A corridor-wide, multi-criteria assessment of the Zaancorridor TOD project

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Abstract
Where the car used to be the most favorable option for travel, changing viewpoints have led to an increasing interest towards public transportation. The general opinion is that the current extent to which modern society utilizes the car is unsustainable, but public transport is not a satisfying alternative. The concept of transit-oriented development (TOD) attempts to make public transport the natural way of moving through the urban pattern by integrating the transit system with spatial planning. This thesis tries to assess the urban design on its suitability of supporting public transit ridership, using the Dutch Zaancorridor project as an example. Through both quantitative analysis and cartography, the comparative differences between the station areas were analyzed and compared. From these results, it was discovered that only Amsterdam Central and Alkmaar can, theoretically, be deemed proper implementations of TOD. The smaller villages are weaker links in the total project, and must be critically looked at if the province wants to stay true to the concept and promote it to other parts of the Netherlands.

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1. Introduction

The public opinion on the importance of the car as the primary means of transportation has shifted over time (Urry, 2004). Ever since its popularization in the early 20th century, it has established itself as the definitive way to move oneself around. Its prevalence in modern culture has shaped many aspects of today's society. This includes socio-cultural aspects, such as flexibility in time management and a sense of individuality, but it has also influenced the physical world for a long time. In time, infrastructure and urban form were designed on the condition that car accessibility should be maximized. This has had irreversible effects on the physical design of urban areas, such as in the extensive infrastructure networks and city layouts.

However, in recent years, public opinion on the private car seems to have changed. Goodwin and Van Dender (2013) provide an overview of academic discourse on the phenomenon known as 'peak car'. The expansion of car usage has hit a ceiling in the past decade. Although opinions on the matter differ, they conclude that car use has become saturated. The marginal gains of increased car ownership and driver's licenses per 1000 inhabitants have dropped due to increased density of destinations, policies actively combating car usage (mostly in large city centers), and the increased availability and utility of alternative modes of transport.

Most of these developments have been the result of the years of effort stemming from New Urbanist and sustainable mobility ideologies (Marshall, 2003; Pharoah and Apel, 1995). After realizing the polluting and costly side effects of car travel, many policy-makers have actively tried to make travel more sustainable. The underlying principles have been adopted by many national and supranational governments. A popular concept within this school of thought is transit-oriented development (TOD), first described by Peter Calthorpe (1993). The concept is intended as a way to make more destinations accessible by means other than the car. Since its inception, many studies on the concept have been performed (Jacobson & Forsyth, 2008; Pojani & Stead, 2015; Thomas & Bertolini, 2014), though it is only recently discussed whether there are common practices in the planning process that lead to a larger degree of success. "Success", here, is defined as a relative decrease in car use (or a relative increase in the use of other modes of transport). Both the content of the plan, as well as the process leading up to its implementation, are important to consider.

This research aims to find out how the intended modal transition of future TOD projects can be improved by looking at past projects and evaluating their development processes and results. By using a pilot project in the Netherlands, called the *Zaancorridor*, as an example, and deriving what is good practice based on academic literature and actual results, the effectivity of such projects can be evaluated. This will help make future projects more effective in reaching their desired outcomes. A corridor-wide, multi-criteria approach is necessary to fully assess the effect of such an integrated planning project. The research question is formulated as follows:

How can the evaluation of a past transit-oriented development project in a Dutch context contribute to the effectiveness of future projects in terms of public transport ridership?

The subquestions are:

-How are TOD's supposed to affect the modal split for local and regional residents?

-How can elements in urban TOD designs be systematically categorized and compared?

-To what extent do the TOD areas along the Zaancorridor conform to the proposed designs?

The concept of the TOD and its intended results are described in the following chapter, as well as the criteria on which TOD should be assessed. The data and methods necessary to make these assessments are detailed in chapter 3. The results, split per station along the project, will be discussed in chapter 4. Conclusions will be drawn from the calculations and observations in chapter 5.

2. The TOD concept: intention, shortcomings and assessment

Scientists and policy-makers alike have been looking for ways to effectively curtail car use, mostly for economic and environmental purposes. The TOD concept by Calthorpe (1993) was one such concrete efforts to facilitate this. The most important principle is a clustering of activities near public transport nodes. Residential, commercial and office real estate are to be mixed so as to maximize the number of relevant destinations within an area. Walking and cycling would suffice for trips within the area, and public transport (most commonly train stations or bus nodes) allows for access into and out of the area. Quinn (2006) describes the example of Laguna West in California, USA, an attempt at achieving the predicted benefits of such developments. Unfortunately, this development was rather unsuccessful in driving back car ridership. At the time of planning, this region was intended as an exemplary TOD, being connected to the greater city of Sacramento, but this intention was seemingly lost over time. The main connection to the area is a large highway, instead of the intended railway extended from Sacramento. Density is low and uses are barely mixed. Most importantly, it is the only development in a wide area with such a spatial layout. He observes similar spatial patterns in the experimental new town of Northstowe, UK. Many of the faults observed in the Sacramento area are mostly of organizational nature, most notably a lack of understanding of the local residential and commercial market situation, a local approach where the implications for the wider region are not sufficiently taken into account, and misjudgment of how ingrained the car is in American culture (Urry, 2004). In conclusion, to effectively realize its goals, a broader implementation is necessary.

These criticisms are not only directed towards the policy-makers who made this plan, but also to the concept itself. These insights were not included in the initial concept by Calthorpe (1993), pointing towards some serious flaws in its original design. The concept remains of value, though, as many researchers have elaborated and tried to perfect the concept, making it more applicable and effective. Despite the multitude of criticisms that the concept has received over the years, many policy-makers have attempted to apply it in their plans, with varying degrees of success. Thomas and Bertolini (2014) give an in-depth overlook of several case studies all over the world, and especially their management and implementation strategies, in an attempt to derive common ‘success’ criteria within the planning process. They have performed an extensive meta-analysis on 11 different case studies of the implementation of TOD in various cities (or city regions that have shown to form a solid urban network together) and found a grand total of 16 aspects of planning processes that can influence successful implementation (see Figure 1). These categories could then be categorized into 3 topics: plans & policies, actors and implementation. The degrees in which these criteria were present differed between projects, as do their degree of success. Their research reinforces that proper implementation can only follow from an equally proper planning process. Their work creates a valuable foundation for other works discussing commonalities in planning practices.

However, they describe ‘success’ not by an actual decrease in car ridership and an increase in trips made through other transport modes, but rather merely as the actual realization of the project. In other words: if the envisioned buildings and infrastructure are built, it is deemed successful. As seen from the example given by Quinn (2006), this does not necessarily mean the desired effects are achieved. From their research, it is hard to say whether the cases were actually bringing down car ridership and boosting public transport use, which is ultimately the essential goal of TOD. This information is valuable in assessing the actual efficiency of such projects.

Content-wise, similar procedures for finding out good practices in TOD planning have been done. Jacobson and Forsyth (2008), like Thomas and Bertolini (2014), performed a cross-case study on 7 TOD developments, but focused solely on the United States, and, more importantly, on urban design factors. Based on their compiled literature and evaluations, they propose 12 principles of effective TOD design (see Figure 1). These, too, can be divided into 3 categories: place-making, facilities/logistics, and processes. The principles in the lattermost category have overlap with the procedural success factors mentioned by Thomas and Bertolini (2014), which serves to reinforce their importance and implications in the end result. They conclude that there are plenty of tools and design features available for planners to work with to create attractive, livable and accessible areas. Local context, naturally, remains decisive in which tools are appropriate. Strong collaboration with all stakeholders also remains a necessity.

This context dependence drove Pojani and Stead (2015) to perform a similar analysis in the Netherlands. Up until now, literature on TOD has mainly focused on its performance in the setting of the United States, or in general settings with many context-specific details being left out. They used the same principles posed by Jacobson and Forsyth (2008). Through extensive workshop sessions and discussions, many overarching benefits and challenges of design approaches could be identified, as well as a general image of the ‘ideal’ Dutch TOD. Although they found that the general view of a successful Dutch TOD is mostly similar to the general concept, some context-specific elements were discovered, such as a common aversion towards high-rise buildings, grid-like road structures and excessive open (green) spaces.

Their research limits itself to largely unrelated, single spaces around stations. As illustrated by Quinn (2006), singular TOD projects do not suffice in attaining the results that planners are looking for. A wider approach is needed to serve as many origins and destinations as possible. Therefore, projects must also be evaluated on that same scale. To that end, this thesis intends to look at the results of TOD implementation on the scale of the transit corridor.

Figure 1 on the next page shows a conceptual model of the purpose of this research. The 3 categories on the process side are derived from the work of Thomas and Bertolini (2014). The 3 categories on the content side are derived from Jacobson and Forsyth (2008). The elements within each category are the corresponding success factors found in the respective literature. All these factors together contribute to the actual realization of the project. Ideally, the successful realization of such a project should lead to a relative increase in public transport ridership (Calthorpe, 1993). Once this is achieved, it is worthwhile to evaluate the content and process of the plan and find out what made realization go so well. A continuous evaluation of these practices after every realized plan will contribute to a steady body of good practices in TOD planning for the future, creating a positive feedback loop (Thomas & Bertolini, 2014). This effect is represented by the plus sign, highlighting the iterative nature of spatial planning. In the context of the Zaancorridor, it is expected that the largest and most important stations, such as Amsterdam Central, Amsterdam Sloterdijk and Alkmaar, will have the most beneficial spatial patterns, as they receive large amounts of traffic daily. Furthermore, it is expected that the most effective measures will be those that directly tackle the connections to and from the main stations, such as the presence of bus and tram lines straight to the station, efficient road structures and good cyclist and pedestrian access.

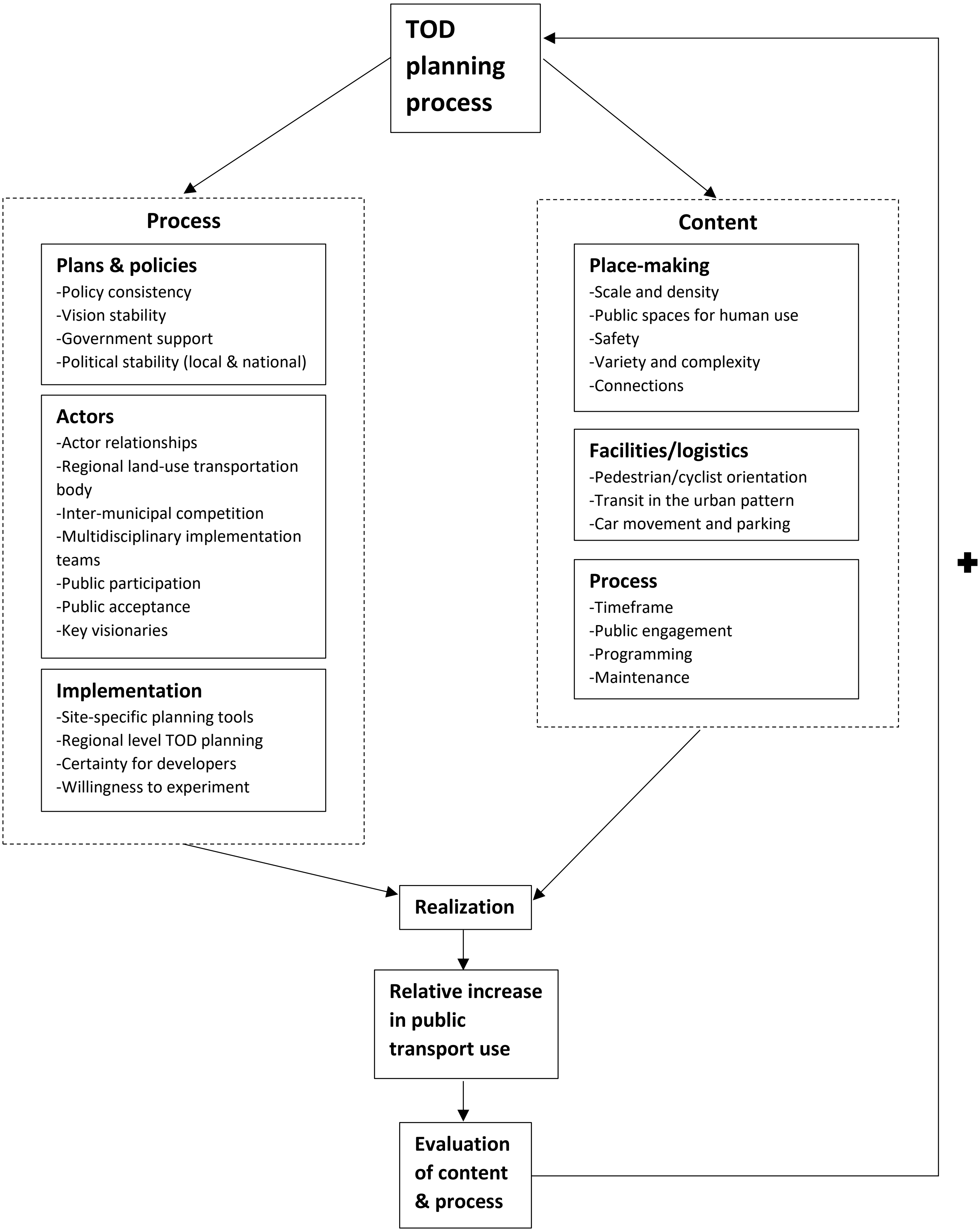

Figure 1: conceptual model showing the positive feedback loop of evaluating TOD projects. Sources: Jacobson & Forsyth, 2008; Pojani & Stead, 2015; Thomas & Bertolini, 2013; author.

3. Data and methodology

The basis for this research lies in the findings of the work by Jacobson and Forsyth (2008) and Pojani and Stead (2015). A selection of their urban design issues will be taken, with a focus on mobility and accessibility. The selection can be found in Table 1 below, including a short description of how the different criteria are assessed, as well as their respective data source. The criteria will be assessed in a 2 kilometer wide radius around the main station, based on the walking and cycling distance that Pojani and Stead (2015) found is comfortable for the majority of the people.

Dimension	Criteria	Quantitative analysis	Cartography
Scale and density	Destinations within walking or cycling distance of transit stops	Number of buildings in area (BGT)	-
	High-rise, high-density in immediate vicinity of station, medium-rise further away	Height-distance correlation (BAG 3D)	-
Connections	Pedestrian- and cyclist-friendly street networks directly connecting local destinations (e.g. cut-through paths)	-	Presence of walking and cycling shortcuts (BGT)
	Bus and tram access to and from the TOD area	Number of non-central transit stops in area (RUG)	Spread of transit stops
	Avoid barriers (highways, large parking lots etc.)	-	Presence of barriers (BGT)
	Pedestrian and cyclist bridges and tunnels to surpass barriers	-	Presence of passages (BGT)
	High-connectivity street network (grid, fan, radial)	Traffic flow analysis (BGT)	-
Pedestrian/cyclist orientation	Equal quality of walking and cycling infrastructure	Ratio of cycle paths vs. pedestrian paths (BGT)	-
	Ample bike parking space at stations	-	Capacity, open vs. closed spaces (Google Maps)
Transit in the urban pattern	Central position for transit station	Mean distance from buildings to station (BGT)	-
	Modal integration (i.e. connections between buses and trains)	Number of transit lines converging on station (RUG)	-
	Underground rail tracks	-	Presence of railway tunnels (BGT)
Car movement and parking	Car parking discouraged (hidden, underground, limited capacity, away from stations)	m^2 of car parking space (BGT), parking space ratio	-

Table 1: list of assessment criteria and their method. Source: Pojani & Stead, 2015.

First, a small summary of the planning processes of the Zaancorridor project will be given, based on policy documents and reports (Provincie Noord Holland & Vereniging Deltametropool, 2014; Rutten, 2016). This will be briefly compared with the success criteria as stipulated by Thomas and Bertolini (2014), but will not be the main focus. There will be more emphasis on the physical design issues (Jacobson & Forsyth, 2008; Pojani & Stead, 2015). For every station along the corridor, there will be a separate section featuring the results of the various calculations and observations. These will be summarized in an assessment grid, which will be useful in comparing the different TOD areas with one another.

For spatial data, the *Basisregistratie Grootschalige Topografie* (BGT) is used (Kadaster, 2020). This is a registry of nearly every spatial entity in the Netherlands. This allows for plenty of calculations, such as parking space ratio, the ratio of cycling and pedestrian infrastructure, and the number of relevant destinations within the area. This source is from official land registry offices, and is deemed sufficiently reliable. The relevant layers used from the BGT can be found in Table 2 below.

BGT layer name	**(Literal) translation**	**Relevant examples**
waterdeel	Water	River, creek, ditch
overbruggingsdeel	Bridge	Bridge, viaduct, flyover
wegdeel	Roads	Asphalt road, cycle path, sidewalks
tunneldeel	Tunnels	-
spoor	Railroads	Train tracks, tram tracks
pand	Buildings	-

Table 2: list of relevant BGT map layers. Source: Kadaster, 2020.

To determine building height, the BAG 3D is linked to the buildings (3D Geoinformation, 2020). This data set provides nearly every building with its appropriate height, albeit rather inaccurately. This will help in showing the height, and subsequently the density, of the built area around the stations. Cartography will be used to discover specialized cycling and pedestrian infrastructure facilitating more convenient access to the area and the station. Information regarding transit stations will be mainly derived from a dataset provided by the University of Groningen (RUG, 2018), as well as satellite imagery from Google Maps.

