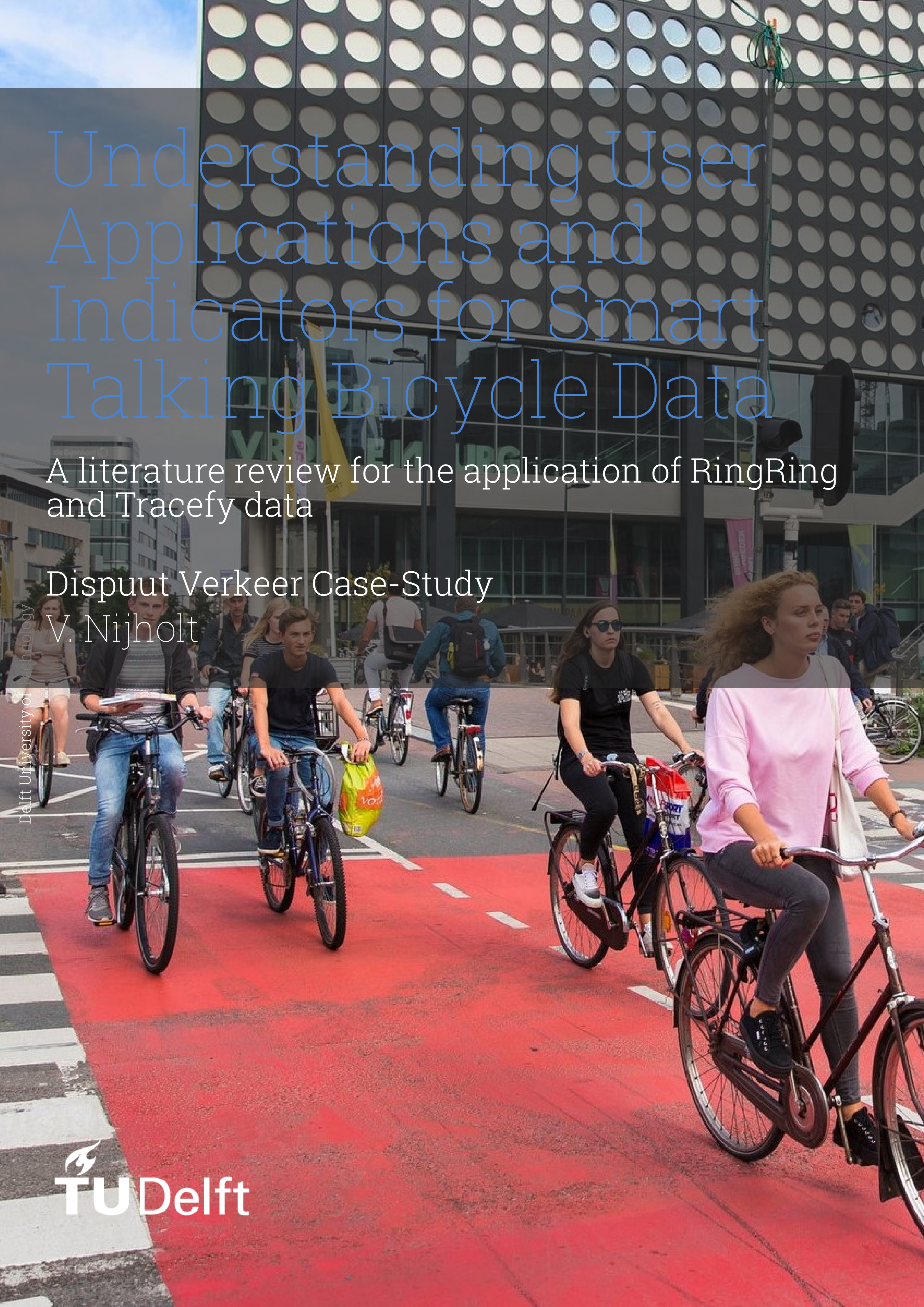

Understanding User Applications and Indicators for Smart Talking Bicycle Data

A literature review for the application of RingRing and Tracefy data

Dispuut Verkeer Case-Study

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1 Introduction

As bicycle traffic is increasing worldwide, cities need to adjust and provide sufficient policy-related support and applications. A data-driven policy approach is explored in this project. This pertains to exploit the capability of Talking Bikes data, which consists of point bicycle data from two providers (RingRing and Tracefy).

