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Societal costs and benefits analysis of integrating bike-sharing systems with public transport: A case study of the public transport bike ('OV-fiets') in the Netherlands

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ABSTRACT

Integrating bike-sharing programs with public transport enhances accessibility and car-independent mobility, yet a comprehensive societal cost-benefit analysis of this integration remains scarce. This study addresses this gap by conducting an ex-durante analysis of the OV-fiets program in the Netherlands, a station-based round-trip bike-sharing system designed to improve last-mile connectivity for train commuters. The analysis reveals that in the average (balanced) scenario, the net present value (NPV) of the OV-fiets scheme is positive, with a benefit-cost ratio (BCR) of 1.5. This indicates that the scheme has benefited the Dutch society over the 20-year period (2004–2023). In the pessimistic scenario, the NPV remains slightly positive with a BCR of 1.1. This implies that even under the least favourable conditions, where high costs and low benefits are assumed, the scheme still slightly exceeds the break-even point. Conversely, in the optimistic scenario, the BCR rises significantly to 2.4. Primary benefits include enhanced accessibility, reduced road congestion, and improved health outcomes. This research underscores the considerable societal value of the OV-fiets program in the Netherlands, warranting continued investment in the program and emphasising the need for ongoing bicycle safety measures and infrastructure improvements. However, OV-fiets might be successful in the Netherlands; our analysis also shows that copying it into other contexts is not straightforward. The seamless integration of bikes with trains is crucial, and the operators should be able and willing to accept operational losses.

1. Introduction

Integrating bicycle and transit systems is a promising approach to enhance accessibility and the appeal of car-independent mobility (Kager, et al., 2016; Tønnesen, et al., 2021; Spierenburg, et al., 2024). Van Mil et al. (2021) found up to 40 factors that should be considered when planning, implementing and operating such an integration, whereby they stress the effort needed for good last mile (from station/stop to the activity destination) solutions. Shared bicycle schemes could offer such a solution, given the interests of (potential) users for cycling over other modes for these trips (Shaheen, et al., 2013; Oeschger, et al., 2020; Torabi, et al., 2022; Montes, et al., 2023).

The interplay between bike-sharing systems and public transport, exploring whether these systems are complementary or competitive, is not straightforward. Cui et al. (2023) and van Marsbergen et al. (2022) found that bike-sharing systems compete with public transit. The competition arises because riders prioritise the cost-effectiveness and flexibility bike-sharing services offer over time savings associated with public transit. In a distinct context, Qiu and Chang (2021), focussing on small cities in the USA, identified a complementary role, particularly in urban cores. Similarly, Montes et al. (2023) found a complementary relationship between integrated systems. Kong et al. (2020) analysed trip data from the largest bike-sharing fleets in four USA cities. Their research suggests that the location of the trip does not singularly determine the relationship; instead, factors such as when (weekday/weekend/time of day) and who (subscriber/customer) play a role. Their data showed that a high percentage of weekday subscribers contributed to a more integrated usage pattern. So, implementing an integrated bicycle transit system comes with uncertainty about complementarity. In addition, these systems involve significant costs, and there is a lack of studies that comprehensively identify and quantitatively assess the societal impacts of this integration (Oeschger, et al., 2020; van

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Marsbergen, et al., 2022).

In response to the knowledge gap, this paper conducts an ex-durante comprehensive societal cost-benefit analysis (SCBA) of a fully integrated bike-sharing system with train transport, the OV-fiets in the Netherlands. By adopting a societal perspective, this study aims to evaluate social, economic, and environmental impacts for all stakeholders involved. In section 2 we explain why we have chosen SCBA as our evaluation method.

Conceived in 2000 by the Dutch Rail Track Manager (ProRail) and the Dutch Cyclists' Union (Fietsersbond), and further developed by NS Dutch Railways through its sub-company NS Stations since 2008, OV-fiets (Dutch for "public transport bicycle") is a station-based bike-sharing program where users must return bicycles to the same station they rented from (Ploeger & Oldenziel, 2020; Wilkesmann, et al., 2023). Designed to improve last-mile connectivity for train users in the Netherlands, it addresses barriers such as distant train stops, costly taxis, and misaligned bus schedules, while encouraging increased ridership and expanding train station catchment areas (Villwock-Witte & van Grol, 2019). As of 2023, OV-fiets has expanded to include 22,500 bicycles at 288 locations nationwide. That year, the program facilitated 5.9 million rides, with rentals offered at a flat rate of €4.45 for 24 h, extendable up to 72 h (NS, 2024). Surcharges apply if the 72-hour limit is exceeded or if the bicycle is returned to a different station.

OV-fiets and privately owned "second bicycles" dominate the 10 % modal share of last-mile trips from Dutch train stations (Shelat, et al., 2018), while other shared schemes, such as Mobike and Donkey Republic, play marginal roles in the Netherlands (Ma, et al., 2020). The pricing model chosen suggests that the intention of NS with OV-fiets is to serve the train traveller that goes once or with a low frequency to a specific destination and requires last-mile transportation. For these travellers, OV-fiets is a handy tool that, without worrying about the rental time (24 h is a long period), gives them a convenient, relatively cheap, and flexible way of last-mile transportation. For regular commuters, one would expect a monthly or yearly subscription model offering better value for repeated use—but OV-fiets does not work that way. Despite this, survey results reported by Pluister (2022) show that most OV-fiets users ride it frequently, with around 40 % using it more than once a week—typical of commuting behaviour. While cheaper alternatives exist, such as owning a second bicycle or using a subscription for the bus, tram, or metro, the regular use of OV-fiets suggests that users are willing to forgo potential cost savings. This may be due to factors such as the convenience and flexibility of the system, the ability to avoid rigid bus or tram schedules, the health benefits of cycling, or the desire to avoid the hassle and theft risk associated with leaving a second bike at the station.

The structure of this paper is as follows: Section 2 presents the methodology employed in the study. In Section 3, a conceptual framework is formulated, identifying the dominant societal impacts and affected parties, thus guiding the subsequent analytical process. The assumptions and inputs for the analysis are discussed in Section 4: Computational principles. After that, Section 5 presents the societal cost-benefit analysis results for different scenarios, including sensitivity analyses. Finally, Section 6 discusses the findings, concludes the study, and offers recommendations and suggestions for future research.

2. Methodology

The overarching methodology employed is a societal cost-benefit analysis (SCBA). We followed the standard approach as explained in the work of Boardman et al. (2018). This analysis also adheres to the state-of-the-art Dutch Societal Cost-Benefit Analysis guidelines (Romijn & Renes, 2013). Unlike a financial cost-benefit analysis (CBA), which evaluates financial impacts from a private or organizational perspective, an SCBA extends the scope to include a broader array of societal effects, such as environmental, social, and public health impacts. This ensures that both market and non-market effects are accounted for in decision-making. We have chosen ex-durante SCBA because we were interested in the aggregated full social value of OV-fiets, from its conception to the present. SCBA can estimate this social value because, within this systematic approach, both investment and operational costs and all societal effects of a project or service are estimated and made comparable in monetary terms. The monetary value of social effects is based on the willingness-to-pay (WTP) for a positive impact and willingness-to-accept (WTA) a monetary reward for a negative impact. So, the outcome of this OV-fiets SCBA, the Net Present Value (the summation of the costs and benefits in monetary terms), gives an idea of the social value OV-fiets has had and which social effects were more important in contributing to this value than others. We realize that SCBA has received severe criticism from academics. Koopmans and Mouter (2020) give a comprehensive overview of the main critique which ranges from theoretical objections to debates about specific monetary valuation methods and outcomes. It goes beyond the purpose of this paper to discuss SCBA and its critique in depth. One of the disadvantages of SCBA is the uncertainty of the outcome. SCBA requires many rough assumptions, such as cost estimates, environmental impacts, discount rates, WTP and WTA values. To deal with this huge uncertainty we have chosen a scenario approach, categorising scenarios into three groups: 'pessimistic' (the lower bound of the estimated benefits is combined with the higher bound of the estimated costs), 'balanced' and 'optimistic' (see section 2.4). We have chosen this straightforward scenario approach because it is a relatively simple and comprehensible approach to depicting the uncertainties of our SCBA outcome and its implications. More sophisticated approaches, such as Monte Carlo Analysis, would not add more insights into the uncertainty we view. Additionally, these methods are difficult to apply because of lacking data, for example, about the distribution of most of the input parameters into the SCBA.

Given the gradual development of OV-fiets and the availability of relevant data, this study considers an analysis period from 2004 to 2023. This 20-year timeframe captures the critical phases of implementation, expansion, and operational stabilisation of the OV-fiets system, providing a comprehensive basis for evaluating the investment and operational dynamics. To account for the time value of money, a discount rate of 2.25 % is used in this analysis, as prescribed by Werkgroep Discontovoet (2020).

Fig. 1 presents the most important (aspects of the) methods that are applied. All details can be found in Mbugua (2024).

2.1. Identification of societally relevant impacts (conceptualisation)

To identify societally relevant impacts/factors that should be considered in the SCBA, scientific literature related to cost-benefit analyses of cycling initiatives was first explored. This search used the terms "('Cost benefit' OR 'cost-benefit analysis' OR 'benefit cost') AND ('bicyc*' OR 'bike' OR'cycl*')" on Scopus, focusing on information within abstracts, titles, and keywords, and limited to articles. Backward and forward snowballing techniques were also employed to uncover additional sources, ensuring a comprehensive understanding of existing research. Additionally, non-peer-reviewed literature, including company reports, government reports, white papers, master's and PhD theses, and case studies, was reviewed. In this conceptual phase, three experts were consulted to provide qualitative insights and enhance the understanding of the societal impacts of OV-fiets. One expert was a 'Transport Policy' professor at Delft University of Technology. One was a researcher at Eindhoven University of Technology who specialised in the history of sustainable urban mobility. The last was a researcher at NS Stations specialised in first- and last-mile issues. These expert consultations aided in validating the factors identified from the literature and uncovering new ones. They also helped establish a reference case for the societal cost-benefit analysis (SCBA), which serves as the benchmark for evaluation. The reference case describes the situation as if no OV-fiets were introduced in the Netherlands since 2000. Furthermore, the interviews provided insights into effects that could not be quantified from