For a more qualitative assessment on some of the criteria, cartography through Google Maps and the geographic information system ArcMap are conducted to obtain an image of the area which cannot feasibly be made by other means. These assessments include the road use, the type and capacity of bicycle parking spaces in and around the station, and the presence of bridges and tunnels that serve to cross barriers such as highways and railways. Ideally, the observations would have been made on-site, but due to the CoViD-19 pandemic and the national lockdown at the time of writing, this was deemed too irresponsible. This will negatively affect the quality of the observations, but it is deemed the most ethical solution under these circumstances.

The results will be discussed per criterion. It should be noted that a number of these areas have great overlap with one another (e.g. Alkmaar and Alkmaar North are less than 2 kilometers apart). This will inevitably affect comparisons made between stations, with those closest to one another having very similar results. Additionally, people living within the radius of two different stations will likely choose the one closest to their origin, assuming they travel along the Zaancorridor. Even so, the less attractive alternative should still be seen as a potential option, especially when it allows access to different bus or train lines.

4. Results

4.1: Policy and process

The Zaancorridor project in North Holland was intended as a pilot to test the feasibility of a TOD-like planning approach in the Netherlands (Rutten, 2016). The stations it covers can be found on Figure 2 on the next page. It was officially started in December 2014. The idea is to promote public transit use along the rail line stretching from Amsterdam Central to Heerhugowaard. This project was preceded by an extensive opportunity analysis, called *Maak Plaats!* (lit.: make room!) (Maartens, 2014). This analysis was a collaborative effort by the province of Noord Holland and the *Vereniging Deltametropool* (2013). They formulated 10 principles on which future spatial developments in the province of Noord-Holland should be based.

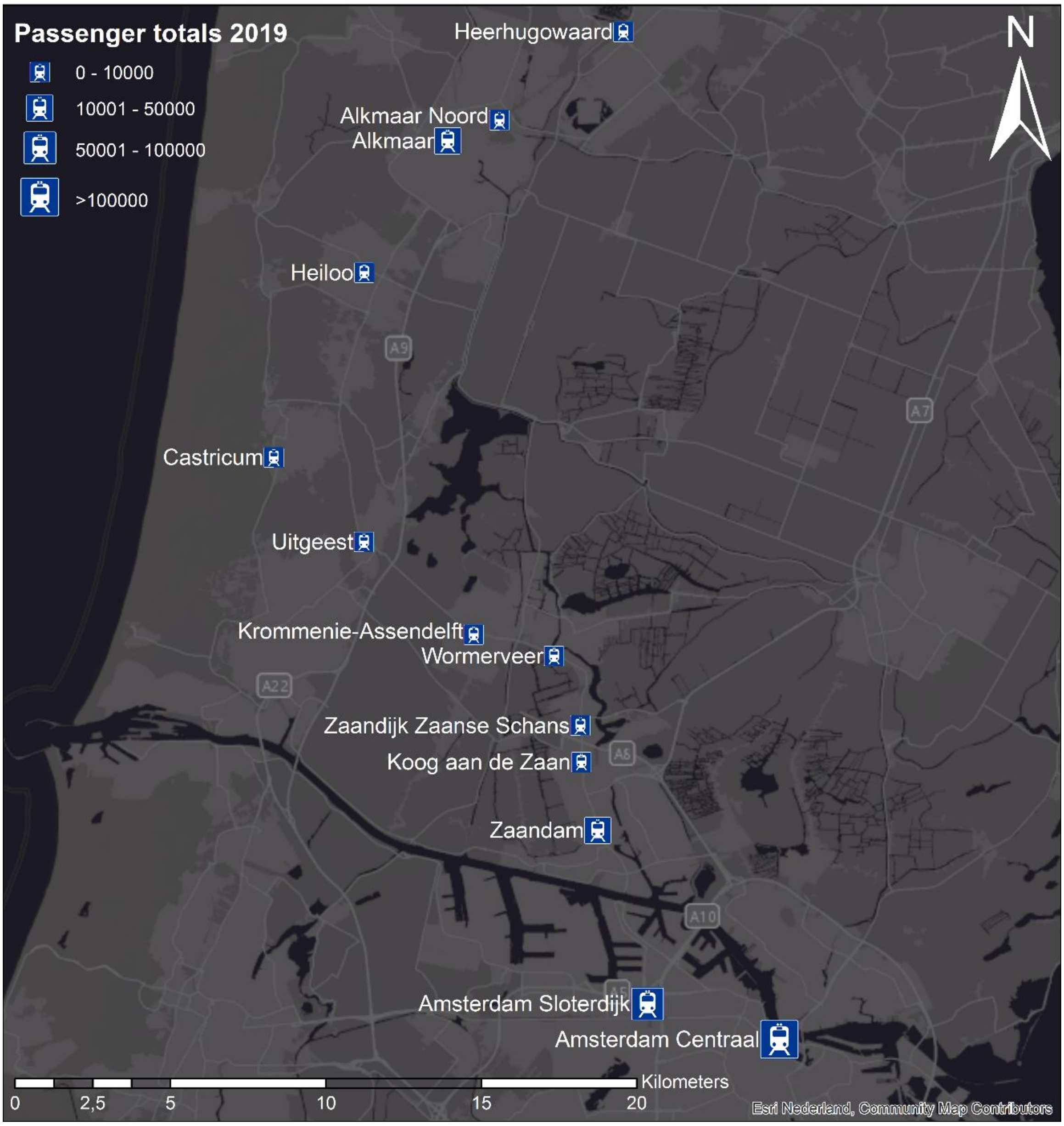

Figure 2: relative location and 2019 daily passenger averages of the Zaancorridor stations. Source: NS, 2020; author

These principles are:

-1: integrate spatial planning and railway transport improvements;

-2: realize at least 50% of new housing demand around public transit nodes;

-3: prioritize existing projects around transit nodes over new ones;

-4: prioritize multimodal accessible areas for excess spatial expansions;

-5: reduce office space vacancy in areas with less multimodal accessibility;

-6: new offices only in highly accessible, high-quality areas;

-7: regional services preferably on multimodal accessible locations;

-8: improve modal transitions;

-9: create gateways to nature;

10: provide open space around transit nodes to make them attractive.

The Zaancorridor plan followed from these principles. A large number of parties is involved, including national and provincial governments, railway operators (ProRail, NS, Arriva), land-owners, investors and developers to name a few. A large issue is that there is no centralized directing and monitoring body. This has caused some procedural difficulties, in particular with responsibility. In practice, such collaborative works lead many stakeholders to be more concerned with their own issues rather than the collective, and there is a lack of shared responsibility. Based on early process analyses, the collaborative platform of Maak Plaats! (Provincie Noord Holland & Vereniging Deltametropool, 2013) summarized the issues in 6 topics:

-1: making parties aware of the shared responsibility by recognizing the consequences of non-participation;

-2: approach problems on the scale of the corridor to make it both feasible to manage and sufficiently impactful;

-3: collaborate in experimenting with new tools and approaches;

-4: make use of existing plans and willing actors, and collaborate with them;

-5: create an organized collaboration and communication network;

-6: create a consistent investment strategy with public funding to leverage private funding in the future.

Some of the issues as formulated by Thomas and Bertolini (2014) become apparent here. There is government participation and financial support, which helps legitimize the project. However, communication and responsibility issues, as well as conflicting interests point to lacking actor relationships. The same goes for municipalities, which are mainly focused on their own markets instead of what they could achieve in collaboration (Maartens, 2014). The organization lacks a central hierarchy, which, while allowing for viewpoints from many different sides, restrains the executive potential of the project. The tools for experimentation are plentiful, in terms of both policy and (site-specific) spatial development, but the involved parties appear to be apprehensive in using them. All in all, from a process standpoint, there is plenty of potential, but it is up to the actors to show their willingness to use it.

4.2: Comparative assessments per criterion

The following pages will consist of per-criterion assessments of all the stations as stated in Table 1. The raw data calculations and full-size maps are in Appendices A-M.

1.Destinations within walking or cycling distance of transit stops

The number of buildings within each TOD area is tabulated below in Table 3 below. The more buildings present within walking or cycling distance, the more beneficial it is in facilitating public transport use.

	Buildings in coverage area
Amsterdam Central	19567
Amsterdam Sloterdijk	7759
Zaandam	32667
Koog aan de Zaan	29168
Zaandijk Zaanse Schans	23613
Wormerveer	19672
Krommenie-Assendelft	22706
Uitgeest	11154
Castricum	10755
Heiloo	11370
Alkmaar	19376
Alkmaar North	18981
Heerhugowaard	15934

Table 3: number of buildings in coverage area of each station. Source: Kadaster, 2020.

Amsterdam Central covers a large amount of buildings, despite the large station building and the many waterways running through the city. Conversely, Amsterdam Sloterdijk, covers water, large parks and comparatively more railroads, as well as large buildings along the harbor of Amsterdam. This explains the relatively small number of buildings. Everything from Zaandam to Krommenie-Assendelft belongs to the Zaanstad municipality and serves as growth hub for the city of Amsterdam, so it has seen rapid urbanization in the last years. Castricum and Heiloo are rather isolated villages. Alkmaar and Heerhugowaard together form another heavily urbanized region.

<u>2.High-rise, high-density in immediate vicinity of station, medium-rise further away</u>

The Euclidean distance to the station has been calculated for every building in the coverage area. This variable, together with the building height provided by the BAG 3D (3D Geoinformation, 2020), have been tested for correlation. The Pearson correlation coefficient indicates the strength of the correlation. To account for the inaccuracy of the BAG 3D, only buildings with a height of at least 2 meters has been taken into account. Significance is taken for $p < 0,05$. Ideally, the result is a significant, negative relation, meaning that building height decreases as distance increases. The results can be seen in Table 4 on the next page.

Of all the stations, only Zaandam, Uitgeest and Alkmaar show something that could be considered a relation, with Uitgeest having the strongest one. These relations are negative and significant, so it is somewhat reasonable to assume the buildings are, on average, higher near the station than those further away from it. Koog aan de Zaan shows the weakest relation, but is also nonsignificant. The rest, while giving statistically significant results, are considered too weak to assume a relation.

	Number of included buildings (*N*)	Pearson correlation	Significance (*p*)
Amsterdam Central	18394	-0,086	0,000
Amsterdam Sloterdijk	7149	0,042	0,000
Zaandam	31364	-0,106	0,000
Koog aan de Zaan	28479	0,008	0,205
Zaandijk Zaanse Schans	22902	0,068	0,000
Wormerveer	18521	-0,041	0,000
Krommenie-Assendelft	21673	-0,049	0,000
Uitgeest	10769	-0,150	0,000
Castricum	10214	-0,068	0,000
Heiloo	10751	0,044	0,000
Alkmaar	18428	-0,105	0,000
Alkmaar North	17650	0,085	0,000
Heerhugowaard	15021	-0,044	0,000

Table 4: Pearson correlation tests for height and distance from station. Source: Kadaster, 2020,

3.Pedestrian- and cyclist-friendly street networks directly connecting local destinations

Bike and pedestrian paths that cut through areas where cars would have to go around it, make it easier for cyclists and pedestrians to move through the urban fabric. The maps can be found in Figure 3 on the next page (full-size in Appendices). Because not every single small pathway can be analyzed like this, especially in dense road networks, the greatest focus here is on the presence of paths that provide a substantial shortcut for cyclists or pedestrians as compared to cars. Such paths are clearly present in Uitgeest, with a large cycle path connecting the southwestern built-up area with the rest, as well as in the city of Alkmaar, especially just south of Alkmaar North. Surprisingly, Amsterdam Central does not feature many such shortcuts. It does, however, provide spacious pedestrian access to and within the city center whereas cars only have relatively little access.

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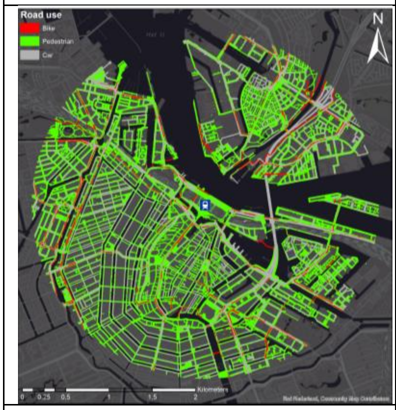

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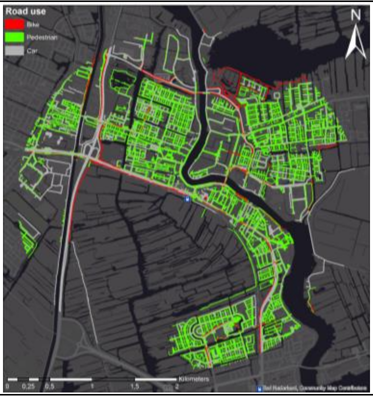

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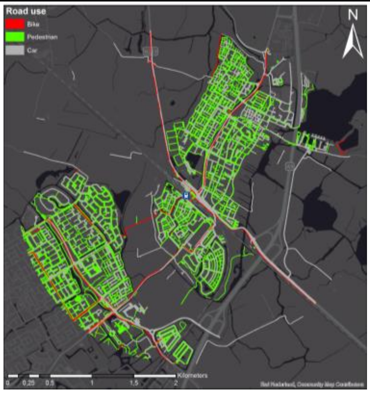

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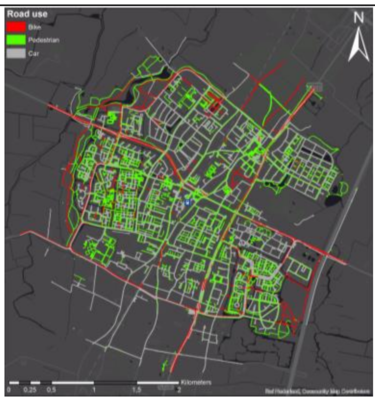

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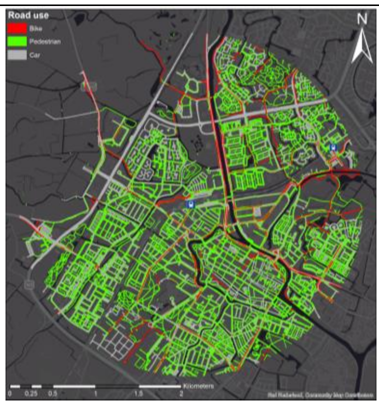

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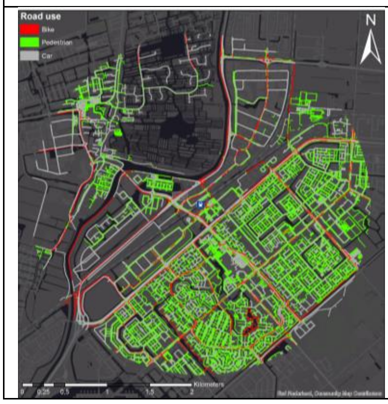

Figure 3: road use around the stations. Source: Kadaster, 2020. Large versions in Appendices.

4.Bus and tram access to and from the TOD area

Most stations only feature bus stops. The exceptions to this are in Amsterdam, where tram, metro, and, in the case of Amsterdam Central, ferry lines are featured as well. The number of unique stops in the coverage area are tabulated below, split per category (Table 5). The locations of the stops can be found in Figure 4 (full-size versions in the Appendices).

	Bus stops	Metro stations	Tram stops	Ferry harbors
Amsterdam Central	62	3	32	6
Amsterdam Sloterdijk	41	4	18	-
Zaandam	45	-	-	-
Koog aan de Zaan	51	-	-	-
Zaandijk Zaanse Schans	44	-	-	-
Wormerveer	39	-	-	-
Krommenie-Assendelft	22	-	-	-
Uitgeest	12	-	-	-
Castricum	22	-	-	-
Heiloo	12	-	-	-
Alkmaar	64	-	-	-
Alkmaar North	59	-	-	-
Heerhugowaard	31	-	-	-

Table 5: number of unique transit stops per coverage area, per type. Source: RUG, 2018.

An important thing to note is that most tram stops found in both Amsterdam Central and Amsterdam Sloterdijk also have bus stops, which improves multimodal traveling options and makes transitions as smooth as possible. The stations in the Zaanstad municipality cover a relatively large number of bus stops, but do not support any other transport methods besides the train. In terms of bus stops, Alkmaar rivals Amsterdam Central, but the latter is easily the better performer due to the many different modes that coexist with the bus network.