RingRing is a service which tries to stimulate cycling by linking data from cyclists to specific advantages. Societal advantages are obtained by connecting entrepreneurs with employers, cities and healthcare insurance companies. While personal advantages are acquired via collecting points which can be redeemed at local initiatives, employers and health insurers. However, this can have other advantages in terms of smart and healthy cities. Via the talking bike data, RingRing tries to contribute to clean air, climate-neutral cities, space for green, safe infrastructure, and accessibility of shops and recreation. But foremost, they want to enhance unity within society. Use of RingRing goes via an app which can be installed on a mobile device (RingRing, 2023). Tracefy on the other hand is a gps-tracking device which needs to be attached to a bicycle. By doing so the main advantage is that bicycles can be traced back after theft. Moreover, it gives notifications when maintenance needs to be done to the vehicle. With the Tracefy system, any type of electric bike or scooter is connected and sends real-time location data. By cleverly using GPS, we connect your vehicle(s) to a powerful online platform for data exchange. At any time of the day, you have insight into your vehicle(s): where they are, how they are performing, when they need maintenance. And the reach is almost limitless. Whether a vehicle is in the city or just outside: Tracefy's advanced tracking software has a highly accurate location view. (Tracefy, 2023).

1.1. Study objective

The objective of this study is to improve the data quality of an existing Talking Bikes dataset. Improvement can be reached by for example using map-matching to the point data, interpolation/extrapolation, and outlier detection. Another objective is to explore more user cases. With these use cases, potential future use of movement data can be obtained. Examples of these cases are speed heatmap distinction in peaks/off-peaks, weekdays/weekends, delay estimation or stop identification. As it stands, already five types of applications have been derived. The first application focuses on real-time traffic information and control. Within this application the way that information which needs to be processed at the actual time is discussed. A second application is multi-modal 'gebiedsgericht benutten' (area-specific utilisation) also denoted as GGB+. Within this application, the focus lies on network optimisation and traffic management plans. The third application is transportation planning in which the demand is estimated and predicted for transport services. Fourth is network design and performance in which the network design and bicycle facilities come in place. Last is the policy-making and assessment application.

1.2. Key Performance Indicators (KPI's)

For each of these applications, different traffic variables or key performance indicators (KPI's) can be derived. Following at least the following categories, these variables are divided (accessibility, reliability, safety, health. environment, equity). The KPI's which already have been introduced by Yuan et al.

(2023) are shown in Figure 1.1. In this figure the KPI's are divided based on the application and category.

Table 1.1: Key performance indicators (Yuan et al., 2023)

Talking bikes KPI's		Application				
		Real-time	GGB+	Planning	Design	Policy making
Category	Accessibility	Flow Speed Travel time Routes Stops at intersections and crossings	Flow Speed Travel time Delays Route choice Stops	OD table Flow Demand	Routes	Routes Flows Demand Distance Travel time
	Reliability	Travel time variability Incident frequency	Travel time variability Incident risk			
	Safety	Exposure Flows Speed variation			Incident Route Speed Stops	Exposure
	Health	Exposure				
	Environment	Modal shift				
	Equity					

1.2.1. Real-time application

For the real-time application, a variety of indicators has been found. With regards to **accessibility** five key indicators are the flow, speed, travel time, routes and stops at intersections and crossings. At first, the flow refers to the volume or rate of bicycle traffic on a particular route or network in real time. With this information, the number of cyclists at a time can be derived. Speed on the other hand represents the average pace at which bicycles are travelling. Thirdly, the travel time indicates the time taken by cyclists to travel from one point to another. Routes pertain to the availability and quality of bicycle routes taken by cyclists. Stops at intersections and crossings at last focus on the presence and effectiveness of designated stops or infrastructure for bicycles. From these indicators, the accessibility of locations and networks can be directed.

Regarding the **reliability** of the real-time application, the travel time and incident frequency have been obtained as indicators. The travel time variability focuses on the differences in travel time between different routes. Also, the time of day characteristics can be filtered. For incident frequency on the other hand the safety and amount of incidents noted are determined. From this information, in real-time measures can be opted for other routes etc.

Safety indicators focus on exposure, flow and speed variation. Exposure focuses on the number of interactions between cyclists and other road users. When the exposure is high, the risk on the route also increases. When the flow increases so does the exposure which has a direct relation. Regarding the speed variation, the difference between different road users can be filtered. It is generally believed that there are more safety issues when there is high variability in speeds on the road. Therefore, most policy makers aim to reduce the variation in speed.

