage of predicted cases was found in the classification tables generated with and without the use of the dependent variables by SPSS.

Table 2 presents the proportion of road users who have increased their cycling frequency, split according to demographic attributes, so that more can be understood about the predictive power of these variables.

Table 2. Share of road users who have increased their cycling frequency according to demographic characteristics.

| Occupation | Increased | % | Total |
|-----------------------|------------------|----------|--------------|
| Employed | 210 | 39.2% | 536 |
| Student | 43 | 41.3% | 104 |
| Non-employed | 10 | 20.0% | 50 |
| Age | Increased | % | Total |
| ≤29 | 94 | 41.6% | 226 |
| 30–34 | 55 | 46.2% | 119 |
| 35–54 | 97 | 36.2% | 268 |
| ≥55 | 17 | 21.8% | 78 |
| Gender | Increased | % | Total |
| Men | 146 | 36.4% | 401 |
| Women | 117 | 40.3% | 290 |
| Purpose before | Increased | % | Total |
| Work | 105 | 34.9% | 301 |
| School | 30 | 46.9% | 64 |
| Personal | 128 | 39.3% | 326 |
| Mode | Increased | % | Total |
| Walking | 47 | 32.6% | 144 |
| Cycling | 120 | 41.8% | 287 |
| Public | 57 | 38.8% | 147 |
| Motorized | 39 | 34.8% | 112 |

Chi-square tests were used to determine whether the proportions of people in different strata who have increased their frequency of cycling are significantly different from the sample population of respondents. A statistically significant difference in the proportions was only found for the variable “Age” ($p = 0.037$).

3.3. Route Choice

Of the 211 panel participants who drew (at least) two acceptable routes, 88 used a bicycle in both time periods. There were no outliers in the differences between the intervention length utilized, as assessed by the inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box. The difference scores were not normally distributed, as assessed by Shapiro-Wilk’s test ($p = 0.000$). However, according to the Central Limit Theorem [34], the mean is normally distributed considering the size of the sample ($n = 88$ bicycle users) and therefore a paired-samples t-test could be applied. It was found that bicyclists utilized significantly more of the trial project section of Innherredsveien in the after period (mean = 929 m; standard deviation = 470 m) compared to the before period (mean = 550; standard deviation = 555 m). The change in the mean length of intervention utilized was 379 m (95% CI, 242 to 517 m), which was statistically significant, $t(87) = 5.489$, $p < 0.0005$, $d = 0.59$.

In Figure 4 below, all of the bicycle journeys (a subset of the aforementioned 211 participants’ routes) drawn in both time periods are displayed as the change in the number of trips per street segment before and after the intervention. An increase following the intervention is depicted in green, whilst a decrease is shown in red. Thus, the map illustrates both the modal change to cycling and route substitution from nearby streets (the reduction in the use of parallel alternative routes to Innherredsveien). This map was only prepared for bicycle users due to the small sample size of other user groups (from the subset of 211 ‘panel’ participants who drew two usable routes).