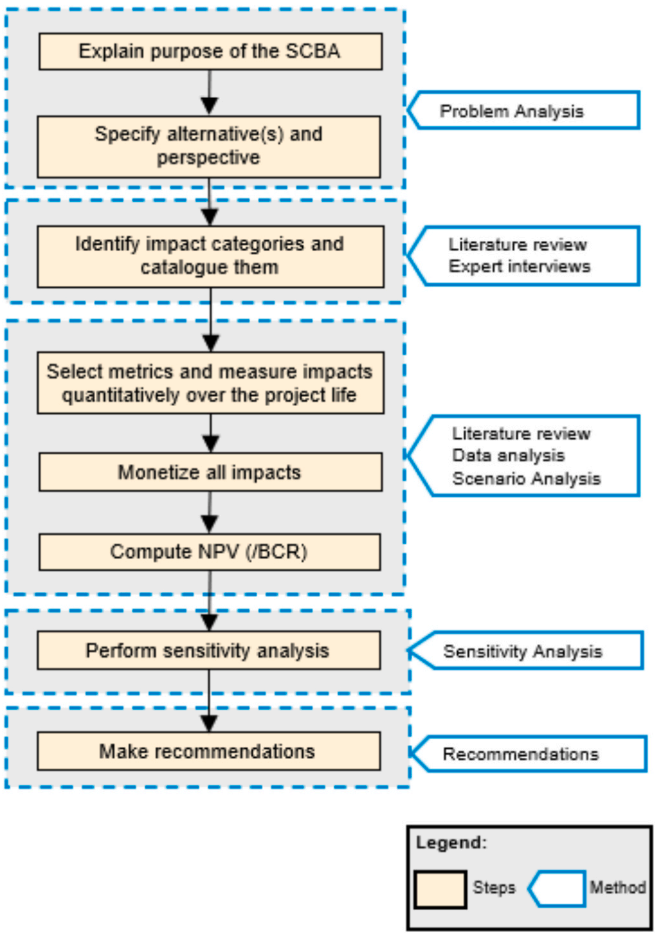

Fig. 1. Steps for conducting a societal cost-benefit analysis and the associated methodologies employed (
Adapted from Boardman et al. (2018)).

existing literature. While these effects were not monetised, their potential impacts are elaborated upon in this paper, enriching the analysis.

2.2. Quantification and monetisation of effects

Given the limited literature on the specific effects of OV-fiets on travel behaviour, scientific literature was explored to uncover the impact of other shared bicycle systems globally on travel behaviour. Eventually, only studies conducted in the Netherlands on other bike-sharing systems were incorporated into the computation model due to the similar context. To account for potential deviations from the actual OV-fiets context, we tested the influence of these assumptions using a sensitivity analysis (see Section 2.4).. This search was conducted on Scopus, focusing on information within abstracts, titles, and keywords using the search terms "Shar* AND ('bicyc*' OR 'bike' OR'cycl*') AND ('mod* shift' OR'mod* choice')". Backward and forward snowballing was employed to uncover additional sources. Grey literature was also used to quantify the effects of OV-fiets. Reports from transport research consultancies in the Netherlands, including CE Delft, Decisio, Significance, MuConsult, and TNO, were explored to determine the effects of OV-fiets on specific factors. These reports were located using Google. Additionally, company reports from NS and published data from the Central Bureau of Statistics (CBS) and Rijkswaterstaat Environment —the executive agency of the Dutch Ministry of Infrastructure and Water Management—were incorporated. These sources provided valuable insights into practical applications and real-world data often not covered in academic studies. Notably, given the national scope of this study, impacts were estimated using national average values for key parameters. As a result, regional and demographic variation was not explicitly included in the analysis.

2.3. Data analysis

This study evaluates the effects of the OV-fiets program using existing data sources. First, quantitative data were synthesised from literature sources to assess the impact of OV-fiets on travel behaviour and relevant societal factors (see before). Additionally, data were extracted from OV-fiets Beschikbaar (2024), an open-source, publicly available database that provides detailed information on the number of OV-fiets bikes by location and location type. These data were used to estimate the operational and maintenance costs associated with the program. While no major data inconsistencies were identified during the analysis, the integrity of the data was considered throughout, and sources were selected based on their use in Dutch policy and planning contexts. To account for data-related uncertainties, particularly where assumptions were required, a scenario-based approach and sensitivity analysis was used to assess the robustness of the results (see Section 2.4).

2.4. Scenario analysis and sensitivity analysis

In a societal cost-benefit analysis, inherent uncertainties exist in estimating costs and monetised effects (Romijn & Renes, 2013). These uncertainties were addressed through two approaches: scenario analysis and sensitivity analysis. The scenario analysis categorised the range of results into three scenarios: pessimistic, balanced and optimistic. In the pessimistic scenario, the lower bound of benefits was combined with the higher bound of costs; the balanced scenario used the median values; and the optimistic scenario paired the higher bound of benefits with the lower bound of costs. The aim was to realistically delineate the solution space and explore the range of potential outcomes.

The sensitivity analysis tested the robustness of the results against key assumptions in the computational model. Specifically, assumptions related to modal shift (including new trips) and trip characteristics were varied. For modal shift, the share of OV-fiets trips coming from each alternative mode—including new trips—was adjusted within plausible bounds identified in the literature (see Section 2.2), while the remaining shares were normalised to ensure the total summed to 100 %. For trip characteristics, parameters affecting the relative attractiveness of OV-fiets—such as average speed, out-of-vehicle time, and user costs—were adjusted. In each case, the resulting Benefit-Cost Ratio (BCR) was evaluated to assess the sensitivity of the outcomes across the three scenarios.

3. Conceptual framework and reference case

In this section, a reference case is established, and the conceptual framework highlighting the societally relevant impacts of OV-fiets is presented.

3.1. Reference case

The base case or reference scenario describes what would have happened if the OV-fiets had not been implemented. Ploeger and Oldenziel (2020) reveal that the initiative was rooted in longstanding political efforts to enhance public transport accessibility through cycling, albeit amidst debates over its necessity vis-à-vis market-driven solutions. While OV-fiets initially encountered resistance, particularly from existing bicycle rental services operated by small independent entrepreneurs, its innovative model, focusing on high rental volumes at minimal profit margins and primarily targeting commuters, differentiated it from traditional rental businesses (Ploeger & Oldenziel, 2020). The reference case is conceptualised as follows. Without public investment in OV-fiets, market-driven solutions would likely have taken precedence with different priorities, such as maximising profitability and/or catering to specific user demographics, as evident in various bike-sharing systems worldwide (Shaheen, et al., 2010).

3.2. Conceptual framework

Fig. 2 depicts a simplified conceptual framework outlining the effects chain from implementing OV-fiets. A more comprehensive and detailed framework can be found in Mbugua (2024). The framework shows how OV-fiets enhances the appeal of the bike-train combination primarily, leading to changes in travel behaviour such as mode shifts and newly generated trips. These behavioural changes generate welfare changes across four levels. Individual users experience improved accessibility thanks to the OV-fiets measured in increased consumer surplus. Society will experience road safety and environmental and road congestion impacts mainly due to the modal shift from car to bike-train combination. Governments will experience, on the one hand, car levies revenue losses due to less car use and, on the other hand, can save money on road maintenance. Finally, the operating companies will experience profits or losses, and companies, in general, will experience higher productivity from their healthier employees if they use bikes more for commuting. Factors that are not quantified and monetised are indicated in blue as excluded factors. Factors such as perceived road safety, subjective (psychological) well-being, travel-time reliability and the option value—the value of having the option to use OV-fits even if it is not used—were excluded due to monetisation challenges and the assumption that these societal impacts are not the dominant ones. Including these factors would likely enhance the estimated benefits (in Section 6 we will return to the issue of omitting certain impact categories).

4. Computational principles

In this section, all the inputs and assumptions adopted for the analysis are presented.

4.1. Travel behaviour changes due to OV-fiets

We use the number of OV-fiets rides reported in NS Annual reports (Fig. 3). Based on an interview with NS, it was confirmed that a "ride" is equivalent to a rental—registered each time a bike is checked out. As OV-fiets bikes are not equipped with GPS trackers, neither the number of trips nor the distance travelled within the rental period is recorded. While the system does not capture short or aborted trips explicitly, such cases are unlikely to significantly affect the data. Most bikes are located in manned stations, where users can inspect and replace faulty bikes before completing the rental. The presence of staff also supports regular maintenance and simple checks, reducing the likelihood of users encountering unusable bikes. In contrast, multiple trips may occur within a single rental period but are not individually recorded. For example, a bike rented for multiple destinations—or even over multiple days—would still be recorded as a single ride. To address this, we draw on survey data from Pluister (2022), which indicates that 70 % of users have one destination (implying two trips: outbound and return), 17 % have two destinations (three trips), and 12 % have three destinations (four trips). Using this distribution, we calculate a weighted average of 2.4 trips per rental, which is then multiplied by the total number of annual rides to estimate the total number of OV-fiets trips.

Each trip is assumed to be approximately 2.6 km, based on reported average distances for bicycle access–egress segments in public transport trips (de Haas & Hamersma, 2020). So, every OV-fiets rental implies, on average, 2.4 trips of roughly 2.6 km per trip, which falls in the range of OV-fiets egress-trip distance (Table 1). This results in an average distance travelled by bike of 6.24 km per rental. The 'range of car trip distance/full trip distance' is the car trip distance in the reference case, which is replaced by the OV-fiets train combination due to the OV-fiets program. For personal car trips, Jonkeren and Huang (2024) report that the average distance of car trips that can shift to a bike-train combination ranges from 31 km to 44 km, significantly longer than the average of 18 km for all car trips (Centraal Bureau voor de Stastiek, 2023). This analysis adopts that 31–44 km range as the estimated full-trip distance,