Since an increase in exposure provides higher risk and thus a higher incident probability this is also of use for **health**. Since cyclists are one of the most, vulnerable road users any incident can cause injuries. When the exposure of cyclists is known in real-time, appropriate measures can be taken to provide for maximum health. Regarding the **environment** on the other hand, the modal shift is of importance. Bicycles are known to be a green alternative to transportation compared to car traffic. The modal shift in real-time can provide information towards a reduction in emissions.

1.2.2. GGB+ application

Within the GGB+ some overlap exists within the indicators for **accessibility** compared to the real-time application. Similar to real-time, the flow represents the volume or rate of bicycle traffic on a particular route or network. However in this case this application focuses more on the utilisation of the area. With the speeds and travel time, the time spent within an area can be derived. Delays on the other hand refer to any disruptions or time lost due to factors such as traffic congestion, road closures, or other obstacles. Route choice considers the options available to bicyclists in choosing their preferred route. While stops focus on the availability and quality of designated stops or infrastructure for bicycles along the routes.

Similar to the real-time application does the travel time variability focus on the differences in travel time between routes for **reliability**. From this perspective however, this indicator looks towards the utilisation of an area. From this perspective, locations can be filtered which cause for the differences in travel time. Incident risk on the other hand tends towards the combination of exposure and severity of the incidents. With this information different locations can be marked as hazardous.

1.2.3. Planning application

An origin-destination matrix provides information about the number of trips or movements between different origin and destination points for bicycles and can be used as an indicator for **accessibility**. Connecting this information to the demand, the level of transportation patterns can be distinguished. This information however also relates to the demand or need for bicycle infrastructure or services based on factors such as population density. Flow on the other hand focuses similarly to the previous columns, on the volume or rate of bicycle traffic on specific routes or networks. This information can be used to determine whether the transport planning is adequate.

1.2.4. Design application

Within the design, the key **accessibility** indicator focuses on the routes of the design of bicycle routes. With this information, the effectiveness, safety, connectivity, accessibility, and infrastructure quality can be assessed. This can give information on whether road design stimulates cyclists to use certain routes.

Four different indicators are derived within the design application (incidents, routes, speeds and stops) for **safety**. The first indicator shows the locations which are often vulnerable to incidents. From this information, the design can be altered to make the infrastructure more safe. In comparison to the routes, however, this indicator shows the popular routes that people take. With this information, appropriate measures can be taken to make sure the infrastructure can be capable of handling demand. Focusing on speed the average can be taken to check whether bottlenecks are present in the area. From this different designs can be proposed to reduce these locations. At last, the stops focus on the number of times that cyclists have to wait for intersections. Since stops will slow the cyclists down, the design can be altered to enhance cycling.

1.2.5. Policy making application

Within the policy-making application five indicators have been proposed (Routes, flows, demand, distance and travel time) for **accessibility**. Routes at first can be looked at to enhance specific cycling corridors within networks. Flow and demand are closely related to the number of people who use talking bicycles. Policy measures can be to try to have as many people as possible use the bicycle. With these indicators, the effectiveness of these measures can be derived. Distance and travel time on the other hand can be indicators to confirm the level of health and emission reduction of the users.

Similarly to the exposure in real-time does this exposure focus on **safety** and the number of interactions between cyclists and other road users. Since there is a direct relation between interaction and the hazard of being on the road, policy measures can be placed to reduce the exposure. Examples of these measures can be to separate cyclists from other road traffic.

1.3. Data

The data which has been made available by both RingRing and Tracefy is the following:

- Operator;
- Trip ID;
- Route;
- Time [dd-mm-yyyy:hh-mm-ss];

- Sequential number;
- Lateral (WGS84);
- Longitude (WGS84);
- Direction [Degrees];
- Speed [km/h];
- Modality;
- Accuracy [m];
- Waypoint.