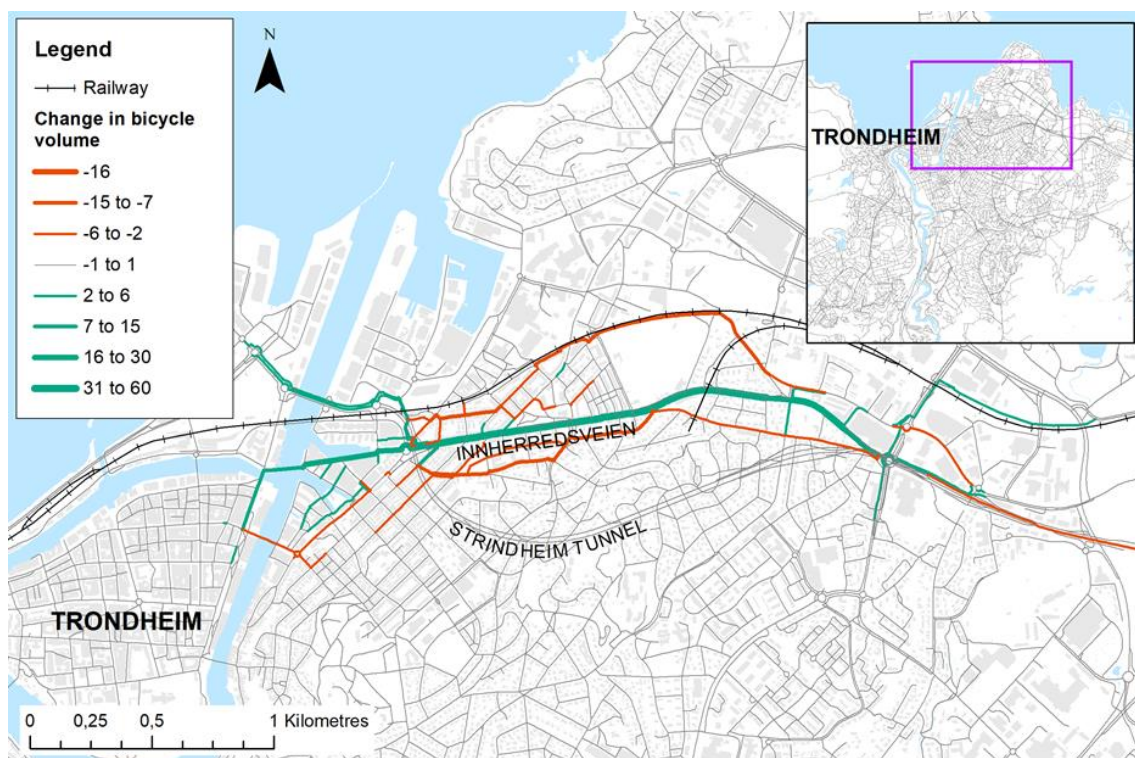


Figure 4. Map showing the change in numbers of bicycle trips on each street segment made by the route choice panel respondents ($n = 211$).

For walking journeys, 32 participants drew valid routes for their most usual trip on or in the vicinity to the trial project in both periods. The average pedestrian utilization of the intervention

section was 441 m, while the corresponding average distance during the after period was 550 m. However, due to the non-normality of the data and the small sample size, the difference between them cannot be assessed for statistical significance.

In the evaluation report, it was concluded that 16% (1500 vehicles/day) of the pre-intervention motorized traffic flow (9500 vehicles/day) has shifted from Innherredsveien to the Strindheim tunnel, while 500 vehicles/day have transferred to other routes. However, it has been found that 800 vehicles/day do not conform to the signage midway along the intervention banning through-traffic, illustrated in Figure 1 [32].

3.4. Attitude

Respondents were asked whether they agree that the trial project has been positive for the neighborhood in terms of noise, safety, air quality, and attractiveness of the urban space. It was found that 87% (627) of the respondents agreed with this statement.

A binary logistic regression model was run, using data for the collected variables to try to explain how the variables affected the participants' attitude towards the project. The binary logistic regression model fitted the data poorly and the explanatory variables could not explain the variation in the users' attitude towards the success of the trial project.

To explore reasons for the poor fit of the model, a further comparison was made between the group of respondents who were positive towards the project, and the total group. Table 3 presents the results of this comparison.

Table 3. The share of road users who reacted positively to the intervention.

| Occupation | Agree | % | Total |
|----------------|-------|-------|-------|
| Employed | 472 | 88.1% | 536 |
| Student | 93 | 89.4% | 104 |
| Non-employed | 39 | 78.0% | 50 |
| Age | Agree | % | Total |
| ≤29 | 198 | 87.6% | 226 |
| 30–34 | 114 | 95.8% | 119 |
| 35–54 | 234 | 87.3% | 268 |
| ≥55 | 58 | 74.4% | 78 |
| Gender | Agree | % | Total |
| Men | 347 | 86.5% | 401 |
| Women | 257 | 88.6% | 290 |
| Purpose before | Agree | % | Total |
| Work | 267 | 88.7% | 301 |
| School | 57 | 89.1% | 64 |
| Personal | 280 | 85.9% | 326 |
| Mode | Agree | % | Total |
| Walking | 135 | 93.8% | 144 |
| Cycling | 260 | 90.6% | 287 |
| Public | 126 | 85.7% | 147 |
| Motorized | 83 | 74.1% | 112 |

Chi-square tests were used to determine whether the proportions of respondents in different strata who agree that the trial project has been positive for the neighborhood are significantly different from the population as a whole. A statistically significant difference in the proportions was not found within the categories of any of the variables, which explains why the model did not explain the variation. Those respondents with a positive attitude towards the project do not seem to differ much demographically from the respondents in general.