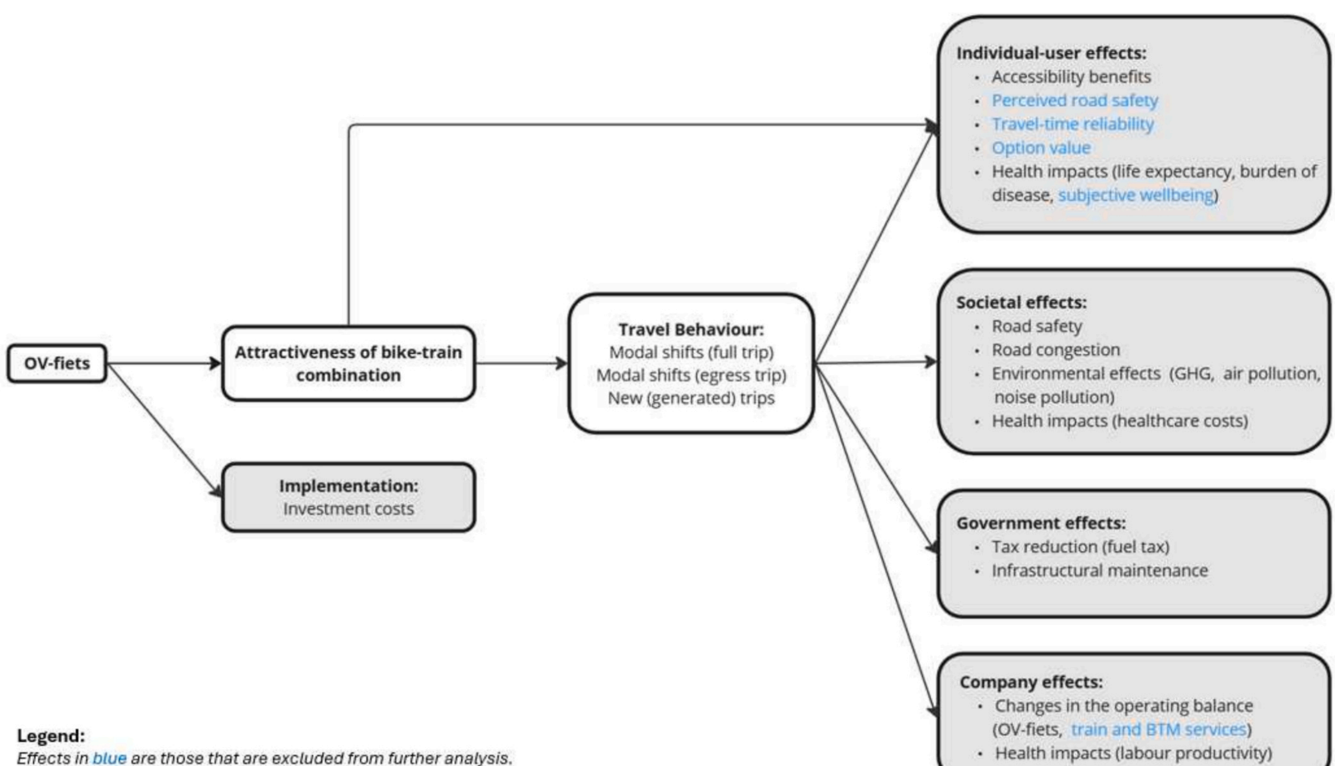

Fig. 2. Conceptual framework of the dominant societal impacts of OV-fiets.

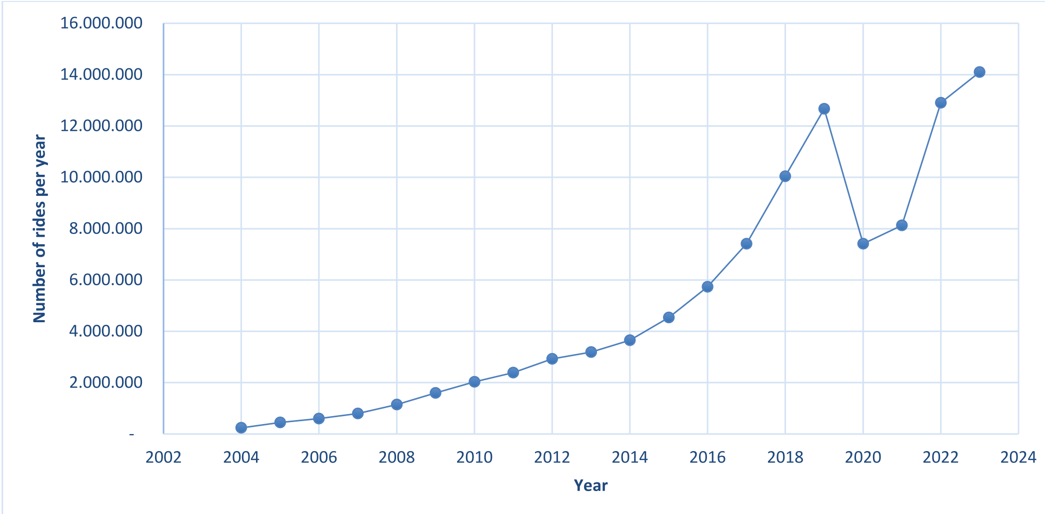

Fig. 3. OV-fiets rides over the years.).
Source: NS Annual Reports (NS, 2024; NS, 2020; NS, 2014

Table 1
Assumptions on trip characteristics.

Description	Value	Source
The average number of trips per OV-fiets rental	2.4	Estimated based on Pluister (2022)
Range of OV-fiets/egress-trip distance	1.9–4.2 km	(Pluister, 2022)
Average cycling distance as access/egress	2.6 km	(de Haas & Hamersma, 2020)
Range of car trip distance/full-trip distance	31–44 km	(Jonkeren & Huang, 2024)
Range of new train trip distance	25.8–38.8 km	Estimated

using an average of 37.5 km. To estimate the length of the train segment in the new OV-fiets–train trips, the full trip distance was reduced by twice the average cycling distance, accounting for both access and egress. This results in a 'range of new train trip distances' of approximately 25.8 to 38.8 km.

Insights were derived from literature on modal shifts induced by other bike-sharing programs (BSPs) (van Marsbergen, et al., 2022; Migley, 2011; van Gerrevink, 2019; Murphy & Usher, 2015; Fishman, et al., 2014; Bachand-Marleau, et al., 2012) because studies specifically addressing the effects of OV-fiets on modal shifts and new trips are limited. Fig. 4 displays a box and whisker plot illustrating modal shifts associated with bike-sharing programs globally ("all studies") and those specifically in the Netherlands ("NL studies") (van Marsbergen, et al., 2022; van Gerrevink, 2019). Typically, BSPs attract users primarily from

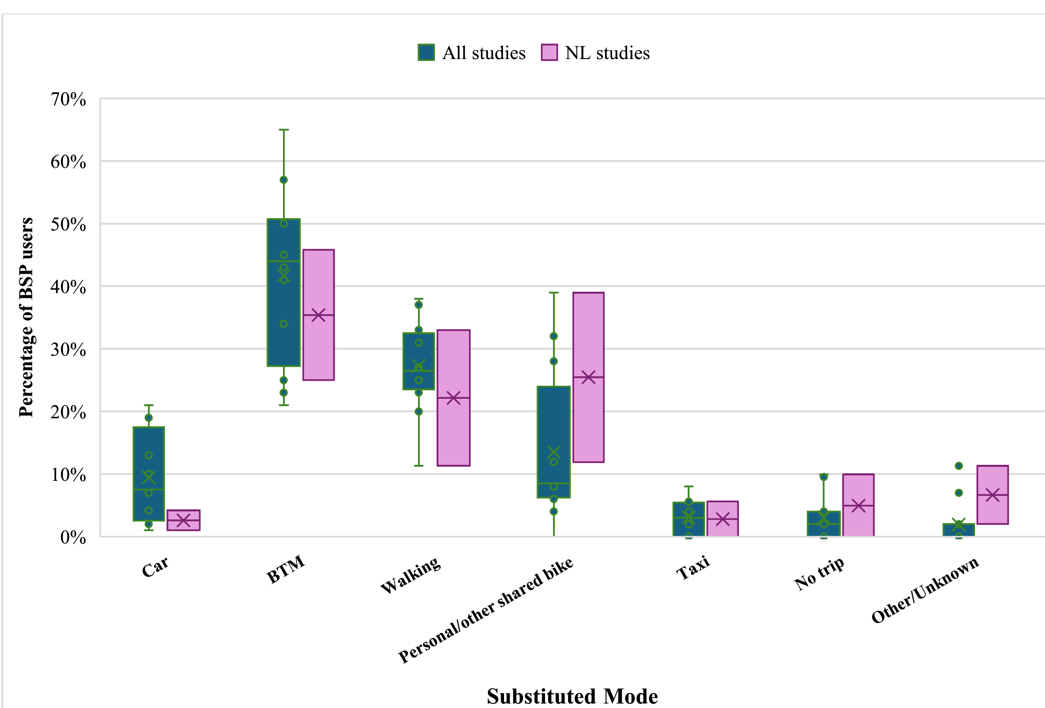

Fig. 4. Modal shift to bike-sharing program.

bus, tram, metro (BTM), and walking modes. Conversely, shifts from car usage are relatively modest, ranging from 1 % to 19 %, with Dutch studies reporting even lower shifts from car usage, typically between 1 % and 4 % (van Marsbergen, et al., 2022; van Gerrevink, 2019). Fishman et al. (2014) attribute variations in modal shifts between cities to existing modal splits; cities with low car usage or a strong cycling culture may see less substitution of car trips by bike-sharing programs. Given the country's well-established cycling culture, this might explain the lower car shifts observed in Dutch bike-sharing programs. However, evidence suggests that OV-fiets induces a slightly higher shift from car travel, ranging from 7 % to 8 % (Ploeger & Oldenziel, 2020; Pluister, 2022), compared to other Dutch bike-sharing programs (van Marsbergen, et al., 2022; van Gerrevink, 2019). This higher shift may be due to OV-fiets' integration with train services, making it a more competitive alternative to cars, especially for longer distances (Jonkeren & Huang, 2024). Given these insights, the average percentage values for modal shifts reported by Dutch studies, as illustrated in Fig. 4, are adopted for the analysis. These values are later subjected to sensitivity testing in Section 5 to evaluate their robustness and impact on the overall findings.

Table 2 presents which OV-fiets trips were made by which mode in the reference case or are new trips. 8 % (originating from personal car and 'no trips') of the OV-fiets trips have led to new train use. The others (92 %) are still multi-modal trips with a changed egress modality, namely the OV-fiets, and an unchanged train part.

Fig. 5 presents the resulting changes in passenger kilometres travelled by mode over the years due to OV-fiets, based on average trip distances.

4.2. Quantifying and monetizing the effects

4.2.1. Accessibility benefits

Conceptually, the main benefit for OV-fiets users is accessibility gains. To measure this benefit, we used the concept of Generalized Travel Cost (GTC), which encompasses both monetary and non-monetary costs incurred during travel (Koopmans, et al., 2013; Schroten, et al., 2022; Wardman, 2014). Changes in welfare due to improved accessibility were assessed using the standard concept of consumer surplus, quantifying the net benefit consumers derive from using a product or service by comparing the maximum price (in GTC, in our case) they were willing to pay with the actual price paid (Romijn & Renes, 2013; Mouter, 2014). To give a simple example, if users were willing to pay 7 euros in GTC for the egress trip in the reference case and thanks to the concept of OV-fiets they now must pay 6 euros, their increase in consumer surplus (and thus their accessibility gain) is 1 Euro for this one trip.