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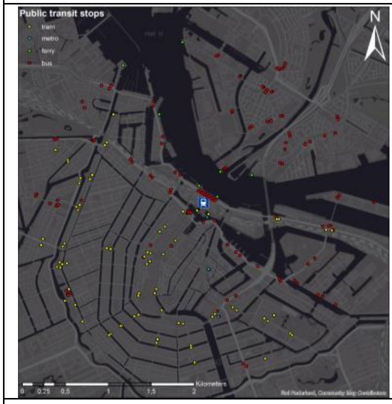	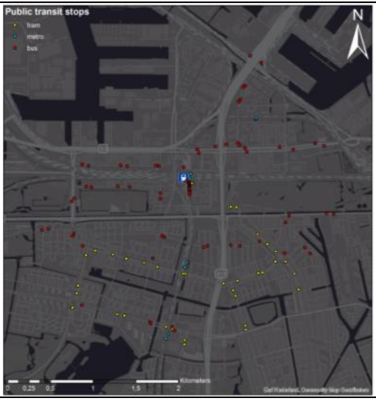	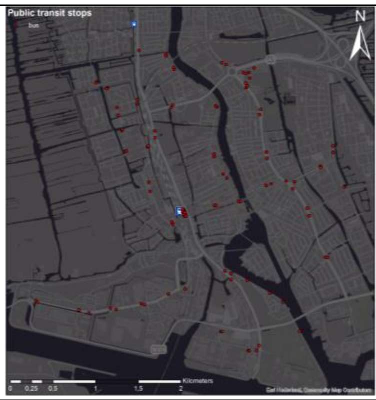	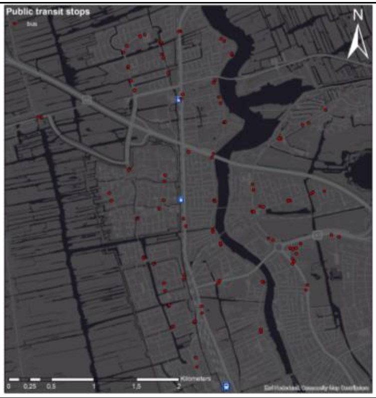
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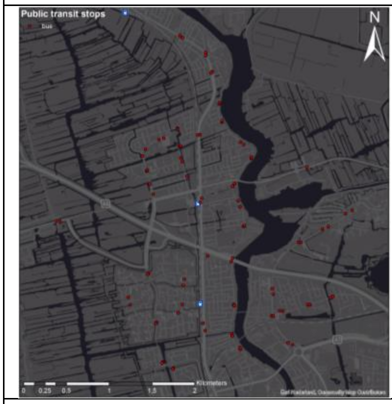
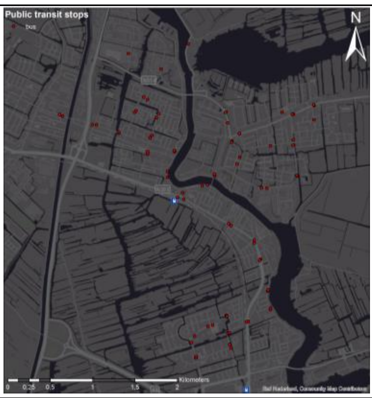
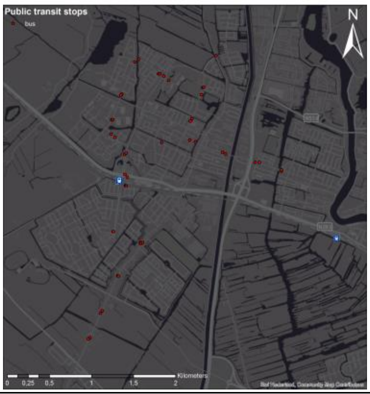
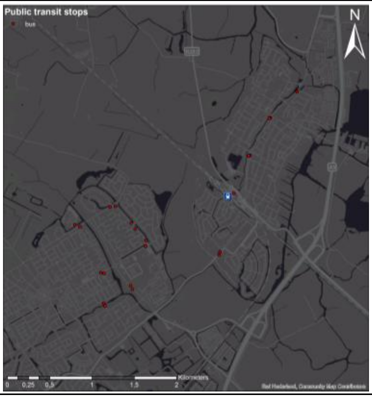
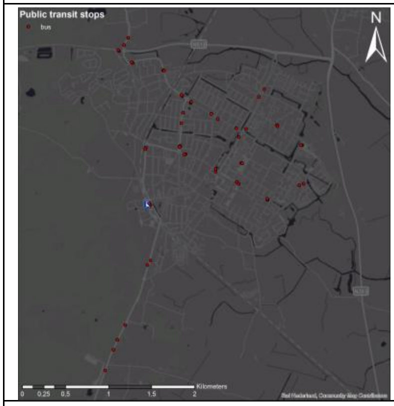
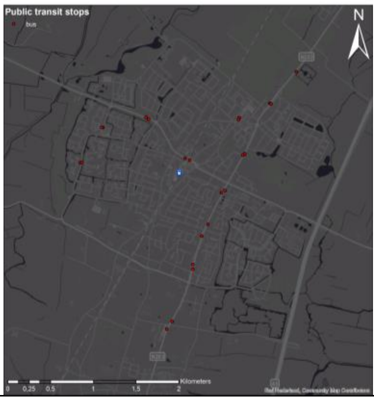
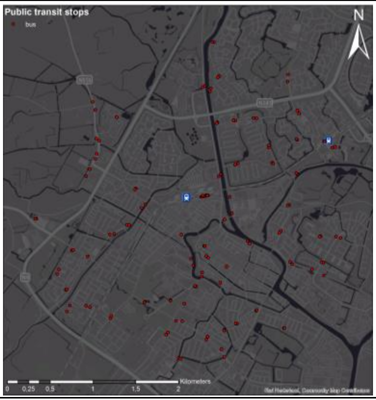
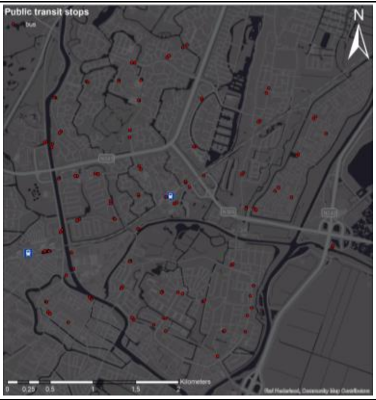
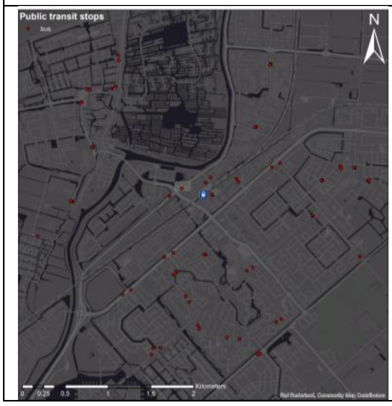
			
CAS	**HLO**	**AMR**	**AMRN**
			
HWD	Figure 4: public transit stops around the stations. Source: RUG, 2018. Large versions in Appendices.		
			

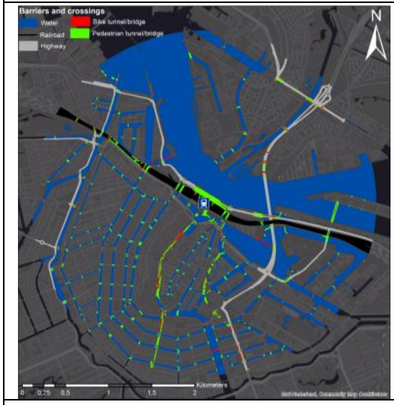
5.Avoid barriers & pedestrian and cyclist bridges and tunnels to surpass barriers

The presence of barriers can have a great impact on the infrastructural fabric, as they only allow passage on certain occasions. The criteria of avoiding barriers and providing pedestrian and cyclist over- or underpasses are best discussed together. After all, a barrier shouldn't be considered a barrier if there are plenty of opportunities to cross it. Barriers include water, highways and surface-level railroads. The maps can be found on Figure 5 (full-size in Appendices). As expected, Amsterdam Central has a great number of bridges to cross the canals at many locations. One glaring flaw, however, is the lack of an easy opportunity to cross the IJ River by bike or on foot. There are ferries to compensate for this (as seen on Figure A2), but there is no seamless way for pedestrians or cyclists of getting to the station from the north. The same can be said about the stations along the Zaan River (Zaandam, Koog aan de Zaan, Zaandijk Zaanse Schans and Wormerveer): the opportunities to cross it are rather sparse. In terms of road crossings, some important ones are the highway underpass between Koog aan de Zaan and Zaandijk Zaanse Schans, which has a whole supermarket incorporated into it, and the pedestrian/cyclist bridge providing easy access to the station from the north in Heerhugowaard. The city of Alkmaar does a great job in providing crossings for water, major roads and railroads throughout the city.

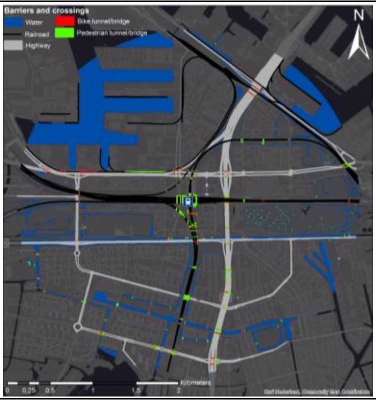
6.High-connectivity street network (grid, fan, radial)

A strong road network improves traffic flow and increases capacity by providing many different options through which traffic can flow. This can be analyzed using Figure 3 (or Figures A1-M1). Amsterdam Central covers a strong, radial grid network, both for cars and pedestrians. Other station areas show a clear hierarchy in road structure, which eventually guides most traffic through a small number of large arterial roads. This can put heavy strain on these roads, although it can be argued that this is not so much of an issue in small villages (Uitgeest, Castricum, Heiloo). The city of Alkmaar does provide many different options for entering this road, therefore spreading out the traffic more evenly.

ASD



ASS



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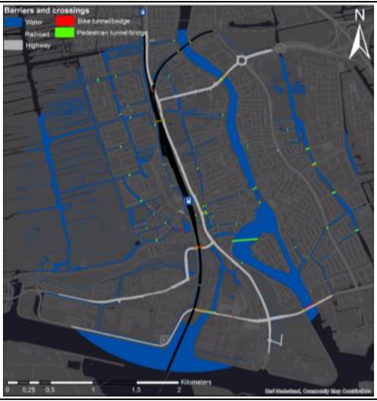

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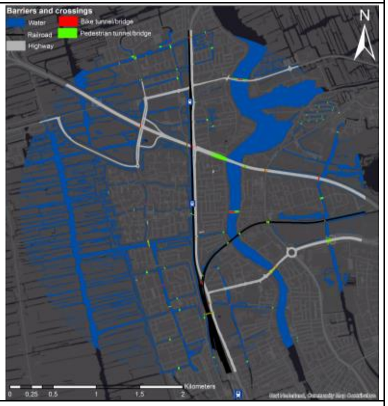
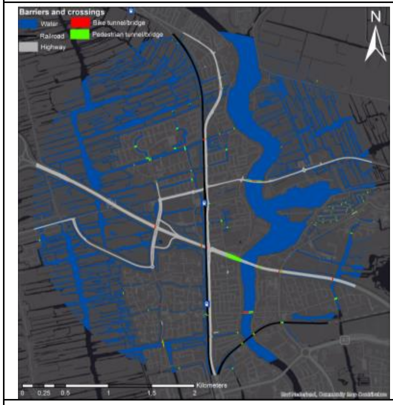
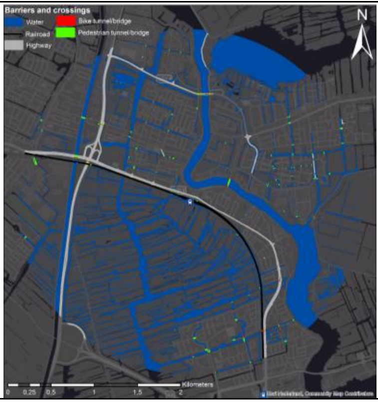


ZZS



WM



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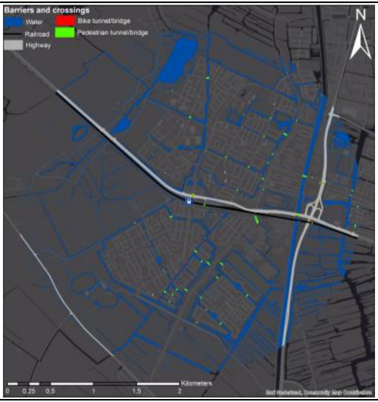
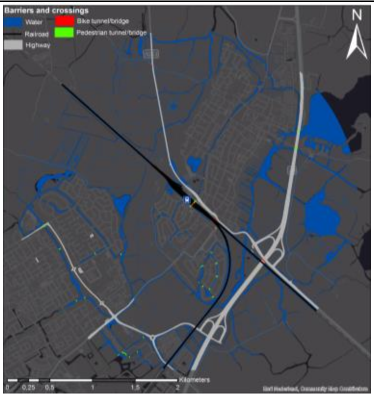
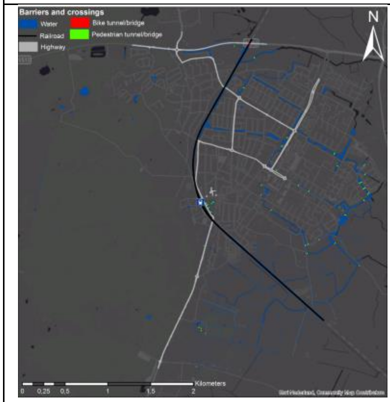


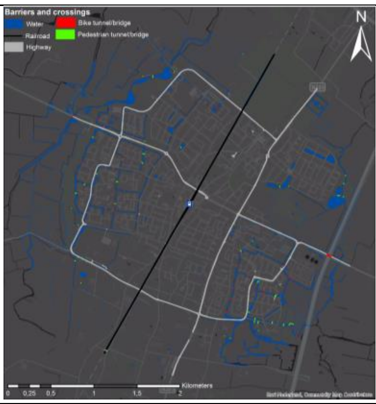
UTG



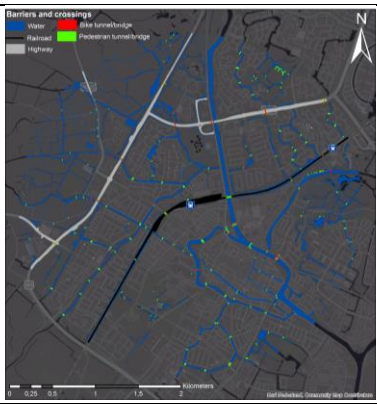
CAS



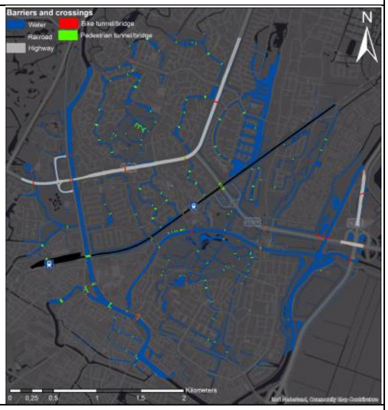
HLO



AMR



AMRN



HWD

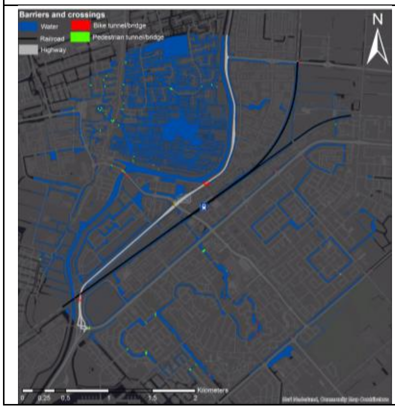


Figure 5: barriers and crossings around the stations. Source: Kadaster, 2020. Large versions in Appendices.

7.Equal quality of walking and cycling infrastructure

Pojani and Stead (2015) found that pedestrian and cycling infrastructure should gain equal attention in planning. Table 6 below shows, per station, the ratio between pedestrian and cyclist infrastructure. The closer the ratio, the better this balance. Bear in mind that for pedestrians, this includes large pedestrian surfaces such as squares or parks, because these can serve as alternative pathways for them.

	Infrastructure ratio (bicycle : pedestrian)
Amsterdam Central	1 : 9,43
Amsterdam Sloterdijk	1 : 4,83
Zaandam	1 : 6,16
Koog aan de Zaan	1 : 4,95
Zaandijk Zaanse Schans	1 : 6,38
Wormerveer	1 : 8,10
Krommenie-Assendelft	1 : 6,78
Uitgeest	1 : 7,11
Castricum	1 : 5,76
Heiloo	1 : 2,70
Alkmaar	1 : 5,64
Alkmaar North	1 : 3,91
Heerhugowaard	1 : 3,53

Table 6: ratios of cycling infrastructure to pedestrian infrastructure. Source: Kadaster, 2020.

In terms of dedicated infrastructure, there is far more pedestrian paths than cyclist paths. The closest ratio is found in Heiloo, where there is 2.7 times as much pedestrian path as cyclist path, and the largest discrepancy is found in Amsterdam Central, yet again underlining the pedestrian oriented city center. This trend contradicts what Pojani and Stead (2015) found: they observed that cyclist infrastructure was usually deemed much more important. However, this is most likely compensated for by the fact that bikes are allowed to use the car roads if no cycling path is present.

8.Ample bike parking space at stations

Based on aerial photos from Google Maps, an assessment of the bike parking capacity near the station has been made, ranging from small to large. Additionally, a distinction is made between open and closed spaces, i.e. openly accessible bike racks versus enclosed buildings. The results can be found in Table 7. Bear in mind that these assessments may not be perfectly accurate.