2
Materials and Methods

To obtain more use cases for the talking bike data and derive KPI's for the applications a systematic literature study is performed in Scopus on the 28th of June 2023. The objective of this literature study is to find key performance indicators for the use of talking bicycle data. To find appropriate literature, the following search term has been used:

("Talking Bike Data" OR "Talking Bikes" OR "Smart Bikes" OR "Connected Bikes" OR "Connected Vehicles") AND ("Use cases" OR "Application" OR "Real-Time" OR "Transport Planning" OR "Design" OR "Policy making")

From this search term a total of 52 papers have been obtained. From these papers, the abstracts are scanned which gives an overall understanding of the content of the text. Based on this assessment, a total of 23 papers are eligible for this study. In addition to the Scopus database analysis, literature is retrieved by 'snowballing'. By reading related papers and associated references additional literature can be obtained. Due to time constraints, this has not been done in this study. A total of 23 extra scientific pieces of literature are therefore reviewed. This workflow is also shown in Figure 2.1.

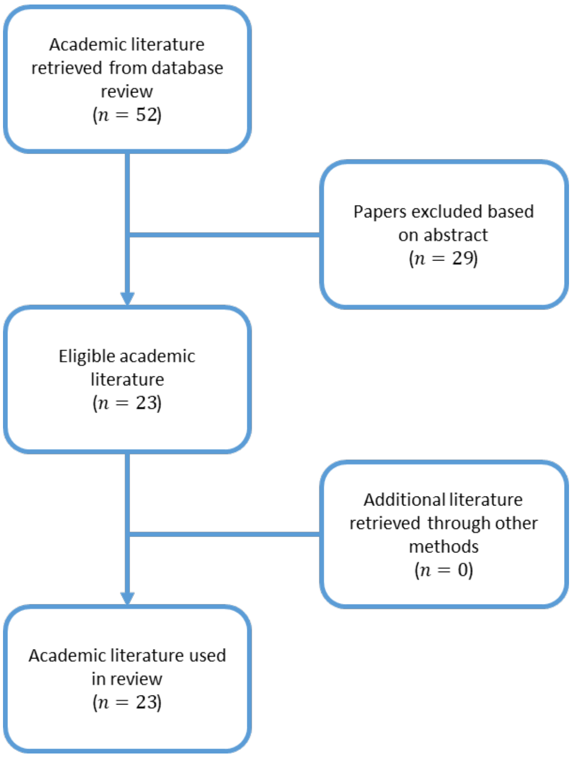

Figure 2.1: Flowchart of methodology literature review

3 Results

In this section, the results of the literature review are presented. As a result, **??** is extended with the addition of more KPI's. These results are shown in red in Figure 3.1. Within this chapter, the reasoning behind these KPI's in correspondence to the literature is discussed. This discussion is done based on the five applications. Literature which is assessed focus on the real-time (Chiariotti et al., 2018; Gironés & Vrščaj, 2018; Halim et al., 2023; Makarova et al., 2017; Muhamad et al., 2020; Razzaque & Clarke, 2015a, 2015b; Swamy & Khuddus, 2019; Warlina & Hermawan, 2020), GGB+ (Aguiari et al., 2018; Rahman & Kiyomoto, 2016; Warlina & Hermawan, 2020), Planning (Gironés & Vrščaj, 2018; Hughes, 2021; Islam et al., 2020; Rahman & Kiyomoto, 2016; Rani & Vyas, 2017; Trujillo & Correal, 2016; Warlina & Hermawan, 2020), Design (Cremades Oliver, 2021; Patel et al., 2018; Rani & Vyas, 2017; Trujillo & Correal, 2016) and Policy making (**Trujillo2016**; **175**; Cremades Oliver, 2021; Islam et al., 2020; Patel et al., 2018; Youssef et al., 2022). In this chapter, an elaboration is given for the additional indicators per application. The full table with KPI's is shown in Figure 3.1. In this table, the KPI's as discussed in section 1.2 are shown. Besides these indicators, the newly proposed indicators are shown in red. A more elaborate discussion of these new indicators is found in the sections below.

Table 3.1: Completed KPI's, newly identified indicators are presented in red

Talking bikes KPI's		Application				
		Real-time	GGB+	Planning	Design	Policy making
Category	Accessibility	Flow Speed Travel time Routes Stops at intersections and crossings	Flow Speed Travel time Delays Route choice Stops	OD table Flow Demand	Routes	Routes Flows Demand Distance Travel time
	Reliability	Travel time variability Incident frequency Retention rate	Travel time variability Incident risk Time variability	Purpose	Network connectivity	Flow
	Safety	Exposure Flows Speed variation Distance Alertness	Road utilization Road category usage	Incident frequency	Incident Route Speed Stops Light on route	Exposure Severeness of incident
	Health	Exposure Travel time Heart rate Physical effort	Travel time Routes	Travel time Distance Network utilization rate	-	-
	Environment	Modal shift Pollution reduction	Area usage	Road utilization	Usage relation greenery	Pollution reduction
	Equity	User group variation Parking availability	Facility utilization	Access OD Distribution User group variation	Network coverage	User group variation