We are aware of a debate in the literature on travel time savings as a potential poor proxy for accessibility benefits in standard SCBAs. Metz (2008, p. 333; Metz, 2017) comments that in his view, '*once the new route or mode becomes part of an established pattern of daily activity, the benefit may then be perceived as an improvement in access, rather than as a time saving*'. Others, such as Mackie et al. (2018, p.641), have argued in response to Metz's paper that '*it is questionable whether changes in accessibility can be defined in terms of anything other than some amalgam of changes in time, reliability, comfort and money cost which make up an index of real service quality*'. We agree that the accessibility benefits of OV-fiets might be broader than measured by only taking changes in GTC into account. However, it is also very difficult, as Mackie and others comment, to define and estimate these benefits differently. So, we have chosen this GTC approach pragmatically, but we also think it is an acceptable proxy to estimate the accessibility benefits.

Table 2
Assumptions of authors regarding train usage and composition of OV-fiets trips by previous travel behaviour.

	Train use compared to the reference	Reference case trips including no trips that are substituted and generated by OV-fiets
Personal Car	New	3 %
Bus/Tram/Metro (BTM)	Unchanged	35 %
Walking	Unchanged	22 %
Personal bike / another shared bike	Unchanged	25 %
Taxi	Unchanged	3 %
No trip	New	5 %
Other/unknown mode	Unchanged	7 %

To evaluate the impact of OV-fiets on the consumer surplus, we estimated GTC both with and without the OV-fiets system, specifically focusing on egress trips from train stations, as these are directly affected by OV-fiets, as seen before. The reference case considers the GTCs for the alternative egress transport modes (Table 2). These GTC calculations are carried out using Equation (1). The underlying trip assumptions per mode for these calculations are outlined in Table 3, which are later tested in the sensitivity analysis.

$$GTC = TC + (\frac{IVT + (\beta \times OVT)}{60}) \times VOT \tag{1}$$

Where:
GTC: Generalized Travel Cost (in euros).
TC: Trip Cost (in euros).
IVT: In-Vehicle Time (in minutes) calculated as:

$$IVT = \frac{tripdistance}{averagespeedofthetravelmode} \tag{2}$$

β: Out-of-Vehicle Time penalty as a multiplier.
OVT: Out-of-Vehicle Time (in minutes), including waiting time, walking time and parking time.
VOT: Value of Time (in euros per hour).

Notably, the GTC per trip depends on the trip distance, influencing the in-vehicle time and trip costs for distance-based and time-based tariffs, including BTM, other shared bikes and taxi fares. The modelled GTC per mode by trip distance is plotted in Fig. 6, where the attractiveness of different modes by trip distance can be compared. Walking is the most attractive option for short trips below 2.2 km as it has the lowest GTC, has no trip costs, and only travel time. For trips between 2.2 km and approximately 5.5 km, OV-fiets is the most attractive option. This aligns closely with the trip distances where OV-fiets is most used (Pluister, 2022). Beyond 5.5 km, BTM becomes the most attractive option. To determine the change in consumer surplus, the benefits for unchanged multimodal trips (Table 2) are fully accounted for by the reduction in GTC due to OV-fiets. Only half of these benefits are considered for the new bike-train trips, applying the "rule of half."

VOT levels (Table 3) are dependent on income levels. In Dutch CBA practice, it is assumed that the growth in real travel time valuation is equal to half the growth in real wage rates (Knoope, 2023). The real wages (so-called collective employment agreement wages, 'CAO-lonen' in Dutch) have increased between 2004 and 2023 by 10 % (Ter Weel et al., 2023). This implies that at the start of OV-fiets (2004), real VOT values would be 5 % lower compared to the figures given in Table 3, final row. Over the whole ex-durante period, the 'average' VOT (halfway between 2004 and 2023) would be roughly 2.5 % lower compared to the VOT for 2023 values as presented in Table 3. This 2.5 % represents such a small correction that we did not take it into account.

4.2.2. Environmental benefits

The environmental impacts of OV-fiets are assessed by applying the marginal environmental costs per passenger kilometre (Table 4) to the total change in passenger kilometres for each mode of transport. This study uses the marginal costs estimated by CE Delft (Schroten, et al., 2022) specific to the Dutch territory, adjusted to the 2023 price level. For greenhouse gas emissions, three different valuations of CO_2 are

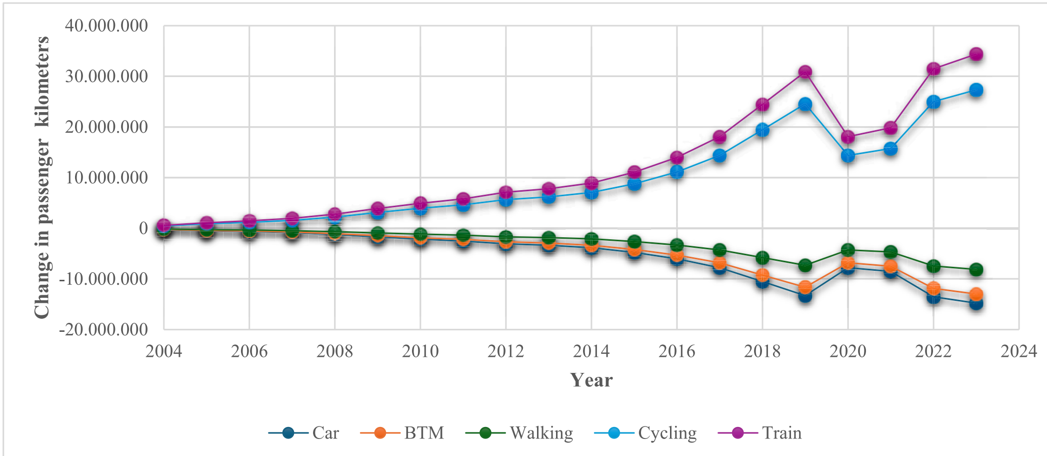

Fig. 5. Average change in passenger kilometres by mode over the years due to OV-fiets. Own estimates.

Table 3
Assumed trip characteristics with and without OV-fiets for generalized travel cost estimation for the egress modes.

	Units		Without OV-fiets			
		OV-fiets	BTM	Walking	Other shared bike	Taxi
Travel time estimation						
Total out-of-vehicle time	min	6	15	0.0	9	10
Out-of-vehicle time penalty	multiplier	2.0	2.0	2.0	2.0	2.0
Average speed	km/h	13.0	30.0	5.0	13.0	50
Travel cost estimation						
Ov-fiets rental price	euros/ day	4.5	–	–	–	–
Number of trips per rental	number	2.4	–	–	–	–
OV-fiets cost per trip	euros	1.9	–	–	–	–
Base rate	euros	–	–	–	1	3
Travel cost per min	euros/ min	–	–	–	0.1	–
Travel cost per km	euros/km	–	0.2	–	–	2
Value of travel time						
Value of travel time, price level 2023 (Kouwenhoven, et al., 2023)	euros/hr	10.6	10.6	12.1	10.6	10.7

considered in this study: “2-degree”, “high price”, and “low-price”. The “2-degree” price represents the CO_2 price for a policy to keep global temperature rise below 2 degrees Celsius. The “high price” scenario aligns with the 2030 policy adopted by the EU in 2014, implemented through measures like the EU Emissions Trading System (EU ETS). The “low price” assumes that by around 2025, it will become clear that international climate policies are ineffective, leading to a phase-out and weakening of the initially promised policies (Schroten, et al., 2022). These three prices are incorporated in the scenario analysis as follows: the “2-degree” price is used for the optimistic case, the “high price” for the balanced case and the “low price” for the pessimistic case.

4.2.3. Health benefits

As shown in the conceptualization (Fig. 2), the health benefits of OV-fiets include labour productivity (benefit for companies), lower healthcare costs (benefit for society), lower burden of disease, and higher life expectancy (benefit for OV-fiets users). These effects are evaluated using the range of marginal benefits reported by van Ommeren et al. (2017), adjusted to the 2023 price level (Table 5).

van Ommeren et al. (2017) estimate the effect of cycling on labour productivity through reduced absenteeism in terms of euros per commuting cycling kilometre. According to Pluister (2022), 51 % of OV-fiets trips are for commuting. Using these estimates, the total productivity benefit is calculated as 51 % of the total change in cycling kilometres multiplied by the marginal benefit.

In addition to productivity gains, cycling provides health benefits which are influenced by an individual’s existing level of physical activity. Less active people typically gain more than those who are already active (van Ommeren, et al., 2017; Rabl & de Nazelle, 2012; Ricci, 2015). To estimate the reduction in healthcare costs due to cycling, van Ommeren et al. (2017) use the ‘Nederlandse Norm Gezond Bewegen (NNGB)’, the Dutch standard for a healthy amount of exercise, as a benchmark, noting that 55 % of the Dutch population already meets these requirements. A range of marginal benefits is then estimated, assuming that individuals who meet the NNGB requirements receive only between 0 % and 50 % of the benefits compared to those who do not. Additionally, adjustments are made for the net extra exercise by cyclists, assuming that each additional cycling kilometre represents 53 % of extra exercise, considering potential alternative forms of exercise.

Beyond healthcare cost reductions, cycling impacts the burden of disease, which affects the quality of life. As in the calculation for reduced healthcare costs, adjustments are made for cyclists’ NNGB adherence and corrections for the net extra exercise. Additionally, this effect is (partially) internalised by the cyclist. The rationale is that when individuals decide to use OV-fiets, they may already consider the health benefits this brings. In such cases, health-related benefits become part of their perceived generalised travel costs (GTC), and we will double count if they have internalised health with their accessibility gains (Flügel et al., 2021; Börjesson & Eliasson, 2012; Björklund & Mortazavi, 2013; Veisten et al., 2024). While there is evidence that health benefits do influence cycling decisions, indicating some level of internalisation, the extent to which these benefits are fully and accurately accounted for by cyclists remains inconclusive (Börjesson & Eliasson, 2012; Björklund & Mortazavi, 2013). Given this uncertainty, this study follows the approach of van Ommeren et al. (2017), who propose an internalization rate of 50–75 % for societal cost-benefit analyses of cycling projects in the Netherlands. To estimate the lower bound of these benefits, the lower marginal benefit is combined with a high (75 %) internalisation rate. Conversely, for the higher bound, the higher marginal benefit is paired with a low (50 %) internalisation rate.