	Capacity	Parking type
Amsterdam Central	large	open and closed
Amsterdam Sloterdijk	medium	open
Zaandam	medium	open and closed
Koog aan de Zaan	small	open
Zaandijk Zaanse Schans	small	open
Wormerveer	medium	open and closed
Krommenie-Assendelft	small	open
Uitgeest	small	open
Castricum	medium	open and closed
Heiloo	small	open
Alkmaar	large	open and closed
Alkmaar North	small	open and closed
Heerhugowaard	medium	open and closed

Table 7: bike capacity and parking type. Source: Google Maps

In general, the cities with the highest number of inhabitants also have the best bike parking facilities. Wormerveer and Castricum are outliers in this case, having relatively large capacity for their size and function. Alkmaar North has lower capacity than expected, but this is mainly due to this station being largely overshadowed by the central station of Alkmaar, which is very close by.

9.Central position for transit station

From all the aforementioned Euclidean distances to the station, the mean is taken. This gives an indication of how ‘central’ the station is. The lower the number, the closer the station is to the majority of the buildings. A perfectly equal distribution of buildings would result in a mean distance of 1000 meters, half the radius of the coverage area. The results can be seen in Table 8 on the next page.

	Mean distance from station (meters)
Amsterdam Central	1350,10
Amsterdam Sloterdijk	1349,34
Zaandam	1257,72
Koog aan de Zaan	1154,18
Zaandijk Zaanse Schans	1197,82
Wormerveer	1287,28
Krommenie-Assendelft	1005,28
Uitgeest	1162,94
Castricum	1181,62
Heiloo	901,88
Alkmaar	1206,38
Alkmaar North	1356,20
Heerhugowaard	1347,26

Table 8: mean Euclidean distance between every building in the coverage area to the station. Source: Kadaster, 2020.

Interestingly, the largest cities have the highest mean distance. This could be due to a number of factors, the most obvious being that larger cities will have more rail lines connected to them, and therefore have larger station buildings. This logically removes the possibility of having a lot of buildings very close to the midpoint of the station. In the case of Amsterdam Central, it is also mainly due to the river flowing right next to the station. In this category, Heiloo is the best performer: the station serves as the focal point of the town.

10.Modal integration (i.e. connections between buses and trains)

Based on the dataset provided by the RUG (2018), an overview of all the public transit lines converging at each station is made, the results of which are tabulated below (Table 9 on the next page).

	Train	Bus	Night bus	Metro	Tram	Ferry
Amsterdam Central	22	13	19	4	8	4
Amsterdam Sloterdijk	14	12	1	2	1	-
Zaandam	5	9	3	-	-	-
Koog aan de Zaan	2	1*	1*	-	-	-
Zaandijk Zaanse Schans	2	1	1	-	-	-
Wormerveer	2	4	1	-	-	-
Krommenie-Assendelft	2	4	1	-	-	-
Uitgeest	3	3	-	-	-	-
Castricum	4	4	-	-	-	-
Heiloo	3	1	-	-	-	-
Alkmaar	4	22	1	-	-	-
Alkmaar North	3	2	-	-	-	-
Heerhugowaard	3	3	-	-	-	-

*: from bus stop Leliestraat 150m away; no bus stop at station itself.

Table 9: modal integration per station. Source: RUG (2018)

Unsurprisingly, Amsterdam Central features the best modal integration, with the widest variety of transport modes available and in large quantities. More surprising is the fact that the night buses outnumber the regular lines. This seems to highlight the great commercial focus on the city’s night life. Another interesting find is that station Koog aan de Zaan does not have its own bus station. This may increase transfer times, especially for passengers with impaired mobility. Finally, the sheer number of bus lines converging at Alkmaar is remarkable.

11.Underground rail tracks

Underground rail tracks are only present as metro lines around Amsterdam Central. All other stations had railroads at surface level (including the Amsterdam Sloterdijk metro lines), and are as shown in the sections regarding barriers. Amsterdam Central does have a section with raised railroads, but the supports underneath only allow passage in a few places, so it still serves as a disruption of the road network.

12.Car parking discouraged

The total amount of car parking space, as well as the total parking space as a percentage of the whole of the infrastructure network, gives an indication of the extent to which the area facilitates car use (Table 10 below). To give an idea of how many cars the coverage area can hold, the total parking space is divided by the average parking space size, in accordance with general parking norms (2,25m * 5,25m = 11,8125m^2) (NEN, 2013; TU Delft, 2016).

	Total surface area (m^2)	Estimated number of cars	Percentage of total infrastructure
Amsterdam Central	447197,32	37858	6,87%
Amsterdam Sloterdijk	313441,77	26535	4,48%
Zaandam	517083,14	43774	8,96%
Koog aan de Zaan	448078,87	37933	8,67%
Zaandijk Zaanse Schans	347152,90	29383	8,88%
Wormerveer	339036,58	28702	8,58%
Krommenie-Assendelft	305996,94	25905	7,83%
Uitgeest	278226,49	23554	6,13%
Castricum	196388,56	16625	7,59%
Heiloo	241940,58	20482	8,19%
Alkmaar	425319,86	36006	9,07%
Alkmaar North	389484,80	32972	8,53%
Heerhugowaard	303954,63	25732	8,33%

Table 10: total parking space in m^2 and as percentage of the whole road network. Source: Kadaster, 2020.

Castricum and Heiloo perform the best in terms of absolute numbers. This is unsurprising, however, as they are the smallest towns in this study. This is why the relative numbers are much more important. Amsterdam Sloterdijk performs the best by far in this regard. This means that public transport must make up a large part of commuting traffic, as there is not much room for employees to park their car. Uitgeest also performs rather well.

4.3: Summary: assessment grid and public transit ridership

Based on all the results discussed above, the following assessment grid can be made to summarize everything (Table 11 below).

Criteria	ASD	ASS	ZD	KZ	ZZS	WM	KMA	UTG	CAS	HLO	AMR	AMRN	HWD
1	3	1	5	5	4	3	4	1	1	1	3	3	2
2	5	2	5	3	1	4	4	5	4	2	5	1	4
3	3	3	2	3	2	1	1	4	3	4	5	5	2
4	5	5	3	3	3	3	1	1	1	1	4	4	2
5	4	3	2	3	3	2	2	1	1	1	5	5	3
6	5	3	3	2	2	1	1	3	3	3	4	4	2
7	1	4	3	4	3	1	2	2	3	5	3	5	5
8	5	3	4	1	1	4	1	1	4	1	5	2	4
9	1	1	2	3	2	1	4	3	2	5	2	1	1
10	5	5	4	1	1	3	3	2	3	1	4	2	2
11	5	1	1	1	1	1	1	1	1	1	1	1	1
12	3	5	1	1	1	1	2	4	2	1	1	1	1
Avg.	3,75	3	2,92	2,5	2	2,08	2,17	2,33	2,33	2,17	3,5	2,83	2,42

Table 11: assessment grid of all the results, per station. Source: author

As hypothesized, Amsterdam Central and Alkmaar obtain the highest scores. These stations also process the largest amounts of passengers (see Figure 2), so it would be beneficial to have a station area that is planned for it. Zaandijk Zaanse Schans has the worst implementation of TOD, with Wormerveer a close second worst. The employed methods therefore help identify the weak links in the TOD hierarchy. These results are in line with the hypotheses mentioned earlier.

Alongside these results, it would be interesting to look at the development of public transport ridership since the project started. The NS (2019; 2020) provides an overview of traveler behavior every year. An indexed graph can be seen in Figure 6 on the next page. The project was initiated in December 2014, so this year is taken as the base year.

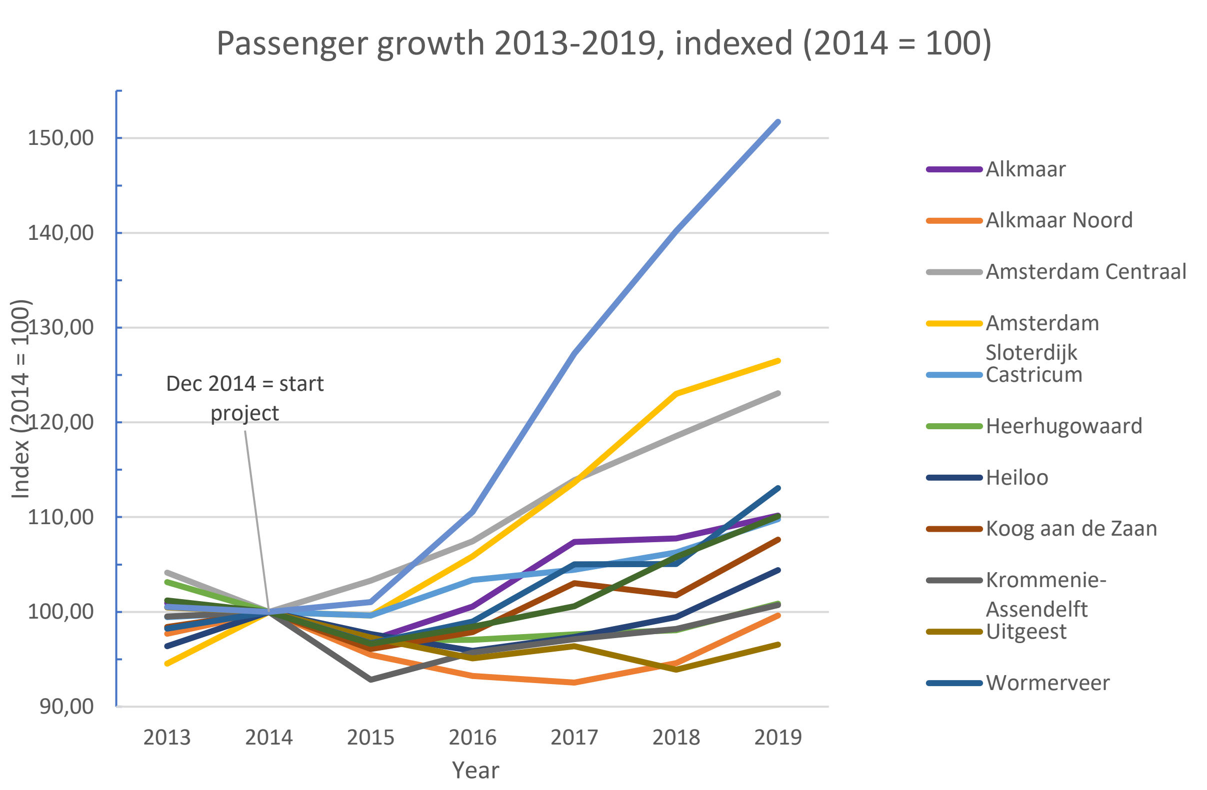


Figure 6: annual passenger growth of Zaancorridor stations, indexed. Source: NS, 20119; NS, 2020.

The biggest increases in passenger totals can be found in Amsterdam Central, Amsterdam Sloterdijk and Zaandijk Zaanse Schans. Amsterdam Central and Amsterdam Sloterdijk score well on most criteria, so these areas seem to be suitable for public transport use. Zaandijk Zaanse Schans, however, is surprising, considering its worst average score. The only stations with a net decrease over time are Uitgeest and Alkmaar North, although Alkmaar North shows a rising trend. Uitgeest has come out as one of the worst in this thesis, but Alkmaar North seems to disappoint a little compared to its results. Alkmaar, the second best scoring in the thesis, show only a medium increase in passenger totals. These comparisons serve to point out the limitations of the methods employed, which will be discussed in the conclusion. Regardless, studying the physical space in a quantitative and cartographic-analytical manner can, to some extent, contribute to a retrospective evaluation on the TOD pilot project.

5. Conclusions

This research has attempted to comprehensively assess the spatial design around the stations along the Zaancorridor through a quantitative approach. There is great need in finding a more sustainable alternative for the rampant car use that modern society has gotten used to. The Zaancorridor pilot project may have great implications on future spatial planning, should it prove successful in the long run. This is why it is important to identify the spatial factors that have contributed to its success. The continuous cycle of evaluation and iteration can greatly benefit from a quantitative and cartographic-analytical, multi-criteria approach in analyzing TOD projects. Mobility and accessibility form the backbone of what makes TOD work; the spatial layout of a city should help make the use of public transport the natural choice of moving oneself around. Translating the urban fabric to quantifiable measures provides policy makers with concrete information from which the performance of a TOD project can be evaluated, and subsequently, new planning strategies can be devised. It is especially important to compare the different stations with one another to establish a hierarchy or spot weak links in the total project. From the employed methods, it becomes apparent that only Amsterdam Central and Alkmaar can be seen as proper implementations of the TOD concept as summarized by Pojani and Stead (2015). These cities should be looked at as exemplary key stations in a TOD hierarchy. There are a number of weak links, especially in the middle of the train line, where many potential passengers can come from. In order to properly apply a corridor-wide TOD, these stations should be the first to be looked at. From the analyses, they appear to lack the most in terms of high-connectivity street networks, public transport access to and from the TOD area and opportunities to cross barriers, of which there are plenty in North Holland. If this pilot can become successful, other implementations elsewhere in the country can be considered. These combined efforts can lead to drastically reduced carbon emissions, healthier lifestyles and highly valued station areas.

Limitations and future work

Some remarks need to be made regarding the results. First, the selection of criteria was focused on mobility and accessibility. Jacobson and Forsyth (2008) and Pojani and Stead (2015) also found a number of factors pertaining to place-making, that is:

making the area around the station pleasant to be around. This might increase ridership even further, but it fell out of the focus of this research, and is furthermore hardly quantifiable. Researching this requires a more qualitative approach, based on on-site observations, interviews and surveys. The on-site aspect of this was unfeasible for this thesis, due to the lack of manpower, time, and beneficial conditions. The CoVid-19 pandemic restricted and discouraged public transport for non-essential workers, so it was deemed irresponsible to perform on-site analyses. Finally, the passenger numbers alone are insufficient in judging TOD performance. A comprehensive look at all the construction projects around stations, and the subsequent changes in population, are also important. This was also deemed unfeasible for the purpose of this research, but should provide valuable information for future studies into the relative decrease in car ridership. Finally, it is advised that the methods employed to assess the criteria be further iterated upon to improve their accuracy.

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Appendices

Appendix A: Amsterdam Central (ASD)