4. Discussion

The main goal of this study was to investigate the changes in travel behavior following the implementation of a trial project, involving the reallocation of street space to vulnerable road users on an arterial street in Trondheim, Norway. The principal data collection method used in this study was a web-based survey, soliciting responses from users of the street and residents living in the area of the infrastructural intervention. The results indicated an increase in the frequency of cycling and a route choice shift to the intervention section. However, limited relationships were established between the user characteristics and the change in their travel behavior.

4.1. Mode Choice

It was hypothesized that the reallocation of space to bicyclists would result in an increase in the number of cyclists along the trial project. In the evaluation report commissioned by the Norwegian Public Roads Administration, it was found that the number of cyclists had increased by between 95 and 120% [32]. However, it should be noted that the pre-intervention counts were performed in June, during the university students' summer vacation, which could have negatively impacted cycling volumes given that roughly 20% of Trondheim's population consists of students.

The survey conducted by the authors was launched around a year after the changes took place, a time period that allowed people to adapt to the new infrastructure so that they could be asked about possible mode and route choice changes. Having this information allowed us to get more in-depth insights into the reasons for the increase in bicycle usage. However, it should be noted that long-term impacts can continue to change even after one year. In the British iConnect study, which evaluated the impacts of new active transport infrastructure, living in proximity of the intervention had been related to changes in activity levels only after the second year, but not at the one-year follow-up [35]. Future research could consider reasons for changes in the long-term use patterns.

One of the possible explanations for the observed increase in bicycle volumes is that some of the users of the street changed their transport mode to bicycling. The respondents were asked for the mode they had used for their most usual trip on or in the vicinity of Innherredsveien. It was found that 106 respondents or 29% of the 369 who used a bicycle in the after period had been previously using a different mode. This corroborates the findings from Standen et al. [15] from Sydney, Australia, where 40% of the cyclists riding on the path had been previously using a different transport mode.

Nearly half (43.4% (46)) of those respondents who switched to cycling had previously been using public transport, which is again similar to the results from Standen et al. [15], where 59% of the intercepted cyclists reported that they had used public transport prior to the intervention. However positive the increase in cycling is, the shift from transit to bicycle use is not the primary intention of the intervention, as it does not contribute to limiting car use, a principal goal for cities in the Norwegian National Transport Plan [36].

In addition to the public transport to bicycle modal shift, Section 3.2 reveals three other modal shifts comprising over 4% of the sample population: private cars to bicycle (4.5%), public transport to walking (4.3%), and walking to bicycle (4.2%). A clear indication of the intervention's success in terms of cycling is that it has attracted substantial numbers of users from all other modes; however, the intervention can also be seen to improve walking conditions, since there are also substantial numbers of users switching from public transport to walking. This could be explained by the freeing up of space on the relatively narrow footpath on the north side of Innherredsveien after cyclists received their own bicycle path. Public transport is the mode that contributes most to the growth of both walking and cycling. Transport mode loyalty or mode retention rate is the percentage of a transport mode's users who continue to use the same mode following the intervention. This is visualized in Figure 3, in which cyclists are observed to have the highest retention rate before and after intervention (92%), followed by pedestrians (66%), car/motorcycle users (51%), and public transport users (44%).

An insight into these findings was provided by Börjesson and Eliasson [16] in a study related to the cost-benefit analysis of cycling investments. The cross-elasticity between car and bicycle use in Sweden was estimated to be low in an indirect way. A stated preference experiment was conducted where the respondents had to choose between bicycle and their second-best mode. It was found that public transport was the alternative for 87% of the respondents, whilst car was the preferred second option for the remaining 13%. Börjesson and Eliasson [16] concluded that amongst transport users who may shift their mode to cycling as a result of bicycle infrastructure improvements, only 10–15% of them would have previously used a car. However, it was noted that their conclusions are context specific, as Stockholm, where the study was performed, has a well-functioning public transport system.

Evidence of the low cross-elasticity between car and bicycle use was also provided by Song et al. [37], who investigated the modal shift resulting from bicycle infrastructure implementation in three cities in the UK using a quasi-experiment panel study. They found that about 20% of the respondents had switched from driving to active transport modes, but also that a similar percentage had done the inverse shift.