Finally, the estimates by van Ommeren et al. (2017) consider the dual effects of replacing short car journeys with bicycle journeys on life expectancy. Specifically, while increased exposure to air pollutants from cycling can slightly decrease life expectancy, physical activity increases

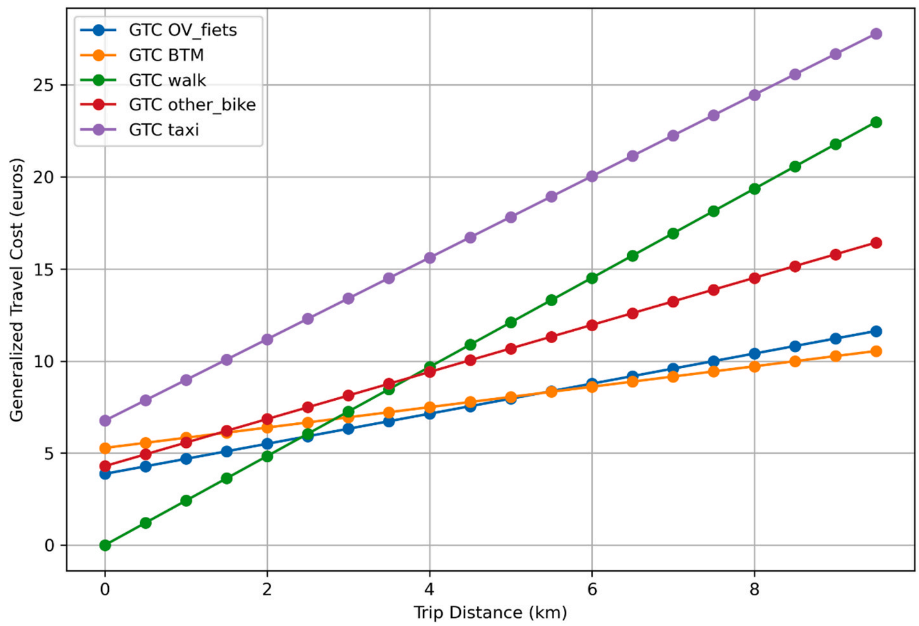

Fig. 6. Generalized travel costs by trip distance for each mode. Own estimates.

life expectancy. Additionally, an internalisation rate of 50–75 % is applied, like the calculations on the burden of disease.

4.2.4. Road safety benefits and costs

This study utilises the marginal external costs related to road safety from van Ommeren et al. (2017) for car, bus, tram, and bike modes and from CE Delft (Schroten, et al., 2022) for trains, all adjusted to 2023 price levels (Table 4). Since OV-fiets usage leads to a modal shift towards increased cycling (a relatively risky mode per kilometre driven), OV-fiets leads to safety costs—however, car use, BTM and walking decrease, which leads to safety benefits. We present the net safety results in the Section 5.

4.2.5. Road congestion

This analysis utilises the marginal external costs associated with road congestion as provided by CE Delft (Schroten, et al., 2022), adjusted to 2023 price levels (Table 4). Marginal congestion costs depend on the road type and the traffic level relative to the road's capacity. This analysis considers marginal costs for Inflow/Capacity (I/C) ratios between 0.8 and 1.0, capturing the range where congestion starts to impact traffic flow but before it becomes extremely severe. Notably, main city roads incur the highest marginal congestion costs compared to other city roads and highways. An average of these marginal costs is used. Further, the marginal costs per kilometre for passenger cars are significantly higher than those for buses due to their lower occupancy rates.

4.2.6. Government budget impacts (Taxes and road maintenance)

As motorists opt for cycling over driving, there is a direct decrease in fuel consumption, leading to a consequent decline in fuel excise tax collections. The broader societal impact entails reduced funds available for societal benefits provided by the government (van Ommeren, et al., 2012; European Commission: Directorate-General for Regional and Urban Policy, 2008). This study estimates this reduction in fuel tax revenues, focusing primarily on petrol, diesel and LPG passenger cars as outlined in Equation (3), using the tax rate, car composition across various fuel technologies, and fuel consumption rates as detailed in Table 6.

$$TR = \sum_{i=1}^{n}\left(\Delta Carkms \times \frac{Composition_i}{Consumption_i} \times TaxRate_i\right) \quad (3)$$

Where:
TR: Tax Reduction
Δ Car kms: Change in car passenger kilometres due to reduced car usage.
$Composition_i$: Percentage composition of vehicle technology i in the car fleet.
$Consumption_i$: Fuel consumption rate for vehicle technology i.
$Tax\ Rate_i$: tax rate per litre of fuel i.
n: Total number of vehicle technologies considered in the analysis.

Conversely, reduced usage of road infrastructure by cars is considered a benefit, as it lowers governmental road maintenance and renewal costs. This analysis utilises the marginal external costs associated with infrastructure as provided by CE Delft (Schroten, et al., 2022), adjusted to 2023 price levels (Table 4). These marginal infrastructure costs are calculated as the variable part of the total infrastructure costs, encompassing variable maintenance and renewal expenses. The underlying assumption in using these marginal costs is that the capacity of the infrastructure has not been reached. This means the cycling and rail infrastructure can accommodate additional usage from OV-fiets and train travel without requiring significant upgrades or expansions.

4.2.7. Investment costs

Given the large-scale nature of the OV-fiets program, this study adopts an initial investment cost ranging between 50 and 70 million euros, including bicycle sheds and additional infrastructure works, as estimated by MuConsult (2004). Although these investments were likely distributed over several years, it is assumed that an initial investment was made at the beginning of the analysis period in 2004, targeting the acquisition of 12,000 bicycles as recommended by MuConsult (2004). According to data on the historic number of bicycles OV-fiets Beschikbaar (2024), this target was achieved in 2017. Consequently, this analysis includes a reinvestment in 2016 to accommodate the current number of bicycles. This reinvestment assumes a lower cost of 1200 euros per bicycle for the bike sheds, as estimated by Rijkswaterstaat Environment (n.d.).

4.2.8. Changes in the operating balance

This study estimates the profits or losses for the operation of the OV-fiets service, excluding impacts from potential changes in revenues and operating costs associated with train and BTM services. This is achieved

Table 4
Marginal external costs from transport in Dutch territory in euros per passenger kilometre (adjusted to 2023 price level).

Effect	Passenger car	Bus*	Train	Bike	Source
Air pollution (PM,NOx)	0.0065	0.0112	0.0021	–	(Schroten, et al., 2022)
GHG emissions (low CO2 price)	0.0023	0.0008	0.00004	–	(Schroten, et al., 2022)
GHG emissions (high CO2 price)	0.0095	0.0032	0.0002	–	(Schroten, et al., 2022)
GHG emissions (2-degrees price)	0.0156	0.0054	0.0003	–	(Schroten, et al., 2022)
Noise pollution (day,busy)	0.0002	0.00002	0.0002	–	(Schroten, et al., 2022)
Noise pollution (day, calm)	0.0001	0.00004	0.0003	–	(Schroten, et al., 2022)
Noise pollution (night,busy)	0.0001	0.00004	–	–	(Schroten, et al., 2022)
Noise pollution (night,calm)	0.0004	0.00008	0.0005	–	(Schroten, et al., 2022)
Noise pollution (average)	0.0002	0.00004	0.0003	–	Calculated
Road safety (average)	0.0391	0.0330	0.0016	0.1038	(Schroten, et al., 2022; van Ommeren, et al., 2017)
Road safety (best-case)	0.0024	0.0177	0.0016	0.1038	(Schroten, et al., 2022; van Ommeren, et al., 2017)
Road safety (worst-case)	0.2346	0.0574	0.0016	0.1038	(Schroten, et al., 2022; van Ommeren, et al., 2017)
Road congestion (main city roads)	0.68	0.09	–	–	(Schroten, et al., 2022)
Road congestion (other city roads)	0.25	0.09	–	–	(Schroten, et al., 2022)
Road congestion (highways)	0.41	0.14	–	–	(Schroten, et al., 2022)
Road congestion (average)	0.44	0.15	–	–	Calculated
Infrastructure maintenance	0.0022	0.0384	0.0272	0.0015	(Schroten, et al., 2022)

* Since the effects apply only to buses while the change in passenger kilometres is calculated for the broader BTM category, 50% of the change in passenger kilometres for BTM is attributed to bus travel based on Van Nes et al. (2014), which shows a near 50–50 split between bus and tram/metro for train trips.

by estimating the revenues from OV-fiets and subtracting the operational and maintenance costs. The revenues are based on the number of rentals per year and the rental price of OV-fiets as extracted from various reports (NS, 2014; NS, 2020; Ploeger & Oldenziel, 2020; NS, 2024; Rosbergen & Emmen, 2004). The rental prices have changed over the years, starting at about 2.5 euros in 2004 (Rosbergen & Emmen, 2004) per rental and rising to 4.45 euros per rental in 2023 (NS, 2024). Until 2017, a yearly subscription fee of about 10 euros was also charged. However, this aspect is not included in the revenue calculations; thus, the revenues may be slightly underestimated. MuConsult (2004) estimated operational and maintenance costs for a bike-sharing system, including payment processing, spare parts, personnel, security, and financing. For a manned location with 50 rental bikes, costs were about 700 euros per bike per year, while smaller locations with 5 bikes incurred 1,100 to 2000 euros per bike per year due to lower economies of scale. Conversely, Rijkswaterstaat Environment (n.d.) suggested a rule of thumb of 1,200 euros per bike per year for small-scale systems. Based on these estimates, this study adopts an operation and maintenance cost of 700 euros per bike per year for large locations (more than 50 bikes) and 1200 euros per bike per year for small locations (less than 50 bikes).

To understand the distribution of OV-fiets bikes across different location types and sizes, Fig. 7 illustrates the total number of bikes per location type and size based on data from OV-fiets Beschikbaar (2024) in 2024. It is observed that most bikes are in manned locations with more than 250 bikes. The proportion of bikes in large, manned locations (greater than 50 bikes) is approximately 80 %. Given that the analysis spans 20 years, the total number of OV-fiets per year is extracted from (NS, 2014; NS, 2020; Ploeger & Oldenziel, 2020; NS, 2024). It is assumed that 80 % of the bikes were in large locations, while 20 % were

Table 6
Tax rates, passenger car composition and fuel consumption rates in the Netherlands.

	Amount	Source
Tax rate		
Petrol	0.79 euro/litre	(Ministrie van Financien, 2024)
Diesel	0.52 euro/litre	(Ministrie van Financien, 2024)
LPG	0.19 euro/litre	(Ministrie van Financien, 2024)
Passenger car composition		
Petrol (including hybrids and ethanol)	82.7 %	(Centraal Bureau voor de Statistiek, 2023)
Diesel (including diesel hybrids)	13.1 %	(Centraal Bureau voor de Statistiek, 2023)
Full electric (and hydrogen)	1.6 %	(Centraal Bureau voor de Statistiek, 2023)
LPG (including LPG hybrids)	1.2 %	(Centraal Bureau voor de Statistiek, 2023)
Plug-in electric hybrids	1.2 %	(Centraal Bureau voor de Statistiek, 2023)
Natural gas (LNG, CNG & hybrids)	0.1 %	(Centraal Bureau voor de Statistiek, 2023)
Fuel consumption rates		
Select petrol models (average)	13.13–16.95 km/litre	(van Gijlswijk, et al., 2020)
Select diesel models (average)	14.95–18.15 km/litre	(van Gijlswijk, et al., 2020)
LPG	11.42–14.74 km/litre	(van Meenen, 2023)

Table 5
Marginal health benefits from cycling. , adjusted to 2023 price level.