Scale and density

Buildings in range: 19567

Connections

Figure A1: road use around Amsterdam Central. Source: Kadaster, 2020

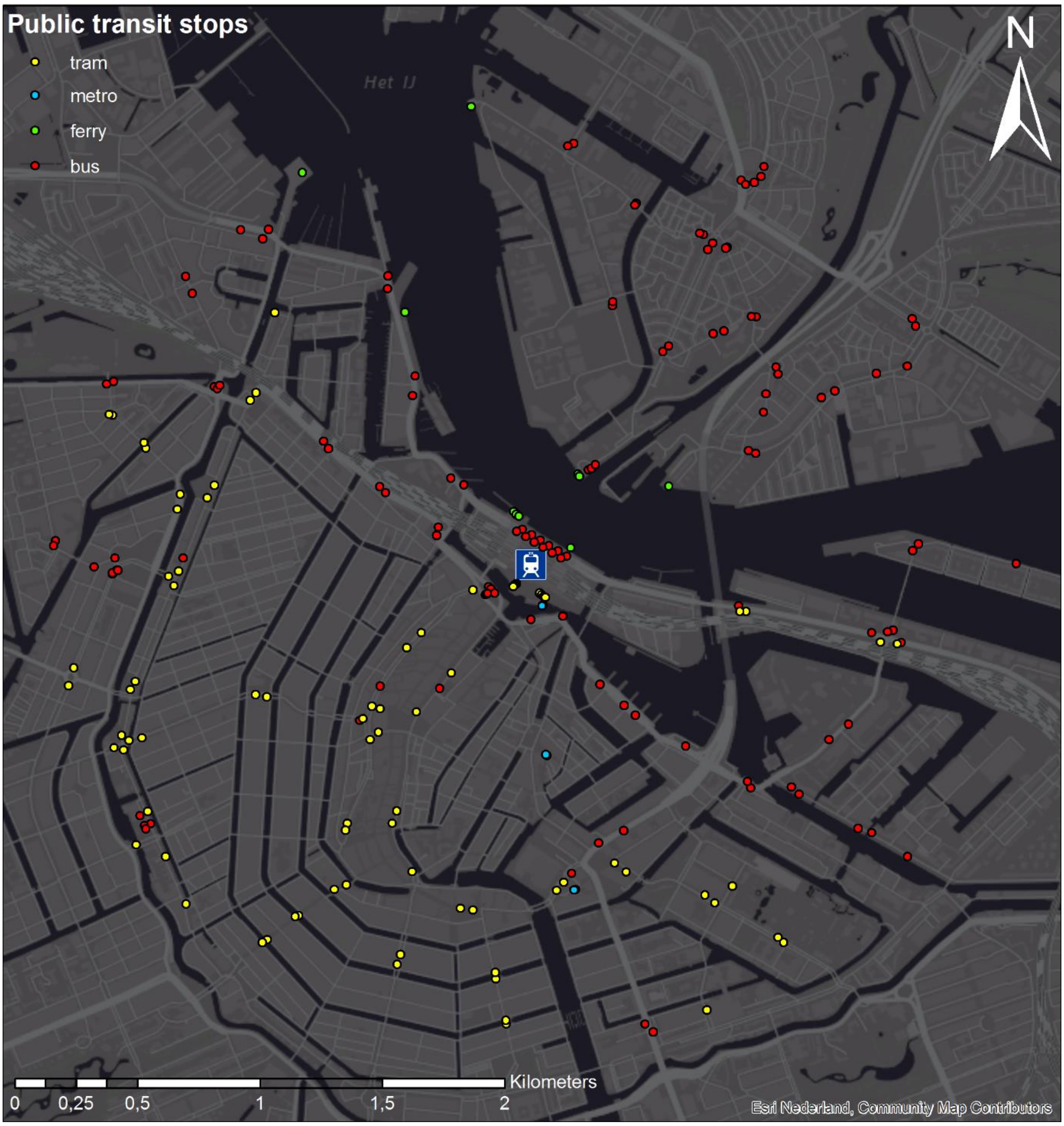

Figure A2: public transit stops around Amsterdam Central. Source: RUG, 2018

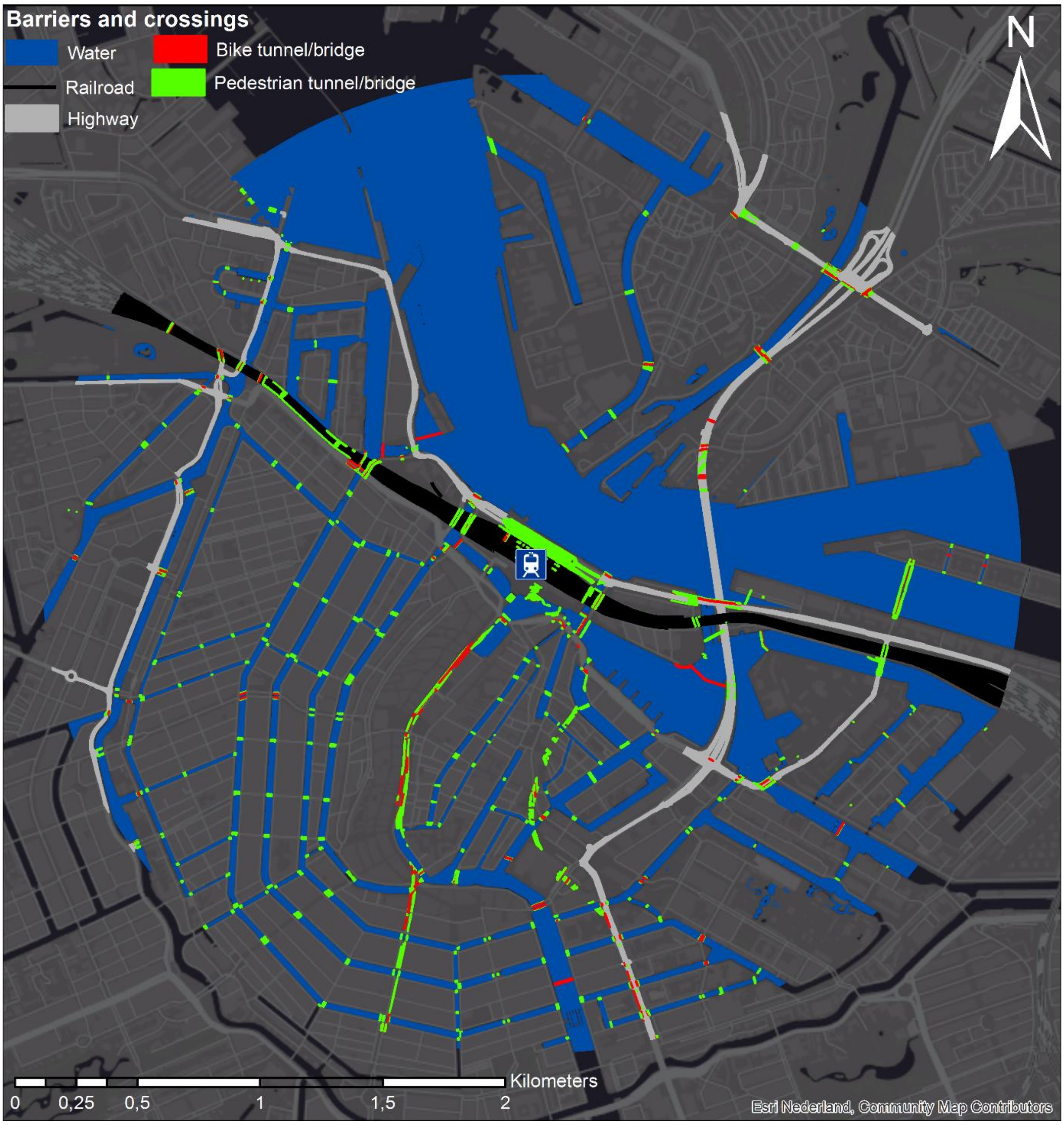

Figure A3: barriers and crossings around Amsterdam Central. Source: Kadaster, 2020

Pedestrian/cycling orientation

Bike parking space at station: large capacity, open and closed space

Bicycle path surface area: 277901,72 m^2

Pedestrian path surface area: 2620528,75 m^2

Ratio: 1 : 9,43

Transit in the urban pattern

Average distance to station: 1350,10 m (st. dev.: 443,31 m)

Lines converging on station: 13 bus lines, 19 night bus lines, 4 metro lines, 8 tram lines, 4 ferry lines, 22 train lines

Underground rails: yes, but only metro lines

Car movement and parking

Parking space: 447197,3233 m^2 ≈ 37858 cars

Parking space ratio: 447197,3233 / 6509049,141385 * 100 = 6,87%

Appendix B: Amsterdam Sloterdijk (ASS)

Scale and density

Buildings in range: 7759

Connections

Figure B1: road use around Amsterdam Sloterdijk. Source: Kadaster, 2020

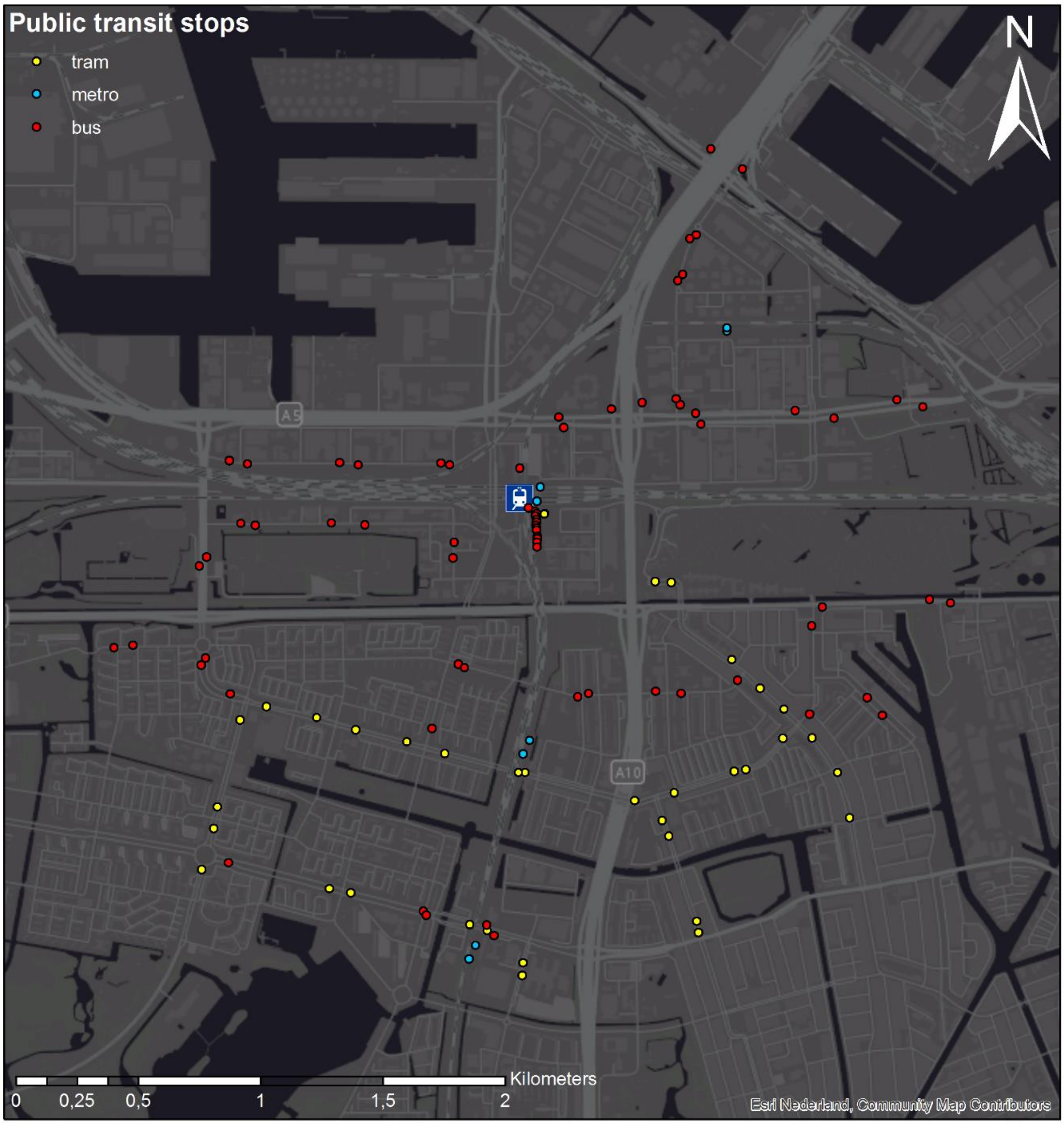

Figure B2: public transit stops around Amsterdam Sloterdijk. Source: RUG, 2018

Figure B3: barriers and crossings around Amsterdam Sloterdijk. Source: Kadaster, 2020

Pedestrian/cycling orientation

Bike parking space at station: medium capacity, open space

Bicycle path surface area: 366243,60 m^2

Pedestrian path surface area: 1767750,35 m^2

Ratio: 1 : 4,83

Transit in the urban pattern

Average distance to station: 1349,34 m (st. dev.: 395,53 m)

Lines converging on station: 12 bus lines, 1 night bus line, 2 metro lines, 1 tram line, 14 train lines

Underground rails: yes, but next to rails on surface level, so no impact on traffic flow

Car movement and parking

Parking space: 313441,773788 m^2 ≈ 26535 cars

Parking space ratio: 313441,773788 / 6989673,346086 * 100 = 4,48%

Appendix C: Zaandam (ZD)

Scale and density

Buildings in range: 32667

Connections

Figure C1: road use around Zaandam. Source: Kadaster, 2020

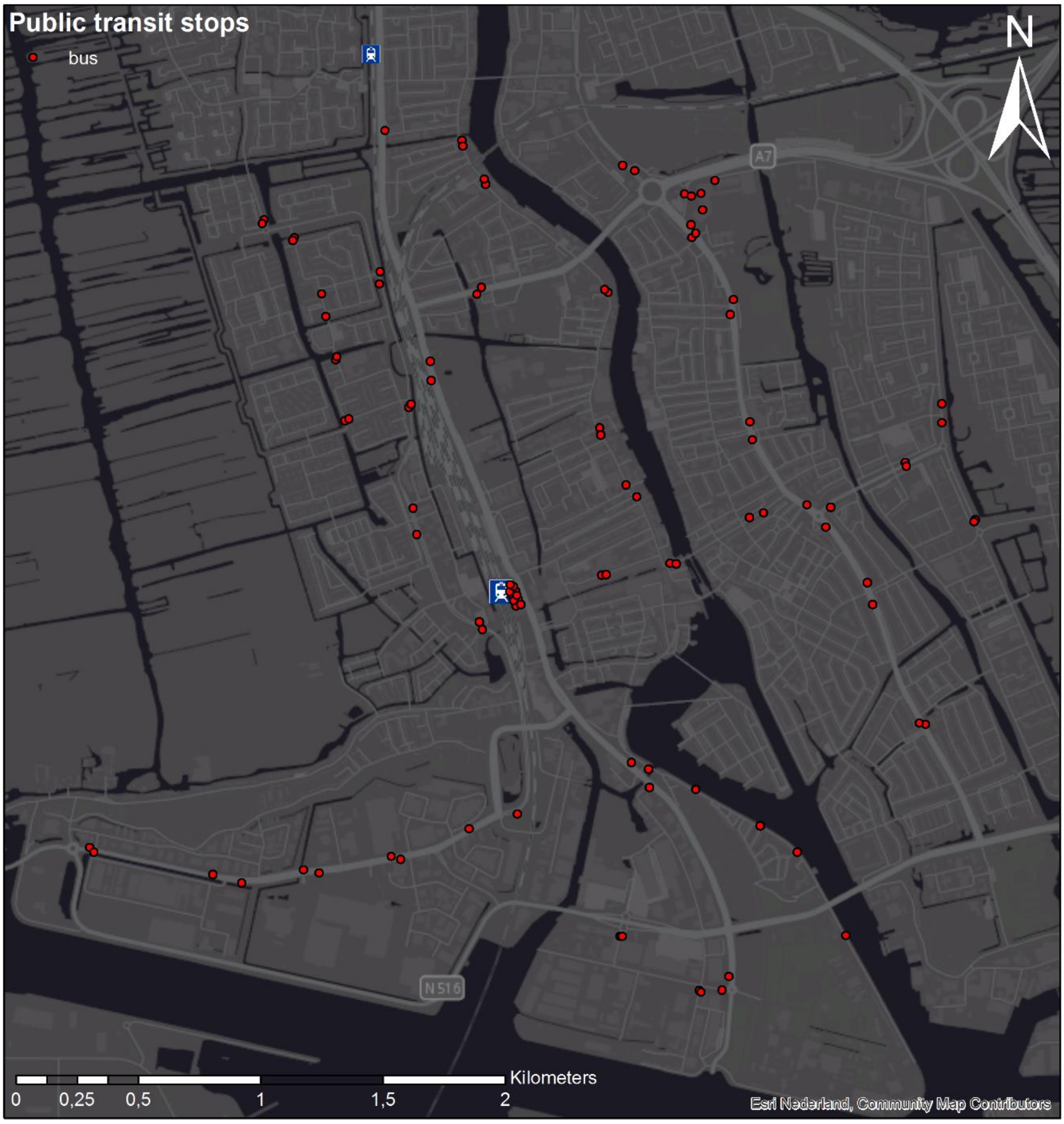

Figure C2: public transit stops around Zaandam. Source: RUG, 2018

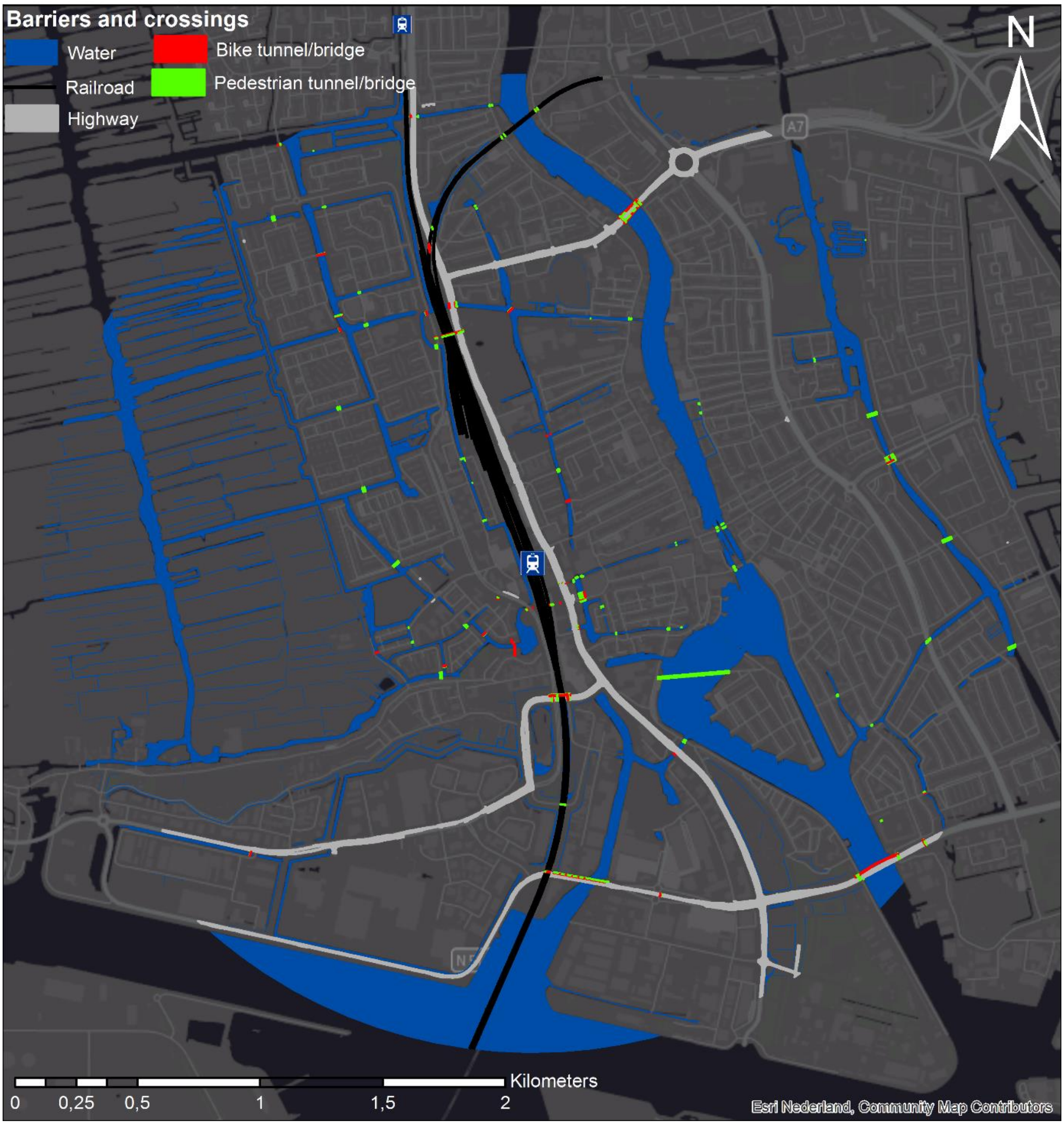

Figure C3: barriers and crossings around Zaandam. Source: Kadaster, 2020

Pedestrian/cycling orientation

Bike parking space at station: medium capacity, open and closed spaces

Bicycle path surface area: 269937,64 m^2

Pedestrian path surface area: 1662819,48 m^2

Ratio: 1 : 6,16

Transit in the urban pattern

Average distance to station: 1257,72 m (st. dev.: 467,27 m)