Van Goeverden [38] reviewed studies that had assessed bicycle infrastructural interventions in the Netherlands and Denmark. One of the aspects that was considered was mode choice, for which seven studies that had used travel behavior surveys were found and summarized. The results indicated that the shifts from driving to cycling had been minimal. Van Goeverden et al. [38] noted that in some of the referenced studies from Denmark, the changes from public transport were significantly larger than the shift from car-use. These findings collaborate the results about mode shift from the current study.

It has also been of interest to find out whether the improved cycling conditions may have had an impact on users' overall frequency of cycling. Only ten respondents or 1.4% of the sample reported to have decreased their cycling frequency, whilst 37.8% (272) reported an increase, 41% (295) had not changed frequency, and the remainder used a bicycle less than once per month in the after period and were therefore not asked this question. The large number of respondents that reported an increase in their overall cycling frequency (47% of those who had received the question) corroborates findings from a similar study in the USA. The US study evaluated eight newly implemented protected bicycle lanes, with nearly half (49%) of the respondents reporting an increase in personal cycling frequency along the protected bicycle lanes, whilst nearly a quarter (24%) reported an increase in their overall frequency of cycling as a result of the protected lanes [14].

The survey also reveals that 10 respondents amongst those 272 who reported an increase in cycling frequency (or 1.4% of the total sample) had begun using a bicycle as a direct result of the trial project. This finding is significantly lower than the aforementioned protected bicycle lane study, in which the proportion of users who began cycling after the interventions ranged from 6 to 21% across the eight examined locations in the USA (10% on average) [14]. Different contextual conditions for cycling in Norway and the USA could explain some of this variation, as cycling rates in Norway are generally higher (8% versus 1% of all trips nationally) and the provision of bicycle infrastructure is more commonplace [25,39].

The fact that the model using the demographic variables given in Table 2 could not predict the increase in the frequency of cycling of the respondents can be explained by the lack of a significant difference between the sample's demographic subsets compared to the population as a whole. As mentioned in Section 3.2, the only significant difference found was for the variable "age" ($p = 0.037$). This suggests that young people (less than 34 years of age) exhibit a significantly higher propensity to increase their frequency of cycling in response to the street redesign than the older respondents.

The high reported increase in cycling and low variation in change of cycling frequency across the sample's different demographic groups can be indicative of a trial project that appeals equally to all users. In other words, women and men exhibit approximately equal propensity to increase their frequency of cycling after an implementation of this kind of infrastructure. This result differs from what was reported by Standen et al. [15] for Sydney, Australia, where commuters who had changed mode to cycling in response to the opening of a separated bicycle path were more likely to be female.

Similar conclusions were made in a study that used survey data from the evaluation of protected bicycle lanes in five cities in the USA [40]. Dill et al. [40] concluded that female cyclists have a greater propensity to increase their overall cycling frequency because of protected bicycle infrastructure. The discrepancy between the findings of the current study and those from the USA and Australia may again be explained by contextual differences between Norway and those countries. Utility cycling is more male-dominated in the USA (75% male) and Australia (79%), whilst in Scandinavian countries, it is nearly equal, with males making 56% of cycling journeys in Norway [25,39].

4.2. Route Choice

A possible reason for the observed increase in bicycle volumes on Innherredsveien is that existing cyclists decided to change their route so that they could use the trial section. To test this hypothesis, survey respondents were asked to draw the route they had used for their most usual trip on or near Innherredsveien both before and after the street intervention. The length of the trial project section of Innherredsveien that was utilized by the participants before and after the changes were implemented was one means to approximately quantify the route choice changes. Participants who increased their utilization of the street post-intervention can be thought of as being attracted to the intervention. This was expected of cyclists who previously rode on alternative streets or without bicycle infrastructure in Innherredsveien and had now received a separated bicycle path. The opposite applies for those who decreased their utilization of the intervention (which could be expected for car users who now are forbidden from driving the full length of the street).

The significant increase in mean distance that bicyclists were riding on the trial section (379 m; 95% CI, 242 to 517 m) is indicative of an attraction to the Complete Streets initiative amongst cyclists. This supports findings from existing literature, in which between 24 to 48% of bicyclists have been found to change their routes to use the newly implemented bicycle infrastructure [14,15].