Health effect	Low	Median	High	Unit	Internalisation rate
Labour productivity	–	0.24	–	euro/commuting cycling km	–
Healthcare costs	0.01	0.04	0.06	euro/cycling km	–
Burden of Disease	0.02	0.10	0.17	euro/cycling km	50–75 %
Life expectancy	–	0.08	–	euro/cycling km	50–75 %

Source: van Ommeren et al. (2017)

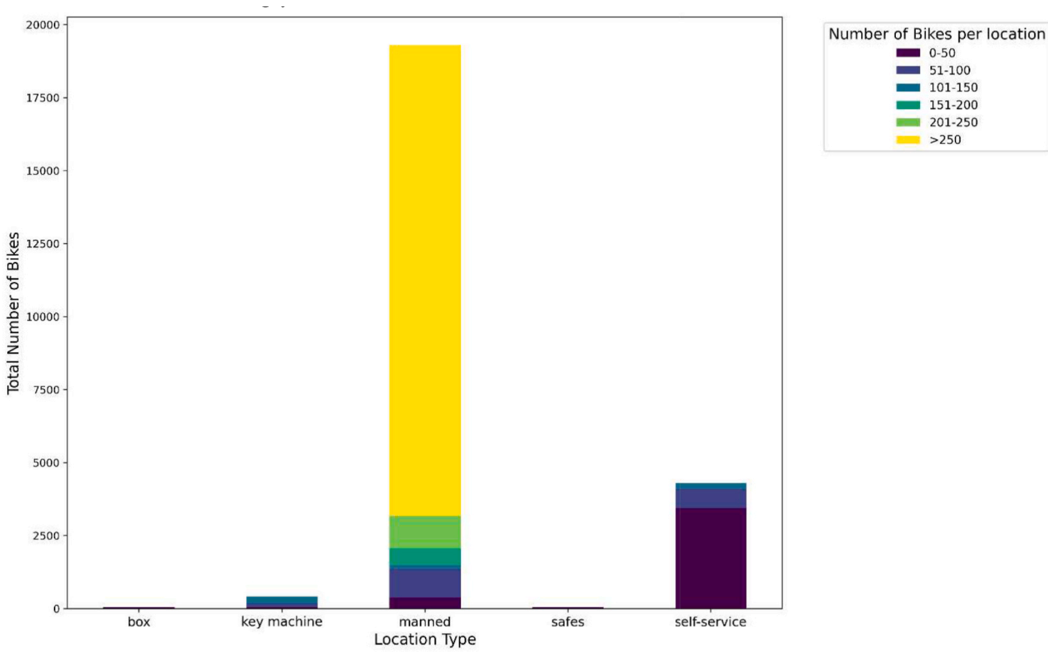

Fig. 7. Distribution of OV-fiets by location type and size (number of bikes per location). Data).
source: OV-fiets Beschikbaar (2024

in small locations, and the operational and maintenance costs were estimated accordingly.

5. Results

5.1. Overall results

Table 7 presents the comprehensive results for the three scenarios described in Section 2.4.

The analysis reveals that, on average, with a balanced view of costs and benefits, the net present value (NPV) of the OV-fiets scheme is positive, with a benefit-cost ratio (BCR) of 1.5. This indicates that the scheme has benefited society over the 20 years, generating about 51 % more benefits than costs in this balanced scenario. In the pessimistic scenario, the NPV remains slightly positive with a BCR of 1.1. This implies that even under the least favourable conditions, where high costs and low benefits are estimated, the scheme still slightly exceeds the break-even point. Conversely, in the optimistic scenario, the BCR rises significantly to 2.4. This suggests that under the most favourable conditions, where estimated benefits are high and costs low, the scheme generates more than double the benefits compared to its costs. The most significant factors influencing this analysis include investment cost, accessibility benefits, road congestion reduction, and health benefits. These factors exhibit the highest values and considerably impact the NPV and BCR calculations. In the discussion (Section 6), we will elaborate further on this.

5.2. Sensitivity analysis

Among the critical areas of uncertainty are the modal shifts and new trips generated by OV-fiets (Table 2 and Fig. 4) and the underlying assumptions related to the estimation of generalised travel costs (Table 3), which influences the accessibility benefits. These uncertainties were tested through a sensitivity analysis to examine their impact on the results. Our results indicate that if there are no shifts from personal cars, the net present value (NPV) remains positive in the balanced and optimistic scenarios but turns negative in the pessimistic scenario with a benefit-cost ratio (BCR) of 0.9. Road congestion is the most impacted factor by this change, with benefits decreasing by about 80 % from 55 million to 10 million in the balanced scenario. The remaining road congestion benefits come from shifts from taxi and bus travel.

Table 7
Summary of Present Values (in millions of euros), and Benefit/Cost Ratios (BCRs) for the balanced, pessimistic and optimistic scenarios.

Item	Balanced Scenario	Pessimistic Scenario	Optimistic Scenario
Investment			
Investment cost	−106	−122	−91
Individual-user benefits			
Accessibility benefits	102	102	102
Health *effects*			
Labour productivity	25	25	25
Healthcare costs	7	2	12
Burden of disease	7	1	17
Life expectancy	6	4	8
Total health benefits	*45*	*32*	*62*
Environmental *effects*			
GHG emissions	1.13	0.28	1.86
Air pollution	0.70	0.70	0.70
Noise pollution	−0.06	−0.06	−0.06
Total environmental effects	*1.76*	*0.91*	*2.49*
Road safety costs			
Road safety costs	−14	−19	10
Road congestion			
Road congestion	55	31	83
Government impacts			
Tax revenue	−5	−6	−5
Infrastructure maintenance	−4	−4	−4
Company impacts			
Change in the operating balance	−7	−7	−7
Net Present Value (NPV)	68	9	153
Total benefits	204	166	259
Total costs	−136	−157	−107
Benefit/Cost Ratio (BCR)	**1.5**	**1.1**	**2.4**

Conversely, increasing the mode shift from cars to 7 %, as evidence suggests is possible (Ploeger & Oldenziel, 2020; Pluister, 2022)), yields substantial benefits: a BCR of 3.6 in the optimistic scenario, 2.0 in the balanced scenario, and 1.2 in the pessimistic scenario, significantly enhancing the overall impact.

Increasing the mode shift from BTM (Bus, Tram, Metro) and walking notably reduces the Benefit-Cost Ratio (BCR), albeit modestly. For example, when the modal shift from BTM rises to 65 % —the maximum global estimate shown in Fig. 4 — representing an 84 % increase, the BCR decreases from 1.5 to 1.3 in the balanced scenario. This change primarily impacts the accessibility benefits. Trips originating from walking and BTM offer lower accessibility benefits because GTCs of these modes are only slightly higher in the OV-fiets travel distance range compared to the GTC of OV-fiets. In contrast, trips originating from other shared bikes and taxis provide higher accessibility benefits. Due to normalisation, increasing the proportion of trips from walking and BTM decreases the number of trips from different modes, mainly shared bikes and taxis, which offer higher accessibility benefits. Consequently, this shift slightly reduces the overall accessibility benefits.

Additionally, health benefits are significantly impacted by changes in mode shifts from other bikes. Health benefits arise from increased cycling kilometres, calculated by subtracting trips that would have otherwise been made by personal or other shared bicycles from the total OV-fiets trip kilometres. Thus, by reducing the mode shift from other bicycles to 0 %, higher health benefits are realised, as all OV-fiets trips are assumed to be new cycling trips. However, this also leads to reduced accessibility benefits, as previously explained.

In an extra uncertainty analysis, two types of adjustments were applied to the assumptions related to GTC calculations:

- Negative Changes: Adjustments that decrease the attractiveness of OV-fiets compared to alternative modes to determine at what point the result shifts from a positive to a negative net present value (NPV).
- Positive Changes: Adjustments that increase the attractiveness of OV-fiets compared to other alternatives to assess the impact on the results under more optimistic assumptions

This analysis shows that the out-of-vehicle time for Bus, Tram, and Metro (BTM) significantly influences the results. A reduction of this time by 33 % achieves a break-even point in the balanced scenario. Further reduction by 67 % results in a Benefit-Cost Ratio (BCR) of 0.6 in the balanced scenario and 0.3 in the pessimistic scenario. Conversely, increasing the out-of-vehicle time by 33 % leads to a BCR of 2.0 in the balanced scenario and up to 3.1 in the optimistic scenario. This substantial impact is attributed to the fact that most users originate from BTM, and the out-of-vehicle time is heavily weighted with a multiplier of 2 in the Generalized Travel Cost (GTC) calculations. For other components, the results indicate that negative changes generally do not significantly affect the outcomes in the balanced scenario. However, in the pessimistic scenario, all changes lead to BCRs less than or approximately equal to 1.0. The BCR shows modest improvements for positive changes when the average cycling speed increases, taxi parameters worsen, and BTM average speeds are reduced. Notably, a 67 % increase in the out-of-vehicle time for other shared bikes produces effects comparable to those of increasing the out-of-vehicle time for BTM by 33 %.

6. Conclusion and discussion

Integrating bike-sharing programs with public transport enhances accessibility and car-independent mobility, yet a comprehensive societal cost-benefit analysis (SCBA) of this integration remains scarce. This study addresses this gap by conducting an ex-durante analysis of the OV-fiets program in the Netherlands, a station-based round-trip bike-sharing system designed to improve last-mile connectivity for train commuters. The use of SCBA, rather than a traditional financial cost-benefit analysis (CBA), means that the Net Present Value (NPV) presented in this study reflects not only direct financial costs and benefits but also broader societal effects, such as health impacts, environmental externalities, and travel time savings. As a result, the outcomes may differ significantly from those of a purely financial analysis, underscoring the relevance of SCBA for informing policy decisions on active mobility and integrated transport systems.

The primary conclusion of this study is that the OV-fiets program has benefited Dutch society. Our analysis reveals that, on average, with a balanced view of costs and benefits, the NPV of the OV-fiets scheme is positive, with a benefit-cost ratio (BCR) of 1.5. This indicates that the scheme has benefited society over the 20 years. In the pessimistic scenario, the NPV remains slightly positive with a BCR of 1.1. This implies that even under the least favourable conditions, where high costs and low benefits are assumed, the scheme still slightly exceeds the break-even point. Conversely, in the optimistic scenario, the BCR rises significantly to 2.4. These findings highlight the viability of shared bicycle schemes as socially beneficial mobility solutions.