Lines converging on station: 9 bus lines, 3 night bus lines, 5 train lines

Underground rails: yes, but only underwater

Car movement and parking

Parking space: 517083,135312 m^2 ≈ 43774 cars

Parking space ratio: 517083,135312 / 5772464,356696 * 100 = 8,96%

Appendix D: Koog aan de Zaan (KZ)

Scale and density

Buildings in range: 29168

Connections

Figure D1: road use around Koog aan de Zaan. Source: Kadaster, 2020

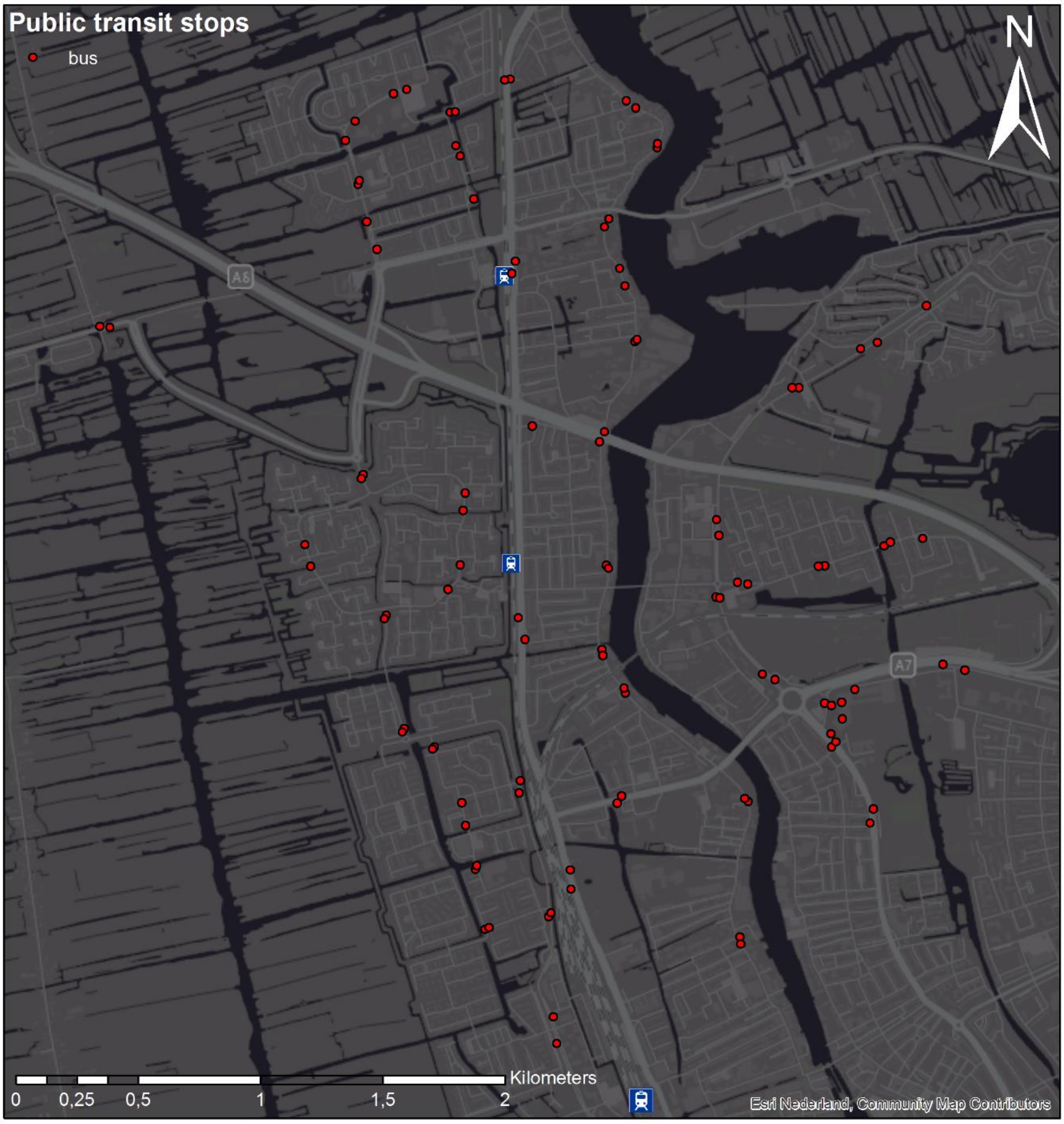

Figure D2: public transit stops around Koog aan de Zaan. Source: RUG, 2018

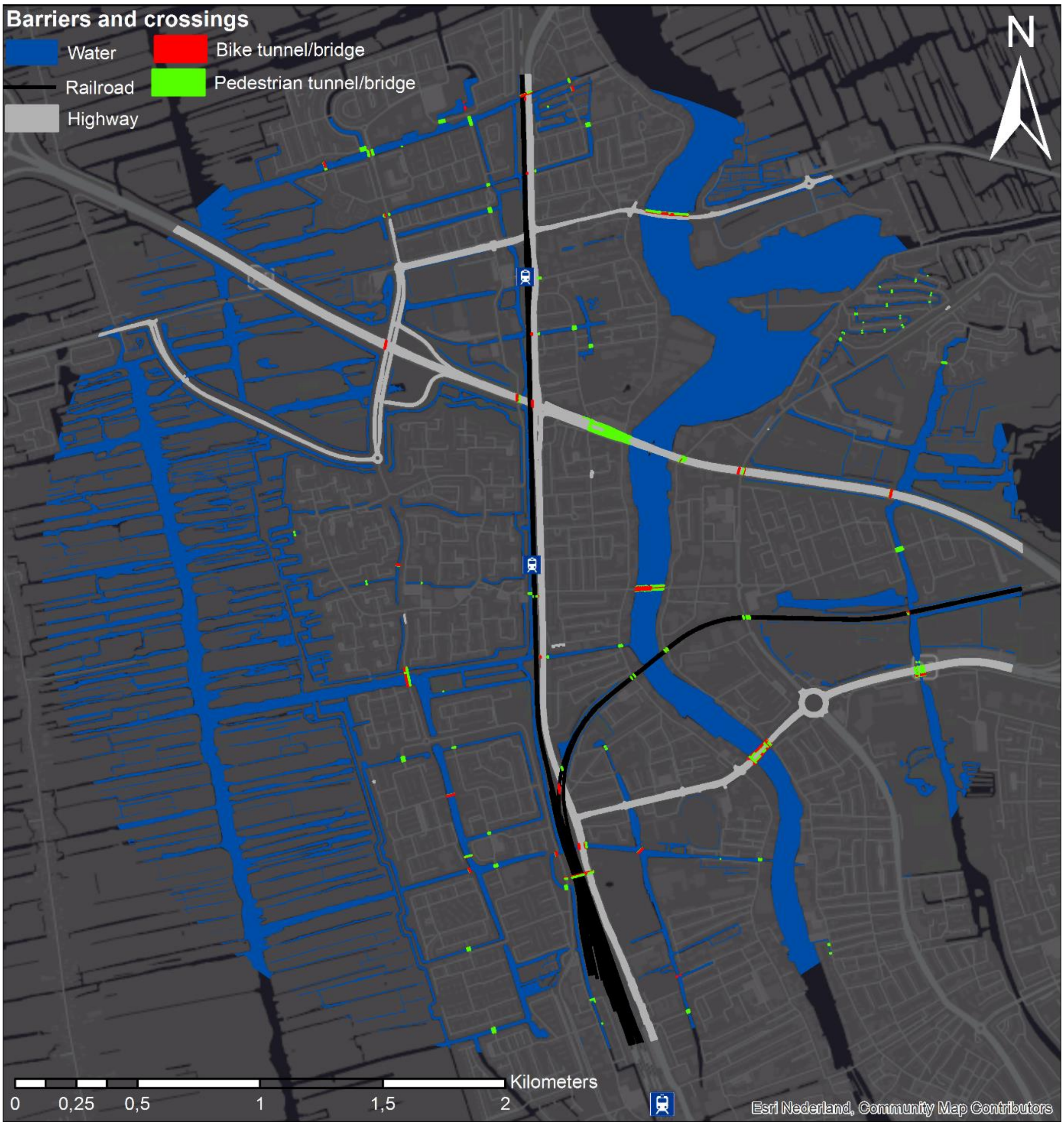

Figure D3: barriers and crossings around Koog aan de Zaan. Source: Kadaster, 2020

Pedestrian/cycling orientation

Bike parking space at station: small capacity, open space

Bicycle path surface area: 287640,89 m^2

Pedestrian path surface area: 1423157,38 m^2

Ratio: 1 : 4,95

Transit in the urban pattern

Average distance to station: 1154,18 m (st. dev.: 564,42 m)

Lines converging on station: 1 bus line, 1 night bus line (bus stop Leliestraat 150m away), 2 train lines

Underground rails: no

Car movement and parking

Parking space: 448078,870798 m^2 ≈ 37933 cars

Parking space ratio: 448078,870798 / 5169013,380541 * 100 = 8,67%

Appendix E: Zaandijk Zaanse Schans (ZZS)