The change in bicycle route choice is illustrated in Figure 4, in which it is apparent that the intervention street Innherredsveien greatly increases in popularity amongst cyclists at the expense of neighbouring parallel streets. The parallel streets are mostly part of the existing bicycle network shown in Figure 1 and witness a decrease in usage (depicted in red). This change in route choice preference, also called route substitution, is a major contributing factor to the increase in volumes in the trial project. Figure 4 illustrates all bicycle journeys from the two time periods made by the panel respondents. Therefore, those cyclists who used a different mode earlier have only one route depicted in the figure. Thus, the overall increase in cycling is also illustrated to some degree in Figure 4 through the larger number of bicycle trips made post-implementation, which is represented by generally thicker lines in green than red (although this is not the primary intention). Given the clear impact the intervention has had on the route choice of existing bicycle users, it is recommended that intervention section traffic counts alone are not used to assess the impacts on bicycle mode choice (as was done in NPRA's evaluation report). Should a traffic counting approach be used, parallel streets should always be considered at a minimum to gauge the extent to which route substitution is present [20,41–43]. It is therefore recommended that traffic counts on an intervention street should not be used to assess the impacts on mode choice, given route choice is clearly shown to be affected as well.

The provision of high quality infrastructure on major arterials to the city center is important as it offers cyclists a more direct and faster route, while at the same time improving their perceived feeling of safety. Interventions like this project that deliver improved connectivity are likely to be of more value to users than projects which only improve isolated road segments. By offering a holistic bicycle network with minimal discontinuities, users with a lower tolerance for traffic interaction are empowered to switch to cycling.

Regarding the route choice of motorized vehicles, the evaluation report concludes that 16% of the former motorized traffic (9500 vehicles/day in total) has shifted from Innherredsveien to the Strindheim tunnel, which is a desired consequence of the project [32]. This substitution of route assists in the minimization of congestion, something that is especially important for buses, for which the street

is a key corridor. The tunnel was built in 2014 specifically to relieve the intervention street of traffic issues, and the change could therefore have been made upon the tunnel's opening. The availability of bypass alternatives is an important prerequisite for the implementation of road restrictions in central urban areas, such as the Complete Streets solution investigated in this study. However, the report also notes that 500 vehicles/day or 5% of the former traffic volume (9500 vehicles/day) have transferred to streets other than the bypass tunnel, potentially due to having a destination not well connected by the tunnel following the through-traffic closure. In San Francisco, the replacement of two out of four traffic lanes with marked bicycle lanes was found to reduce car volumes by 10%, with the difference redistributed to parallel arterials [8]. Sallaberry did not, however, investigate whether a mode shift had occurred [8].

Despite the total decrease in motorized volume, it has been found that 800 vehicles/day did not conform to the prohibition [32], something which could be regulated by the authorities in order to reduce traffic volumes to the extent intended.

Considering that participants could only draw one route and one mode for each time period, the mapped data in Figure 4 only reflects the primary mode and route for transport through the neighborhood. Shorter or less frequent journeys made by participants are thus not well represented by the collected data, and the low numbers of routes drawn with sufficient quality for mapping (from 211 of 719 participants) in both time periods limited the analysis scope.

4.3. Policy Implications

The policy implications of the study are related to the outcomes of planning process issues, the detected mode shift changes, and the public approval of the project.

Concerns have been expressed by various stakeholders during the political planning process. For instance, the public transportation authority was concerned that the reduction in the number of traffic lanes in Innherredsveien would result in a reduced capacity and therefore unnecessary delays for public transport. There have also been disagreements between city and county politicians concerning the role of the street. Therefore, after over four years of debate, the project was implemented temporarily so that it could be reversed in case it did not deliver the expectations.

The evaluation report revealed that the concerns were not realized as the average travel time for buses had decreased and the motorized traffic on the intervention street had reduced [32]. Motorized traffic was to a large extent shifted to the bypass tunnel as originally intended. At the same time, the trial project provided a considerable improvement in the conditions for vulnerable road users and a resultant significant increase in their numbers.

The survey sample's four largest modal shifts all involved a change in mode to cycling or walking. This mode shift, however, was not ideal from a sustainability perspective as the main contributor to the increase in the bicycle share was shifts from public transport rather than private car users. This suggests that initiatives such as the one presented in this study are not sufficient alone to achieve the sustainability goal of reduced car use. Such a shift away from cars is desirable, however, from an urban planning perspective due to improved public health outcomes, and reduced congestion and local air pollution. At the global scale, a modal shift away from cars contributes to decarbonizing the transportation sector, which is critical given the ever-mounting pressure to act on climate change. Other policy tools are likely needed to achieve a modal shift away from cars, such as the removal of parking places, higher parking fees, road pricing, higher fuel taxes, etc. The challenge remains, however, to achieve a combination of policy measures that are politically acceptable.