The OV-fiets program delivers substantial benefits, with accessibility (50 %) primarily aiding users, reduced road congestion (26 %) benefiting society, and health benefits (23 %) supporting society, users, and companies. Environmental benefits, including reduced GHG emissions and air pollution, contribute less than 1 %. On the cost side, the government bears the majority through investment costs (78 %), along with reduced tax revenue (4 %) and infrastructure maintenance costs (3 %). Society incurs 10 % of costs through road safety impacts, while operators bear 5 % of the costs due to operational losses. This distribution highlights the program's broad societal value alongside its concentrated costs.

The accessibility benefits can be primarily attributed to OV-fiets seamless integration with public transport, allowing train travellers to save time and, occasionally, reduce costs by using bicycles for the final leg of their journey. The program proves particularly effective for short-distance travel segments between 2.2 and 5.5 km, which is a more attractive option than other modes of transport from train stations. This aligns with cycling modal share data, which shows that bicycles are frequently used for trips up to 5 km (Jonkeren & Huang, 2024; Nello-Deakin and te Brömmelstroet, 2021). Key factors driving these accessibility benefits include advanced technology that allows commuters to unlock bicycles within seconds using their public transport cards, thus drastically reducing transaction times (Ploeger & Oldenziel, 2020; Martens, 2007). Additionally, the strategic placement of OV-fiets stations at train hubs minimises transfer times (Martens, 2007), providing a notable advantage, especially over other commercial bike-sharing services that may be located at less convenient locations. Furthermore, unlike commercial bike-sharing services that may prioritise profitability, OV-fiets focuses on efficient bike rental at low-profit margins (Ploeger & Oldenziel, 2020; Martens, 2007), enhancing user convenience and supporting the broader public transportation system. It can be noted in Table 7 that the OV-fiets operator accepts a loss.

Though substantial, the health benefits of OV-fiets rank as the third-highest societal benefit, contrasting with other cycling studies where health benefits typically dominate (Gössling & Choi, 2015; Macmillen, et al., 2010; Rich, et al., 2021). This can be attributed to certain moderating adjustments made in this study for the Dutch context. For example, Nello-Deakin and te Brömmelstroet (2021) report that approximately 50 % of bike-train users cycled daily, and about 30 % cycled a few times weekly before adopting the bike-train travel mode. The additional health benefits of someone who has been cycling regularly are smaller than those of someone who is used to using a less active mode of transport (e.g., car, BTM) before. Consequently, the high cycling culture in the Netherlands likely moderates the health benefits compared to regions with lower cycling activity. Nonetheless, the health benefits remain a significant component of the overall societal advantages of OV-fiets, underscoring its positive impact on public health.

Road safety costs are significant primarily due to the high risks associated with cycling. In this study, they account for about 30 % of the total health benefits. In contrast, Gössling and Choi (2015) found that road safety costs offset less than 20 % of the health benefits of cycling in Copenhagen. This disparity may partly be attributed to contextual variations in road safety conditions and methodological differences in the evaluations. Despite these road safety challenges, the significant health benefits derived from cycling underscore its positive impact on public health, warranting continued investment in safety measures and infrastructure improvements.

The estimated operation and maintenance of OV- fiets show a modest overall loss over the 20-year period, with significant losses for operators from 2004 to 2015. In later years, increased ridership led to higher revenues and greater profitability, though a sharp revenue drop in 2020 due to the COVID-19 pandemic disrupted this trend. These findings underscore the critical role of government support, especially during the program's early years and disruptions, to overcome financial challenges and establish stability. The investment costs of OV-fiets for the operator are not a yearly cost number with a stable yearly growth percentage. The reason is that in some years bigger investments or reinvestments must be made than in other years, e.g., every ten years – roughly – the old bike type for the whole fleet is replaced by a new one. Yearly maintenance and operational costs and revenues are more stable financial streams with a yearly growth rate depending on the yearly growth in demand (Fig. 3).

Few studies have comprehensively examined bike-sharing programs' societal costs and benefits for direct comparison with this study's findings. An interesting comparison can be made with London's public bike-sharing program, formerly Barclays Cycle Hire. A CBA study of this program reported a benefit-cost ratio (BCR) of 0.7:1 over 7 years, considering implementation costs, revenues, health gains, travel time savings, and ambience benefits (Transport for London, 2014), much in line with our study. This relatively low BCR was attributed to fewer-than-expected trips and revenues, partly due to the program's policy of offering the first 30 min for free, which resulted in 90 % of trips being completed within this period. In contrast, one of the explanations for the OV-fiets program scoring better in BCR compared to this London case is that the program uses a flat daily rate, ensuring higher financial inflows and encouraging a more prolonged usage. A survey of OV-fiets users highlighted indeed convenience, freedom and speed as significant advantages of the program, indicating that the 24-hour unlimited use offers additional accessibility benefits (Pluister, 2022).

While this study provides valuable insights into the impacts of the OV-fiets program, its findings should be interpreted cautiously when applied to similar programs in different contexts. Transport initiatives are deeply influenced by local conditions that shape travel behaviour and outcomes (Brown, et al., 2016). For example, road safety risks may be more pronounced in developing countries, potentially increasing road safety costs and reducing the overall effectiveness of similar programs. Therefore, efforts to promote cycling must be accompanied by measures to enhance road safety for cyclists. Conversely, such programs could offer substantial health benefits in regions with more sedentary lifestyles by encouraging increased physical activity. Given the already high level of cycling in the Netherlands, the expectation is that the societal benefits in countries with a lower baseline of cycling activity could actually be much higher.

What can be learned from this Dutch case for policy and practice? For Dutch policy and practice, this ex-durante assessment shows that the concept is successful from a Dutch societal perspective, so its roll-out could be continued. Even with more government subsidies if needed to cover the operator's losses as OV-fiets leads to broader societal benefits than only increased train usage, as we show. We have a more nuanced view of the policy and practice implications for other countries. Foremost, although OV-fiets might be successful in the Netherlands, it is not an easy concept to copy into other contexts. First, it is essential to realise that OV-fiets was introduced in a culture where cycling as a transport mode is highly accepted. Dutch people cycle from their youngest age, and many are accustomed to using bikes for commuting. In such a culture, a new cycling concept such as OV-fiets is relatively quickly accepted as an option. In addition, using the OV-fiets is relatively easy in the Netherlands (both in urban and rural areas) as there is an abundance of dedicated cycle paths and cycle storage facilities. Second, OV-fiets is not a 'normal' commercial bike-sharing program. It is a fully integrated bike system within train stations. As emphasised before, this seamless integration provides accessibility benefits. However, to be seamless implies a relatively high investment in stations and the willingness of station managers to make room for bikes in their buildings. Success also means that the OV-fiets operators accept financial losses, especially at the beginning years of this concept. Nowadays, it is a popular concept that makes the Dutch people proud (Schoorl, 2023), but it should not be forgotten that OV-fiets was confronted with opposition when the idea was born. This study shows that other societies can profit from the OV-fiets system, but the roll-out of such a concept to become successful requires courage, subsidies, seamless integration and a long breath.

The interplay between OV Fiets and public transport is both complementary and competitive. OV-fiets complement train travel, as shown in section 4, where it was estimated that 8 % of OV-fiets trips have resulted in new train use compared to the reference. On the other hand, in the last-mile OV-fiets competes clearly with bus, tram and metro (BTM). The resulting effects on transport operators were excluded from the societal cost benefit-analysis primarily due to time constraints. Increased train usage due to OV-fiets may boost revenues from train ticket sales but may also lead to station crowding, necessitating adjustments such as more frequent train services, which can escalate costs. Conversely, shifting some users from BTM to cycling could reduce BTM revenues but enhance operational efficiency by reducing peak demand and lowering operational costs. Due to competition and complementarity, these contrasting impacts highlight the complex interplay of factors that could be further investigated in future research.

As the conceptual model (section 3) explained, some social impacts were left out of the analysis. Omitted factors such as perceived road safety, (psychological) well-being and the option value are benefits of OV-Fiets. OV-fiets makes people feel that road safety increases because people see more bikes (and fewer cars) on the streets. People using OV-fiets psychologically might feel good because they exercise a little and feel the wind in their hair which might give them a positive feeling of well-being and freedom. OV-fiets also has a positive option value because the OV-fiets gives people the possibility of using a bike in case city transit is disturbed, for example. So, omitting these three factors in our analysis does not influence our main conclusion that OV-fiets has benefitted society. The net benefits of OV-fiets only might be even higher. For the factor 'travel time reliability', we omitted, the situation is subtler. On the one hand, one can argue that OV-fiets increases travel time reliability because travellers avoid using cars and taxis, which can unexpectedly get stuck in traffic or use transit, which can be disturbed. On the other hand, anecdotal evidence from the authors of this paper shows that sometimes OV-fiets has become so popular that they run out at some locations, which makes the OV-fiets system less reliable. We do not know to what extent these two reliabilities impacts even out. In brief, while we think that the factors we omitted do not influence our main conclusion, the magnitude of all omitted factors, as well as the direction of the reliability factor, remain unclear, warranting further research.

Lastly, the timeframe of the analysis provides a retrospective view of the OV-fiets program's impacts. Technological advancements—including the introduction of e-bikes (currently in a pilot phase), integration with intelligent mobility platforms, demand-responsive transport, and the emergence of autonomous vehicles—may reshape user preferences, cost structures, and modal integration. These changes could affect both the demand for OV-fiets and its function within a broader multimodal mobility system. Future research may, therefore, conduct ex-ante evaluations to anticipate the complexities of an evolving bike–train system and to support its optimisation within future sustainable transport strategies.

CRediT authorship contribution statement

Leah Watetu Mbugua: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Dorine Duives:** Writing – review & editing, Validation, Supervision, Conceptualization. **Jan Anne Annema:** Writing – review & editing, Validation, Supervision, Conceptualization. **Niels van Oort:** Writing – review & editing, Validation, Supervision, Conceptualization.

Declaration of competing interest

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

References

Bachand-Marleau, J., Lee, B.H., El-Geneidy, A.M., 2012. Better understanding of factors influencing likelihood of using shared bicycle systems and frequency of use. Transp. Res. Rec. 2314 (1), 66–71.

Boardman, A.E., Greenberg, D.H., Vining, A.R., Weimer, D.L., 2018. *Cost-Benefit Analysis: Concepts and Practice*, 5 ed. Cambridge University Press, Cambridge.

Björklund, G., Mortazavi, R., 2013. Influences of infrastructure and attitudes to health on value of travel time savings in bicycle journeys. In: CTS Working Paper 2013, vol. 35. Centre for Transport Studies, Stockholm.Börjesson, M., Eliasson, J., 2012. The value of time and external benefits in bicycle appraisal. *Transport Research Part A: policy and practice*, 46 (4), pp. 673–683.