Scale and density

Buildings in range: 23613

Connections

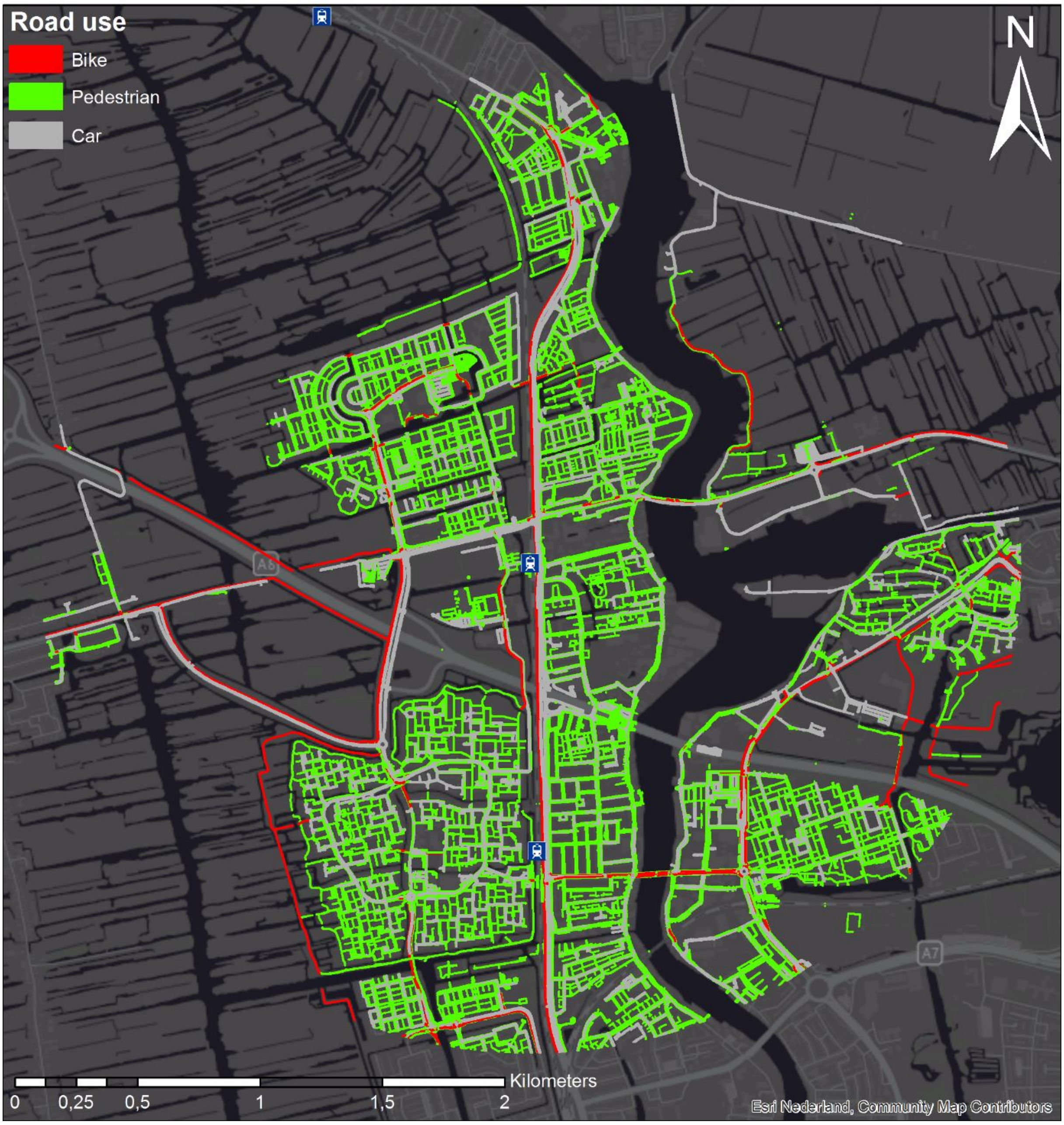

Figure E1: road use around Zaandijk Zaanse Schans. Source: Kadaster, 2020

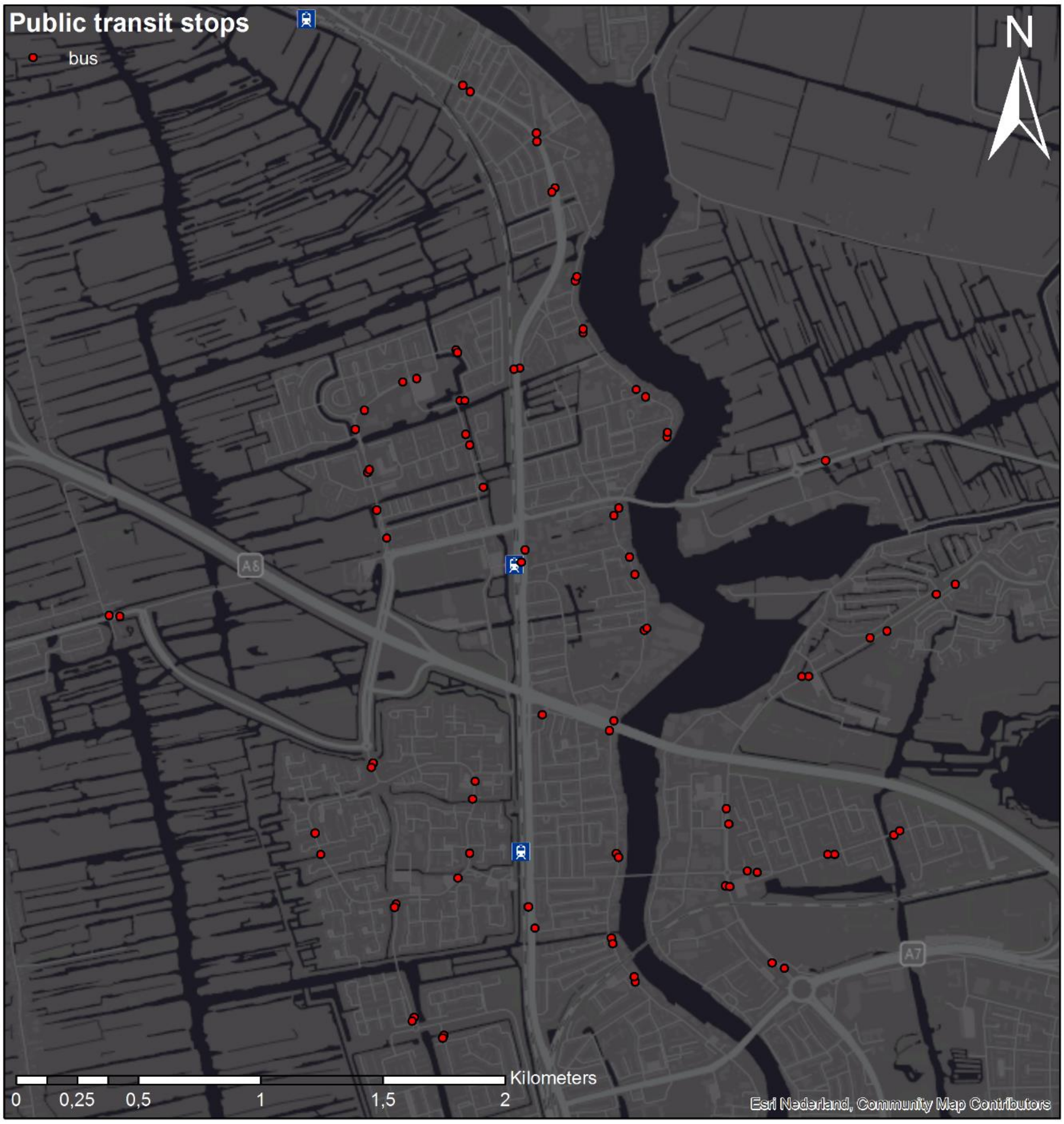

Figure E2: public transit stops around Zaandijk Zaanse Schans. Source: RUG, 2018

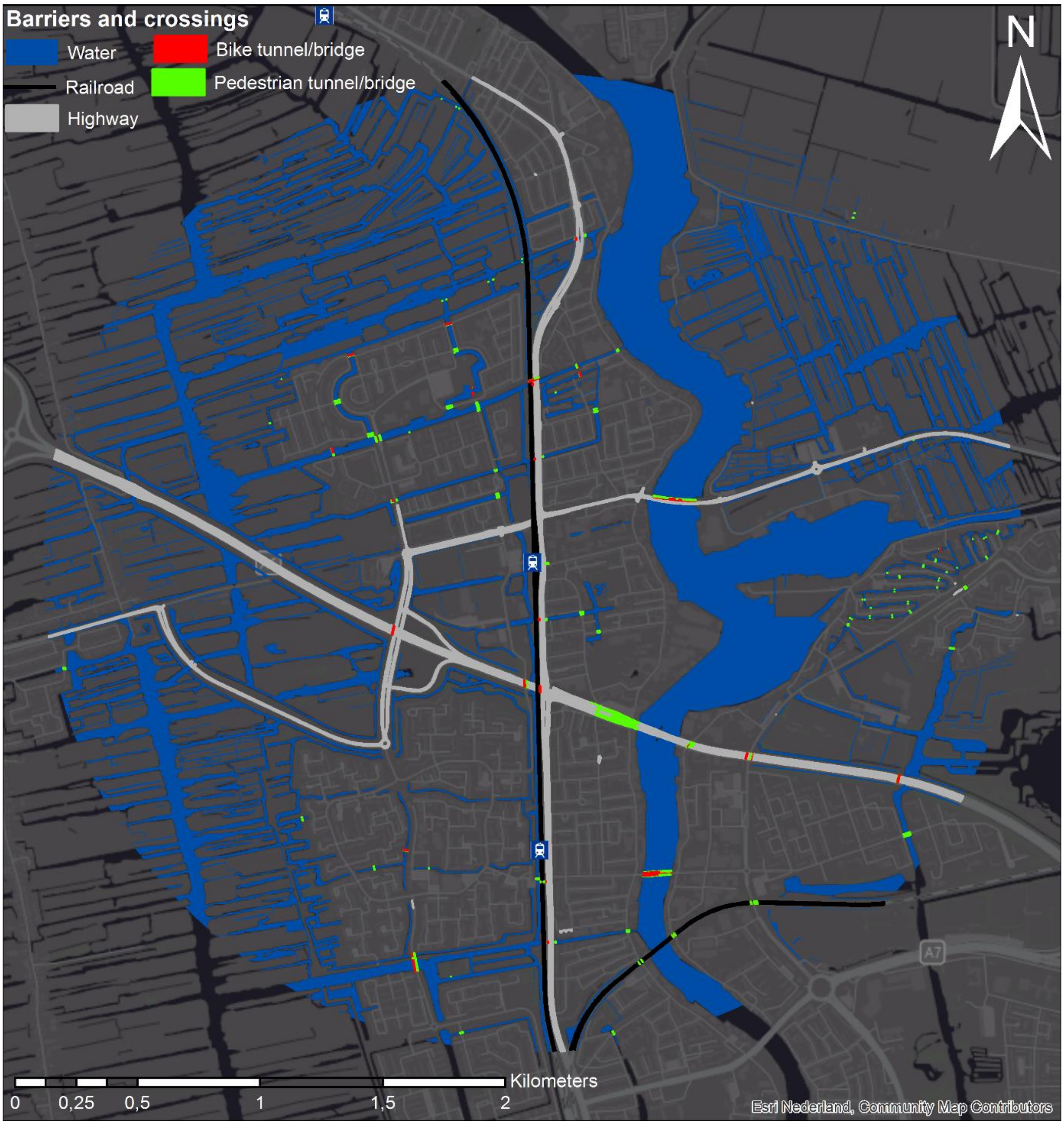

Figure E3: barriers and crossings around Zaandijk Zaanse Schans. Source: Kadaster, 2020

Pedestrian/cycling orientation

Bike parking space at station: small capacity, open space

Bicycle path surface area: 184103,88 m^2

Pedestrian path surface area: 1174291,42 m^2

Ratio: 1 : 6,38

Transit in the urban pattern

Average distance to station: 1197,82 m (st. dev.: 473,73 m)

Lines converging on station: 1 bus line, 1 night bus line, 2 train lines

Underground rails: no

Car movement and parking

Parking space: 347152,90307 m^2 ≈ 29383 cars

Parking space ratio: 347152,90307 / 3907348,158808 * 100 = 8,88%

Appendix F: Wormerveer (WM)

Scale and density

Buildings in range: 19672

Connections

Figure F1: road use around Wormerveer. Source: Kadaster, 2020

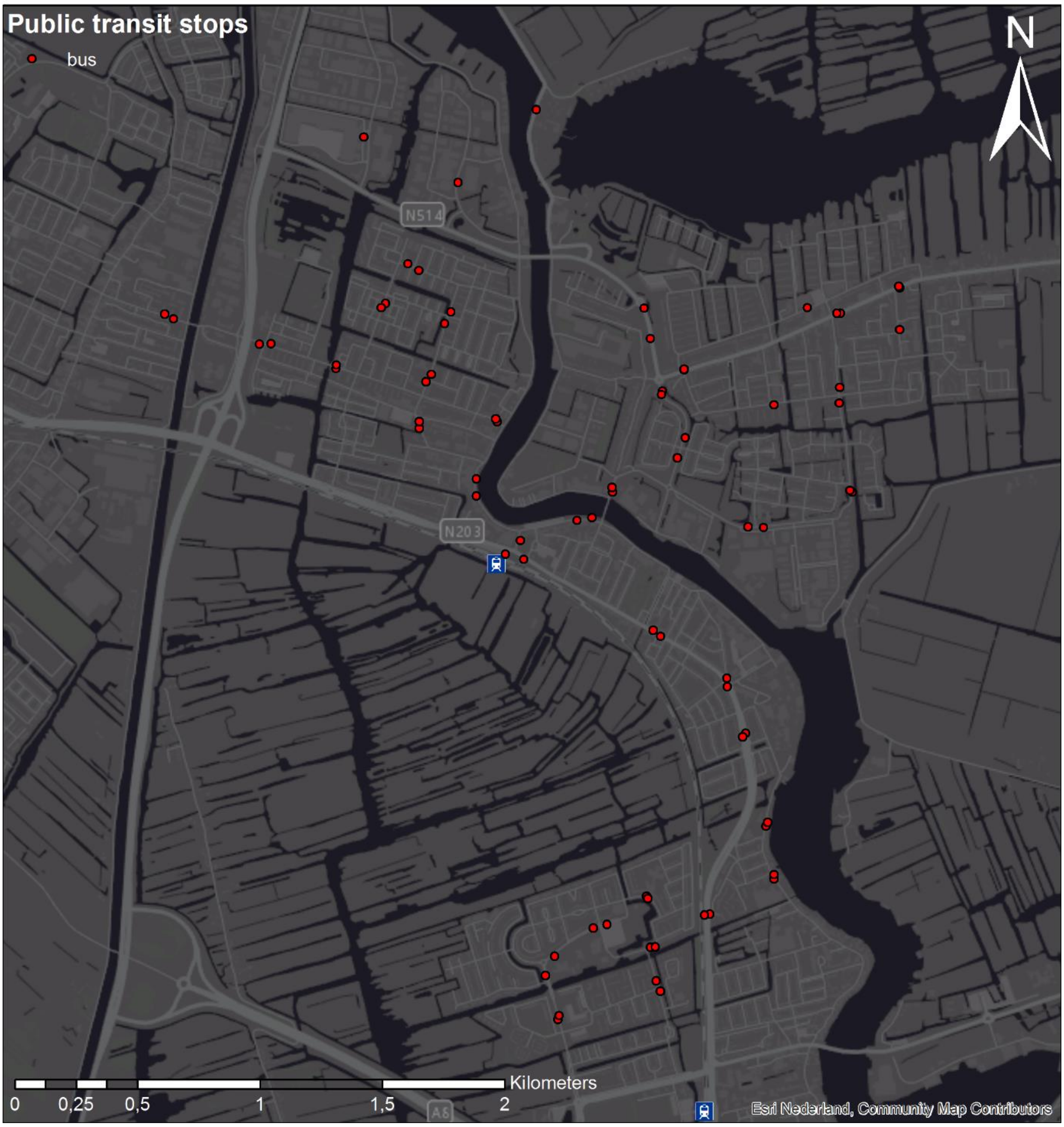

Figure F2: public transit stops around Wormerveer. Source: RUG, 2018

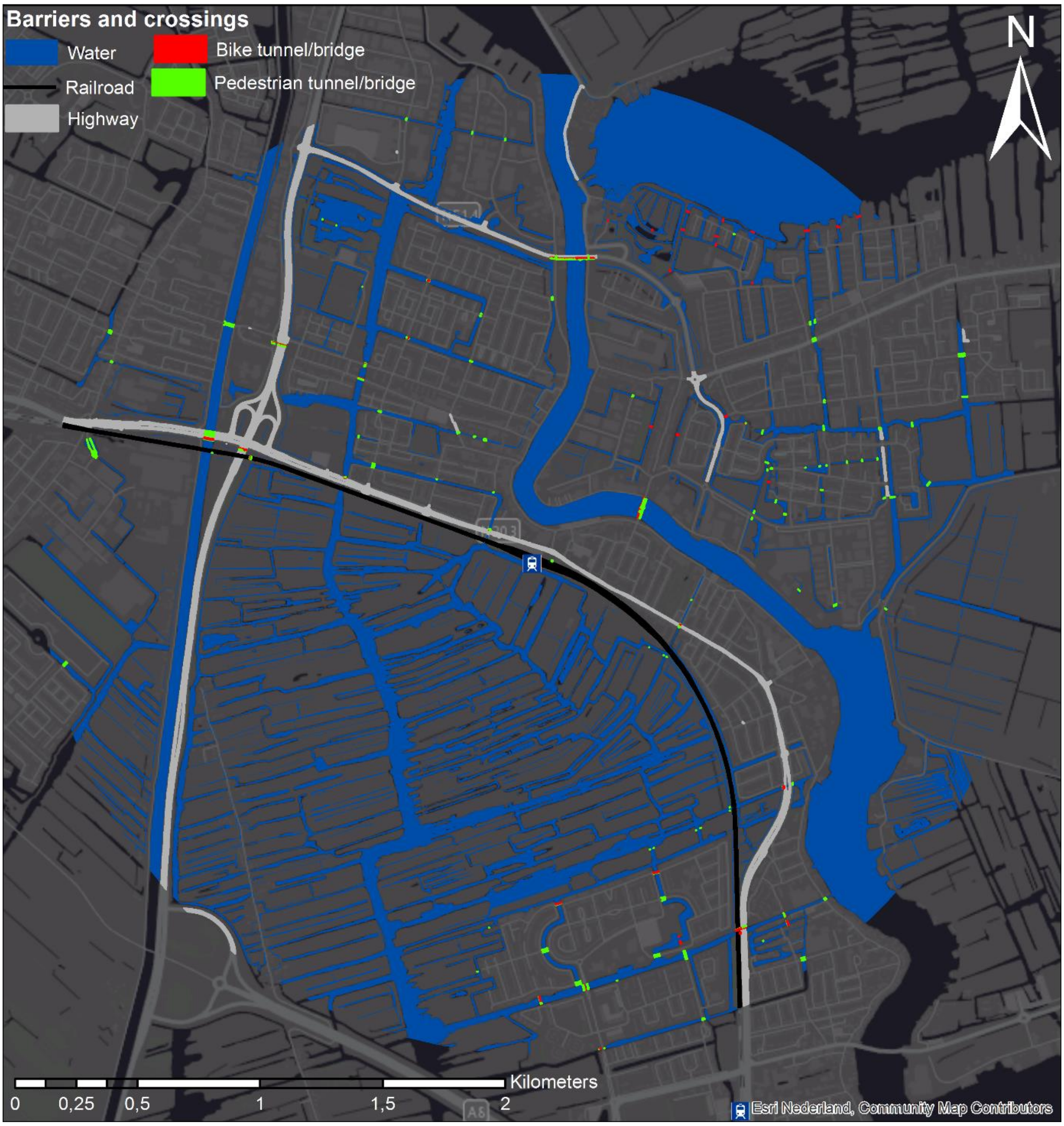

Figure F3: barriers and crossings around Wormerveer. Source: Kadaster, 2020

Pedestrian/cycling orientation

Bike parking space at station: medium capacity, open and closed spaces

Bicycle path surface area: 161408,74 m^2

Pedestrian path surface area: 1307536,10 m^2

Ratio: 1 : 8,1

Transit in the urban pattern

Average distance to station: 1287,28 m (st. dev.: 476,67 m)

Lines converging on station: 4 bus lines, 1 night bus line, 2 train lines

Underground rails: no

Car movement and parking

Parking space: 339036,578601 m^2 ≈ 28702 cars

Parking space ratio: 339036,578601 / 3951606,496287 * 100 = 8,58%

Appendix G: Krommenie-Assendelft (KMA)