3.1. Real-time application

Table 3.2: New identified indicators real-time application

	Accessibility	Reliability	Safety	Health	Environment	Equity
Real-time Application		Retention rate	Distance Alertness	Travel time Heart rate Physical effort	Pollution reduction	User group variation Parking availability

Regarding the real-time application of talking bikes, a more extensive list of indicators is proposed. Chiariotti et al. (2018) at first, has discussed that the retention rate can provide interesting information for **reliability** of a system. With the retention term, the number of current users compared to the number of potential users is expressed. For the case of RingRing and Tracefy, this can be determined by taking the number of people using their app versus the total number of people who have an account. With this information, the most favoured times for users of the system can be determined. Besides reliability, also more **safety** indicators can be added. In studies done by Swamy and Khuddus (2019), both the headway and object distance are mentioned. With these indicators, the risks of being involved in an incident are reduced. From the data, the headway between cyclists can be retrieved from the routes, time and direction. While the coordinates can give the distances to objects in the environment. Another indicator is proposed by Halim et al. (2023) which focuses on measuring the alertness of a driver during trips. With this information, the number of incidents can be reduced. In the context of this study, this alertness can be traced back to the deviance on the route. However, this is highly dependent on the accuracy of the RingRing and Tracefy applications. Another way this alertness can be measured is by checking the accident rates on specific routes and the time of day.

Regarding **health** three main indicators are discussed (trip duration, heart rate, physical effort). To start with the trip duration is closely related to the exposure. With trip duration, the total time one has been active can be retracted. This information can be translated to real-time applications such that a user can see how long their exercise takes (Muhamad et al., 2020). Besides the duration, Muhamad et al. (2020) and Youssef et al. (2022) discussed that the heart rate can be derived which can then be transferred towards coaches or health services. By linking the previous information with environmental conditions and other information about bicycles, the physical effort one takes can be derived. With this, the amount of calories burnt can be determined (Razzaque & Clarke, 2015a, 2015b). Trip duration is an indicator which can be obtained directly from the data provided by RingRing and Tracefy. However, heart rates can be quite difficult since this is very dependent on the characteristics of individuals. However, by map-matching the effort one takes to make a trip regarding the physical environment and speed the physical effort can be determined. With this information, an average heart rate together with the number of calories burnt can be derived.

Environmental factors focus on the total number of cyclists using their smart bikes. With the duration of their trips, a reduction in air pollution can be derived. Based on key figures regarding emissions from vehicles, the pollution reduction can be derived (Makarova et al., 2017; Warlina & Hermawan, 2020). Lastly for real-time applications, Chiariotti et al. (2018) found that the availability of bicycle parking can be of use for **equity**. With this information, everyone within society can see whether they can park their bicycle at their destination. By linking popular destinations from the data with their parking facilities this can be determined (Chiariotti et al., 2018). Another aspect discussed by Gironés and Vrščaj (2018) focuses more on equity amongst user groups for social inclusion. By linking the origins with the destination an average can be outlined about user profiles. From this information, a variation within user groups can be found.

3.2. Area utilisation (GGB+)

Table 3.3: New identified indicators GGB+ application

	Accessibility	Reliability	Safety	Health	Environment	Equity
GGB+ Application		Time variability	Road utilization Road category usage	Travel time Routes	Area usage	Facility utilization

Regarding area utilisation (GGB+) a different set of indicators are derived. When it comes to **reliability**, the time variability by which the bicycles are used can provide interesting information. With this information, the times when an individual chooses to take the bicycle can be derived. With this information, the probability that someone will take the bicycle can be obtained (Rahman & Kiyomoto, 2016). **Safety** aspects on the other hand focus on road utilisation and category usage (Rahman & Kiyomoto, 2016). With the road utilization indicator, the amount of people who use a single link within a network is determined (Aguiari et al., 2018). While for the category indicator, a distinction is made on which type of road category is more preferred by bicycles. Combining the NDW route data with available road information data these indicators can be derived. Concerning **health** the duration of trips can also be used for the GGB+ application. Since the trip duration provides insight into the time that one spends at a location the utilisation of for example green areas can be extracted. When considering health, the information of GGB+ can be related to emission characteristics of a location (Warlina & Hermawan, 2020). Analysing the **environmental** aspects (i.e. emission characteristics) of a location with the NDW routes data allows to make observations about the well-being of both the location and the journey. At last, information on utilisation from specific facilities can also give insights in **equity** for GGB+. Since different facilities are used by different people, a thing or two about equity within bicycle use can be said. By taking OD information from the NDW data, assumptions can be made about whom are using the bicycles.