As the initial intention of the trial Complete Streets project was to create improved transport conditions and a more attractive street environment for the residents and other users of the street, it was expected that the general public would be generally satisfied with the changes that have taken place. The public response towards similar redistributions of space from motorized vehicles to bicyclists has been found to be generally positive in the US [8,9,11]. The high approval rate of the project amongst survey participants (87%) and positive contribution towards sustainability goals can have

policy implications, such as permanently redesigning the street in favor of vulnerable road users or encouraging other cities to consider similar initiatives.

The temporality of trial projects can be advantageous when political disagreement stops the initiative from being implemented, and has in this case demonstrated for stakeholders that the project did not result in unacceptable disadvantages for any transport modes. This does, however, require the trial project to be sufficiently well planned to ensure that the temporality itself does not adversely affect the traffic outcome and thus poorly represent a future permanent solution. It is, however, an additional cost in terms of time and materials to rebuild a road twice, even if the temporary solution has less impact than the permanent solution (presuming it is built).

4.4. Limitations

It was assumed that the increase in the utilized length of the trial project section of Innherredsveien has been due to cyclists changing their route or mode because of the improved conditions of the street. However, there may have been other reasons for some of the respondents' decision to change their route, such as a change of the most common trip origin or destination.

Another aspect of the current study that can have impacts on the results is that only the most common trips on Innherredsveien were analyzed, while the rest of their journeys were not studied. Future intervention investigations of route and mode choice can look into all the trips that users make in connection with changes in transport infrastructure. Heinen et al. [44] investigated the modal shifts resulting from new bicycle infrastructure in Cambridge (UK) using a four-year quasi-experimental cohort study and found that partial modal shifts were more common than full modal shifts. It is reasonable to assume that people use different modes for their different trips and hence studying only the most usual one does not give complete information about the changes in users' behavior. It should be noted that this study is based on the post-implementation evaluation of a single (and temporarily deployed) Complete Streets project, with its associated contextual factors, and is therefore only indicative of the impacts of this type of trial project. Further evaluations of trial projects are recommended so that a more complete picture of the effects of such projects can be acquired.

It should also be noted that cyclists were overrepresented in the sample, with 65% (468) of the respondents reporting that they use a bicycle at least once a week during the warmer half of the year. Having in mind that the cyclists are one of the major beneficiaries of the street reconfiguration, self-selection bias may have influenced the results of the study. The overrepresentation of cyclists was in part due to the nature of the recruitment process for the survey. Besides the delivery of flyers to households in the area around implementation and the other alternatives mentioned in Section 2.2, the recruitment also included advertisement via a social media interest group for cycling in Trondheim and the manual distribution of flyers to bicyclists using the cycling path.

Respondents were asked to recall details from their travel behavior from a year earlier, before the implementation, which is associated with a poorer accuracy compared to journeys conducted more recently [29]. Had it been known some time in advance of the intervention commencement, a before-and-after cohort or cross-sectional design could have been applied to achieve more accurate responses.

5. Conclusions

Using several data sources, it was found that the trial Complete Streets project has resulted in significant changes in users' mode and route choice behavior.

Nearly half of the cyclists increased their frequency of cycling due to the trial project implementation. This corroborates existing research on improvements in the conditions for active transport modes by showing that these types of changes can stimulate people to cycle and walk more. With respect to the findings on the modal shifts to cycling and walking, it can be concluded the observed change is positive, but that more can be achieved in terms of sustainability if the increase in cycling is primarily the result of a decrease in private car trips.

The project's closure to through-traffic was found to have the desired effect on motorized users as part of the pre-intervention traffic flow shifted to the bypass tunnel. The availability of a bypass has contributed to the success of the project by helping to avoid congestion problems and to maintain the bus service in order.

The length of the trial project utilized by cyclists in the after period has increased significantly, suggesting that the redesign of the street was highly attractive to this group of users. This paper demonstrates significant route choice changes by cyclists who substituted their use of other lower standard bicycle network routes nearby with the intervention street's separated bicycle path.

The high approval rate amongst respondents suggests that the project has been successful in satisfying the needs of residents and users. This demonstrated to the various stakeholders that the solution is well-accepted by the public and hence its permanent implementation is justified.

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