Brown, V., et al., 2016. A systematic review of economic analyses of active transport interventions that include physical activity benefits. Transp. Policy 45, 190–208.

de Haas, M. & Hamersma, M., 2020. *Cycling facts: new insights,* The Hague: Netherlands Institute for Transport Policy Analysis | KiM.

European Commission: Directorate-General for Regional and Urban Policy, 2008. *Guide to cost-benefit analysis of investment projects – Structural Funds, Cohesion Fund and Instrument for Pre-Accession,* s.l.: Publications Office.

Fishman, E., Washington, S., Haworth, N., 2014. Bike share's impact on car use: evidence from the United States, Great Britain, and Australia. Transp. Res. Part D: Transp. Environ. 31, 13–20.

Flügel, S., Veisten, K., Sundfør, H.B., Jordbakke, G.N., Hulleberg, N., Halse, A.H., 2021. The effect of health benefits on the value of travel time savings in active transport. J. Transp. Health 21, 101074.

Gössling, S., Choi, A.S., 2015. Transport transitions in Copenhagen: Comparing the cost of cars and bicycles. Ecol. Econ. 113, 106–113.

Jonkeren, O. & Huang, B. A., 2024. *Modal shift van auto naar de combinatie fiets-ov,* The Hague: Kennisinstituut voor Mobiliteitsbeleid (KiM).

Kager, R., Bertolini, L., Te Brömmelstroet, M., 2016. Characterisation of and reflections on the synergy of bicycles and public transport. Transp. Res. A Policy Pract. 85, 208–219.

Knoope, M., 2023. Nieuwe waarderingskengetallen voor reistijd, betrouwbaarheid en comfort. Kennisinstituut voor Mobiliteitsbeleid, Den Haag.

Koopmans, C., et al., 2013. Measuring generalised transport costs as an indicator of accessibility changes over time. Transp. Policy 29, 154–159.

Kouwenhoven, M., et al., 2023. *Values of Time, Reliability and Comfort in the Netherlands 2022: New Values for Passenger Transport and Freight Transport*. KiM Netherlands Institute for Transport Policy Analysis, The Hague.

Mackie, P., Batley, R., Worsley, T., 2018. Valuing transport investments based on travel time savings—a response to David Metz. Case Stud. Transport Policy 6 (4), 638–641.

Macmillen, J., Givoni, M., Banister, D., 2010. Evaluating active travel: decision-making for the Sustainable City. Built Environ. 36, 519–536.

Martens, K., 2007. Promoting bike-and-ride: the Dutch experience. Transp. Res. A Policy Pract. 41 (4), 326–338.

Ma, X., Yuan, Y., van Oort, N., Hoogendoorn, S., 2020. Bike-sharing systems' impact on modal shift: a case study in Delft, the Netherlands. J. Clean. Prod. 259.

Mbugua, L.W., 2024. *Examining the Societal Costs and Benefits of Integrating Bike Sharing Systems and Public Transport: A Case study of the OV-fiets in the Netherlands*. Delft University of Technology, s.l.

Metz, D., 2008. The myth of travel time saving. Transp. Rev. 28 (3), 321–336. https://doi.org/10.1080/01441640701642348.

Metz, D., 2017. Valuing transport investments based on travel time saving: inconsistency with United Kingdom policy objectives. Case Stud. Transport Policy 5 (4), 716–721.

Migley, P., 2011. *Bicycle-Sharing Schemes: Enhancing Sustainable Mobility in Urban Areas*. United Nations, Department of Economic and Social Affairs, New York.

Ministrie van Financien, 2024. *Tarievenlijst Accijns en verbruiksbelastingen, 2024,* s.l.: s.n.

Montes, A., et al., 2023. Shared micromobility and public transport integration - a mode choice study using stated preference data. Res. Transp. Econ. 99.

Mouter, N., 2014. *Cost-benefit analysis in practice: a study of the way cost-benefit analysis is perceived by key individuals in the dutch CBA practice for spatial-infrastructure projects*. Delft University of Technology, Delft.

MuConsult B.V., 2004. *Op weg naar een landelijk fietsverhuursysteem bij Openbaar Vervoersknooppunten: Evaluatie actieplan 'Aansluiting fiets op Openbaar Vervoersknooppunten 2002/2003',* Rotterdam: Ministerie van Verkeer en Waterstaat.

Murphy, E., Usher, J., 2015. The role of bicycle-sharing in the City: analysis of the Irish Experience. Int. J. Sustain. Transp. 9 (2), 116–125.

Nello-Deakin, S., te Brömmelstroet, M., 2021. Scaling up cycling or replacing driving? triggers and trajectories of bike–train uptake in the randstad area. Transportation 48, 3239–3267.

NS, 2014. *NS Annual Report 2013,* s.l.: NS.

NS, 2020. *NS Annual Report 2019,* s.l.: s.n.

NS, 2024. *Annual report 2023,* s.l.: NS.

Oeschger, G., Carroll, P., Caulfied, B., 2020. Micromobility and public transport integration: the current state of knowledge. Transport. Res. Part d: Transport Environ. 89.

Ploeger, J., Oldenziel, R., 2020. The sociotechnical roots of smart mobility: bike sharing since 1965. J. Transp. Hist. 41 (2), 134–159.

Pluister, B., 2022. *OV-Fiets: Where to Go? A Study on OV-fiets user Characteristics and destinations*. University of Twente, s.l.

Rabl, A., de Nazelle, A., 2012. Benefits of shift from car to active transport. Transp. Policy 19 (1), 121–131.

Ricci, M., 2015. Bike sharing: a review of evidence on impacts and processes of implementation and operation. Res. Transp. Bus. Manag. 15, 28–38.

Rich, J., Jensen, A.F., Pilegaard, N., Hallberg, M., 2021. Cost-benefit of bicycle infrastructure with e-bikes and cycle superhighways. Case Stud. Transport Policy 9 (2), 608–615.

Rijkswaterstaat Environment, n.d.. *Fact sheet Bike sharing systems,* s.l.: Rijkswaterstraat.

Romijn, G. & Renes, G., 2013. *General Guidance for Cost-Benefit Analysis.* The Hague: CPB Netherlands Bureau for Economic Policy Analysis and PBL Netherlands Environmental Assessment Agency.

Rosbergen, E. & Emmen, M., 2004. *Op weg naar een landelijk fietsverhuursysteem bij Openbaar Vervoerknooppunten.* s.l., CVS-congres.

Schoorl, J., 2023. *Hoe de nu zo geliefde ov-fiets – met veel moeite – het daglicht zag: 'de NS wilde die hele fiets niet'*. de Volkskrant, s.l.

Schroten, A., Leestemaker, L., Scholten, P., 2022. *De prijs van een reis*. CE Delft, Delft.

Shaheen, S.A., Guzman, S., Zhang, H., 2010. Bikesharing in Europe, the Americas, and Asia: past, present, and future. Transp. Res. Rec. 2143 (1), 159–167.

Shaheen, S.A., Martin, E.W., Cohen, A.P., 2013. Public Bikesharing and modal shift behavior: a Comparative study of Early Bikesharing Systems in North America. Int. J. Transport. 1.

Shelat, S., Huisman, R., van Oort, N., 2018. Analysing the trip and user characteristics of the combined bicycle and transit mode. Res. Transp. Econ. 68–76.

Spierenburg, L., van Lint, H., van Oort, N., 2024. Synergizing cycling and transit: strategic placement of cycling infrastructure to enhance job accessibility. J. Transp. Geogr. 116.

Ter Weel, B., Witteman, J., Stäbler, D., 2023. Loonontwikkeling en AIQ in Nederland analyse van lonen, winst en AIQ. SEO Economisch Onderzoek, Amsterdam.

Tønnesen, A., Knapskog, M., Uteng, T.P., Øksenholt, K.V., 2021. The integration of active travel and public transport in Norwegian policy packages: a study on 'access, egress and transfer' and their positioning in two multilevel contractual agreements. Res. Transp. Bus. Manag. 40.

Torabi, F., Araghi, Y., van Oort, N., Hoogendoorn, S., 2022. Passengers preferences for using emerging modes as first/last mile transport to and from a multimodal hub case study Delft campus railway station. Case Stud. Transport Policy 10 (1), 300–314.

Transport for London, 2014. *Cycle Hire Implementation – phase 2 and CHEI Project Close*. Transport for London, s.l.

van Gerrevink, I., 2019. *The Role of Dockless Shared-Bikes in Delft: From a User Perspective*. Delft University of Technology, Delft.

van Gijlswijk, R., Paalvast, M., Ligterink, N.E., Smokers, R., 2020. *Real-World Fuel Consumption of Passenger Cars and Light Commercial Vehicles*. TNO, s.l.

van Marsbergen, A., et al., 2022. Exploring the role of bicycle sharing programs in relation to urban transit. Case Studies on Transport Policy 10 (1), 529–538.

van Meenen, I., 2023. *Is it Still Cost-effective to Drive on LPG?* LPG-CNG Van Meenen, s.l.

van Mil, J., Leferink, T.S., Annema, J.A., van Oort, N., 2021. Insights into factors affecting the combined bicycle-transit mode. Public Transp. 13, 649–673.

van Nes, R., Hansen, I., Winnips, C., 2014. *Potentie Multimodaal Vervoer in Stedelijke regio's*. Delft University of Technology, Delft.

van Ommeren, K., Lelieveld, M., de Pater, M., Goedhart, W., 2012. *Maatschappelijke kosten en baten van de fiets*. Ministerie van Infrastructuur en Milieu, s.l.

van Ommeren, K., et al., 2017. *Waarderingskengetallen MKBA fiets: state-of-the-art*. Ministerie van Infrastructuur en Waterstaat, Amsterdam.

Veisten, K., Fyhri, A., Halse, A.H., Sundfør, H.B., 2024. Cost-benefit assessments of an e-bike subvention programme in Oslo, Norway. Transp. Res. A Policy Pract. 180, 103974.

Villwock-Witte, N., van Grol, L., 2019. Case study of transit–bicycle integration: Openbaar vervoer-fiets (public transport–bike) (OV-fiets). Transp. Res. Rec. 2534 (1), 10–15.

Wardman, M., 2014. *Valuing Convenience in Public Transport: Roundtable Summary and Conclusions*. OECD Publishing, Paris.

Werkgroep discontovoet 2020, 2020. *Rapport Werkgroep discontovoet 2020,* s.l.: Ministerie van Financiën: Inspectie der Rijksfinanciën/Bureau Strategische Analyse.

Wilkesmann, F., Ton, D., Schakenbos, R., Cats, O., 2023. Determinants of station-based round-trip bikesharing demand. J. Public Transp. 25.