3.3. Planning

Table 3.4: New identified indicators planning application

	Accessibility	Reliability	Safety	Health	Environment	Equity
Planning Application		Purpose	Incident frequency	Travel time Distance Network utilization rate	Road utilization	Access OD Distribution User group variation

From a planning perspective at first the purpose of why people use bicycles can provide insight into potential uses and **reliability** (Rani & Vyas, 2017). By extracting the destinations where people who use the bikes are going the potential use can be derived. By comparing this to the services and facilities present at different locations, the reliability of using the bicycle can be obtained. With the NDW data provided, the destinations when a trip ends can be filtered. Via map-matching these destinations can be linked to activities. On a different note, the incident frequency proves insight into the number of incidents happening and **safety**. Rahman and Kiyomoto (2016) stated that with this information potential hazardous locations can be extracted. From the NDW data, the number of times that the hazardous location is passed can be derived. From a **health** perspective, the travel time indicator can be used to see how much time is spent on the transportation network. Moreover, the total distance cycled can be derived based on the route characteristics. These two indicators are determinants of the health of people who use the transportation network (Hughes, 2021). The utilisation rate on the other hand is an indicator which focuses more on the extent to which the infrastructure is used by cyclists (Islam et al., 2020). From the NDW data, the number of routes within a network can be derived. In this way, something can be said about the overall health of people travelling on the network. With regards to the **environment**, road utilisation can also give interesting information on the number of roads which are used by environmentally friendly bicycles (Warlina & Hermawan, 2020). **Equity** on the other hand has three different indicators (access, distribution and user group variability) (Gironés & Vrščaj, 2018; Trujillo & Correal, 2016). For the last group, an elaborate discussion is provided in the real-time application. However, for the planning application, this information can be used to see to which extent the network is used by all groups in society. Access on the other hand is an indicator to determine which parts of the network are underutilised. This closely relates to the distribution of origins and destinations. With this information, the inclusiveness of the transportation network can be made insightful.

3.4. Design

Table 3.5: New identified indicators design application

	Accessibility	Reliability	Safety	Health	Environment	Equity
Design Application		Network connectivity	Light on route	-	Usage relation greenery	Network coverage

With design the focus lies on the design of infrastructure as road layout. When considering **reliability** of this design, Rani and Vyas (2017) discussed that network connectivity gives insight into the use of different routes. By taking the connectivity of taken routes directly from the NDW data and setting this off against the network the reliability of the design can be obtained. With regards to **safety**, the number of lighted routes during night time that people take can be used to check whether or not different routes are perceived as more safe (Patel et al., 2018). From the NDW data, the routes can be directly extracted and map-matched. The extent to which infrastructure is used more often when there is more green present can be a **environmental** indicator (Cremades Oliver, 2021). In a similar way to the lighted routes, this can be done from environmental and planning perspectives. With regards to **equity** on the other hand the extent to which the complete network is covered is an indicator concerning equity and social inclusivity (Trujillo & Correal, 2016).

3.5. Policy making

Table 3.6: New identified indicators policy making application

	Accessibility	Reliability	Safety	Health	Environment	Equity
Policy making Application		Flow	Severeness of incident	-	Pollution reduction	User group variation

At last, does the policy-making application focus on the way different policies can be evaluated. With **reliability** the effectiveness of specific routes can be evaluated based on the flow (Youssef et al., 2022). Concerning **safety**, Islam et al. (2020) discussed that the severity of any incident can be an indicator of to which extent safety policies are effective. Since many governmental bodies try to enhance the **environment** and thus reduce pollution this can be tested with the pollution reduction indicator (Patel et al., 2018). From the flow and their respective distance, the amount of emissions which are not put in the air can be derived (Cremades Oliver, 2021). From an **equity** perspective, the user group variation can be an indicator to assess the policy of social inclusiveness (Trujillo & Correal, 2016).

4 Discussion

In this report, a literature review is done to find use cases for smart talking bicycle data. A link is made between data provided by the provided NDW data from RingRing and Tracefy. Five different applications have been identified in previous studies (Real-time, GGB+, Planning, Design and Policy making). Performance indicators which can be used for these applications are subdivided into six groups (Accessibility, Reliability, Safety, Health, Environment and Equity). Based on a systematic methodology via Scopus, a list of 23 academic papers has been defined. A more extensive list of indicators has been derived based on this literature review.

Within the real-time application, five indicators (flow, speed, travel time and routes) are found to assess the accessibility of the talking bicycles. Combining these indicators can provide insight into the movements and decisions made by cyclists. The reliability of using these bikes can be assessed with the travel time variability, incident frequency and retention rate. From a safety perspective the exposure, flows, variation in speed, travel distance and driver alertness are indicators for the real-time use of bicycles. From these indicators safety measures can be derived to assess potential hazardous locations. Exposure however can also be used to relate to health. As an example, the exposure to emissions can be derived based on this. Moreover does this count for the travel time, heart rate and physical effort. While the modal shift in combination with pollution reduction in real-time can say something about the environmental impact. From an equity point of view the user group variation and parking availability can be used as indicators. Combining these indicators, information can be obtained relating towards the uses of bicycles and cyclist behaviour. When comparing the travel distance and physical effort to ones user group some characteristics of cyclist groups can be distinguished.

For the GGB+ application, many similar indicators can be used to indicate accessibility compared to the real-time application. However, the delays and route choices made by cyclists can provide additional information about the utilisation of different areas. Combining this with area information (e.g. green per km^2) things can be said popular locations to spent time. Incident risk is besides the (travel) time variability an indicator of the area utilisation concerning reliability. Regarding the safety two indicators are derived being the road utilisation and road category usage. Regarding travel time and routes taken, it can be located whether the shortest route a hypothesis can formulated whether cyclists always take the shortest routes from a health point of view. Also the influence of crowding can be taken into account for the assessment of the environment within area utilisation. From an equity perspective, the facility utilisation is an indicator for the usage of different destinations and activities.

From a transport planning perspective, the origin-destination table can together with the flow and demand provide insight in accessibility. Taking growth into account predictions can be made regarding potential bicycle use. This can then be extended towards route usage, travel time and other cycling characteristics. Focusing on the reliability of planning, the purpose of people to travel can be used as an indicator. Whereas the frequency of incidents relates to safety of the users within the system. Similar indicators can be used when looking at health, however the utilisation rate of the entire network can say something about the overall healthiness of the network. Road utilisation on the other hand can indicate the use and crowding on the infrastructure. While access, OD distribution and user group variation focus on an equity perspective. When obtaining the purpose and travel time different user classes can be found. In combination with area characteristics predictions can be made more clearly for specific area developments. Network utilisation in combination with access can provide insight in whether specific roads are still functioning correctly in the network.

Accessibility from a design perspective can be indicated by routes taken by cyclists. When determining popular routes and comparing this to the road characteristics, underlying cyclist preferences can be derived. The network connectivity indicates whether the design of the network and thus the reliability of the network is sufficient. Whereas the incidents, routes, speed, stops and lights on routes are indicators from a safety perspective for infrastructural design. Greenery and network coverage are identified as indicators for environment and equity respectively. The network coverage indicator can provide insight in whether all social groups can access the network.

Policy-making indicators which tend towards accessibility are the routes, flows, demand, distance and travel time. From this the effectiveness creating key routes can be assessed. Also to stimulate people who take bicycles can be derived based on these indicators. Whenever the flows stay constant over time, the reliability of the system can be indicated. Exposure of the cyclists and severity of accidents are indicators of safety within the policy-making application. Whereas the pollution reduction (environment) and user group variation (equity) are additional indicators.

Due to time constraints there was no academic literature obtained via snowballing. Since snowballing can lead to the extent of the matrix of indicators and applications this is recommended to do in subsequent studies. With regards to the applications used, these can also be extended. Examples of applications which can be introduced can relate to theft and vandalism (Razzaque & Clarke, 2015b), body data matrices for health insurance/care companies (Hughes, 2021). Building on this, can the data provide insights into unauthorised parking. Which can be used by law enforcers (Patel et al., 2018). Within the applications and indicators matrix, some cells are left open. Therefore, further search has to be done towards design and policy-making applications concerning health. Examples of indicators can relate to the way that different road categories can be used by active modes.

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