Scale and density

Buildings in range: 22706

Connections

Figure G1: road use around Krommenie-Assendelft. Source: Kadaster, 2020

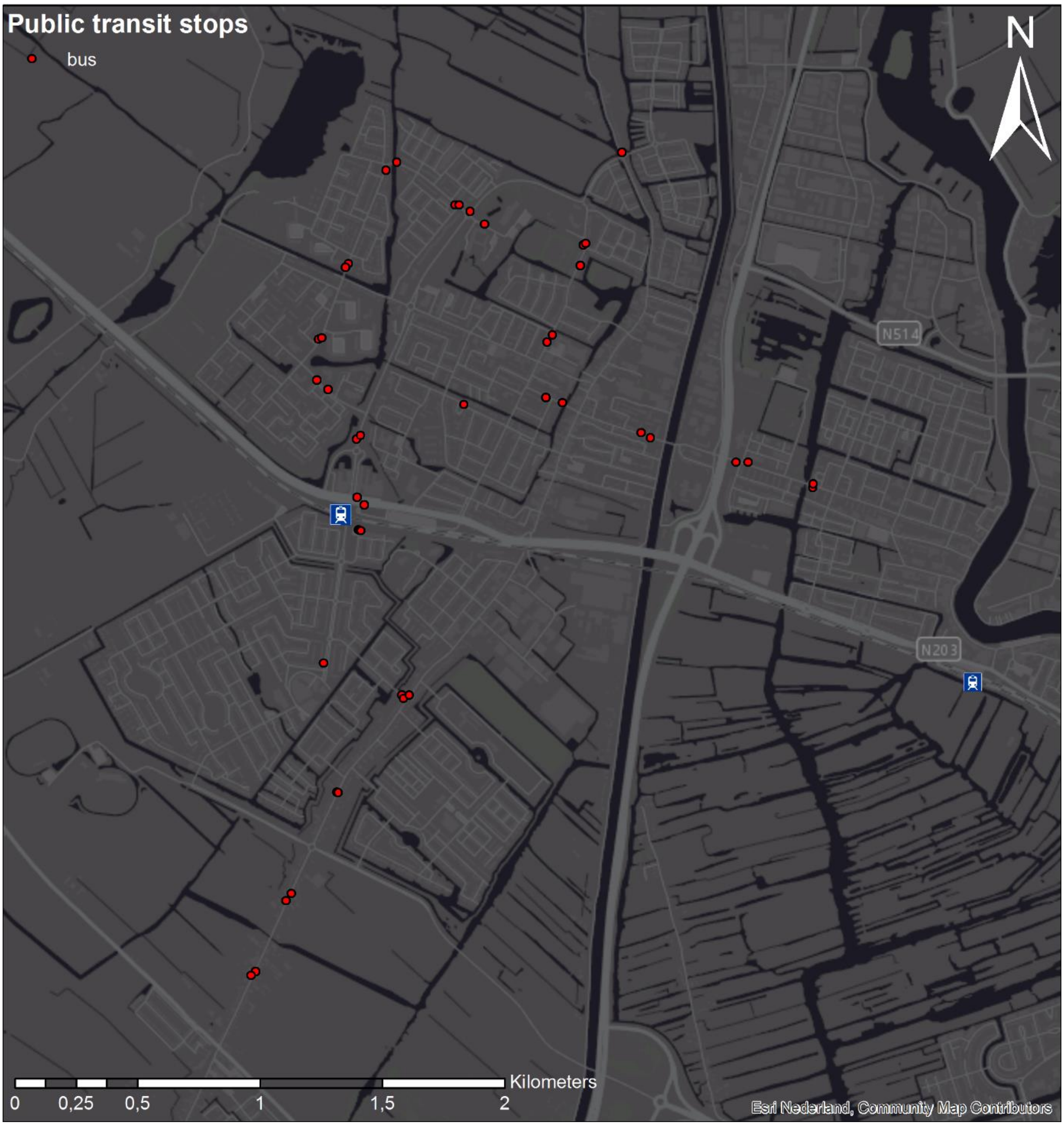

Figure G2: public transit stops around Krommenie-Assendelft. Source: RUG, 2018

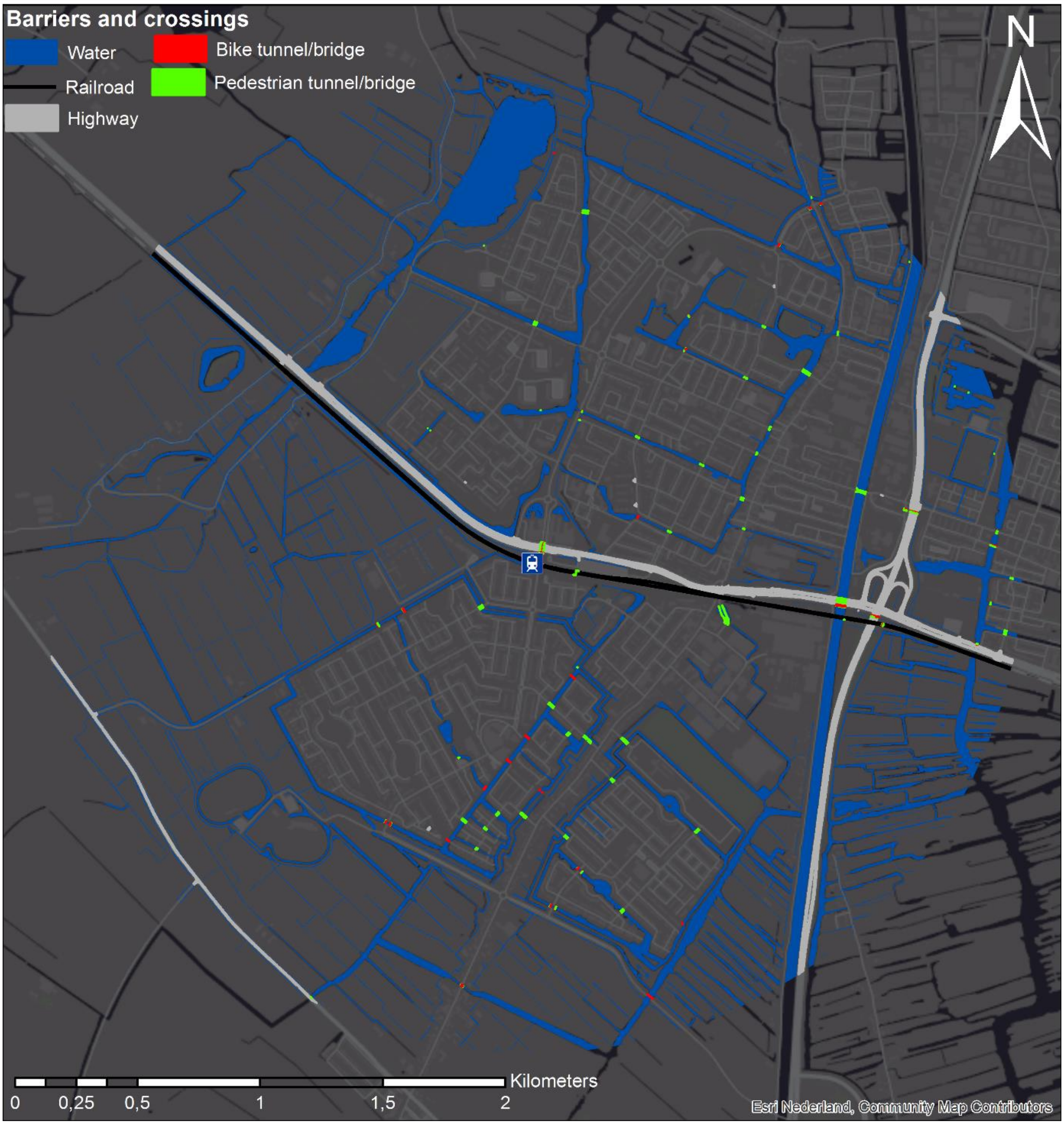

Figure G3: barriers and crossings around Krommenie-Assendelft. Source: Kadaster, 2020

Pedestrian/cycling orientation

Bike parking space at station: small capacity, open space

Bicycle path surface area: 213162,40 m^2

Pedestrian path surface area: 1444951,10 m^2

Ratio: 1 : 6,78

Transit in the urban pattern

Average distance to station: 1005,28 m (st. dev.: 441,38 m)

Lines converging on station: 4 bus lines, 1 night bus line, 2 train lines

Underground rails: no

Car movement and parking

Parking space: 305996,94376 m^2 ≈ 25905 cars

Parking space ratio: 305996,94376 / 3905878,538045 * 100 = 7,83%

Appendix H. Uitgeest (UTG)

Scale and density

Buildings in range: 11154

Connections

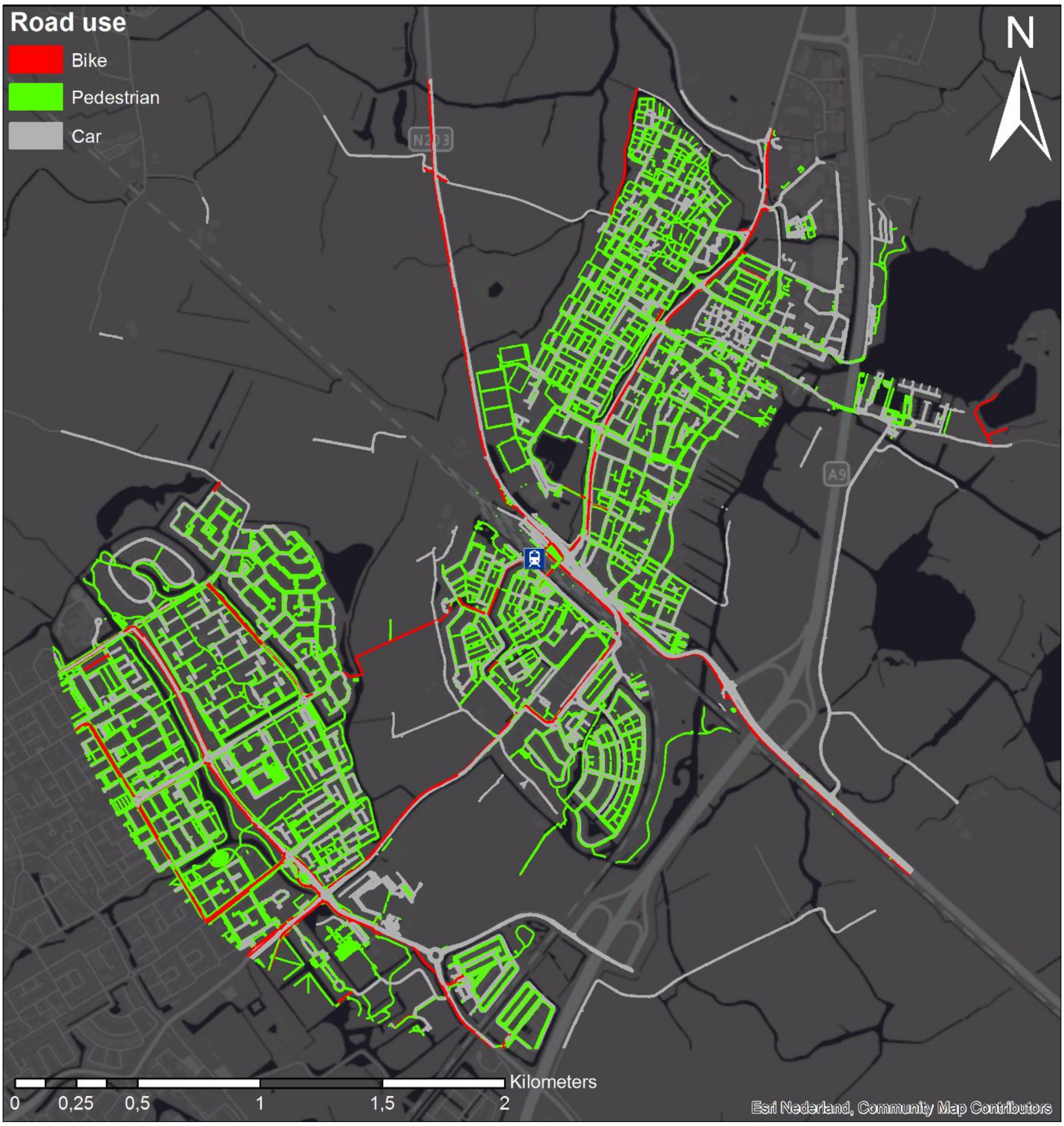

Figure H1: road use around Uitgeest. Source: Kadaster, 2020

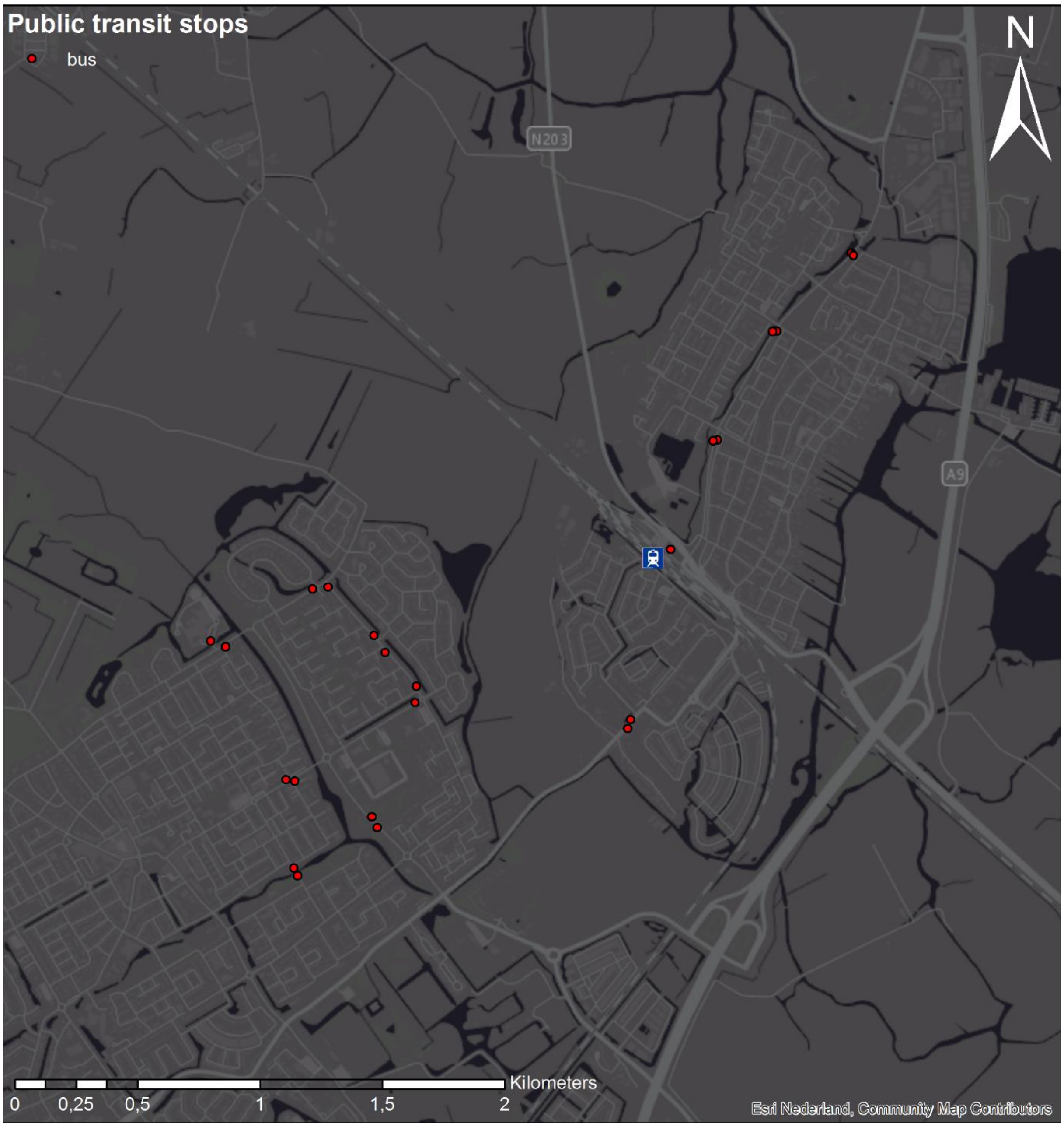

Figure H2: public transit stops around Uitgeest. Source: RUG, 2018

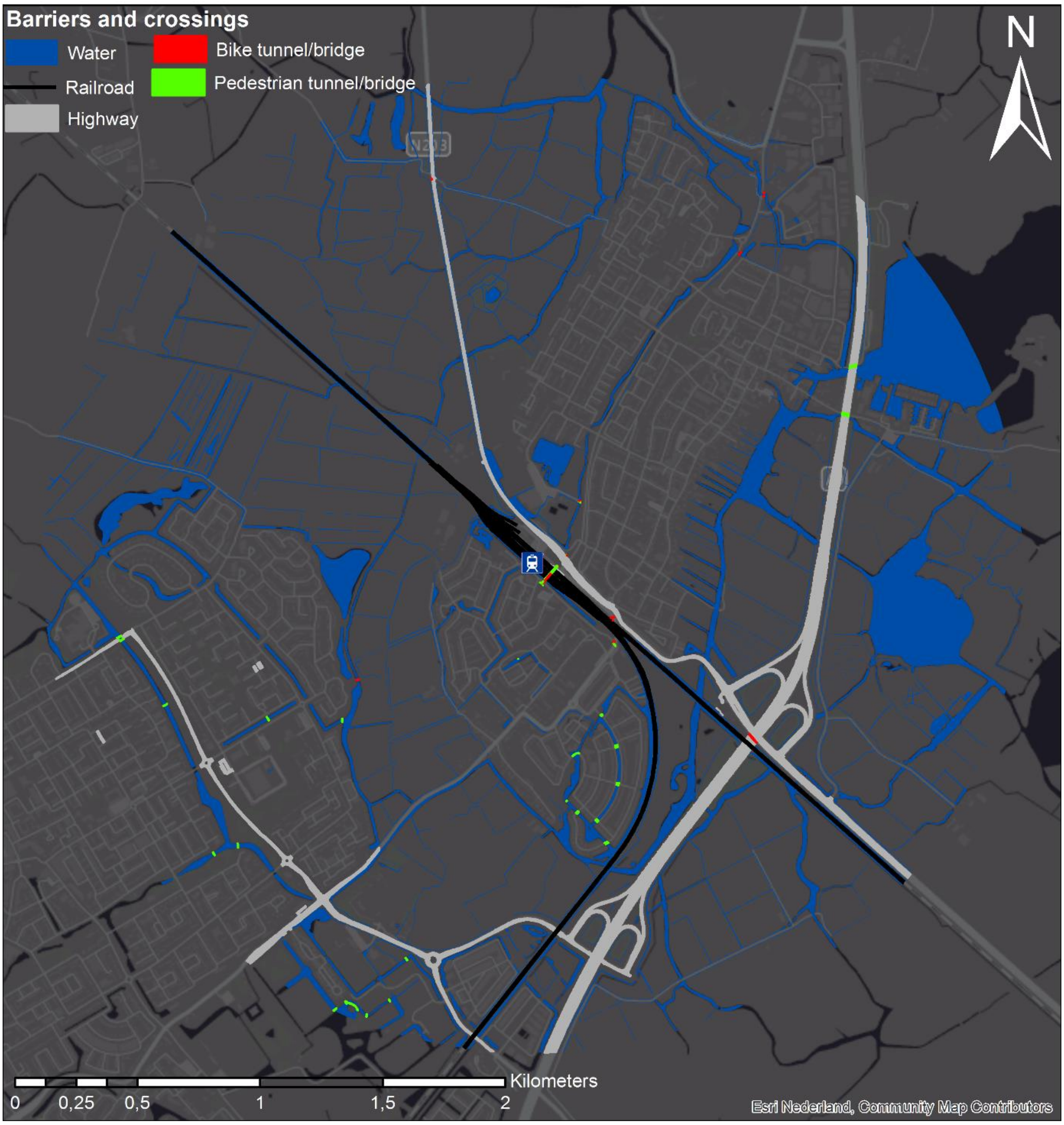

Figure H3: barriers and crossings around Uitgeest. Source: Kadaster, 2020

Pedestrian/cycling orientation

Bike parking space at station: small capacity, open space

Bicycle path surface area: 143155,56 m^2

Pedestrian path surface area: 1017237,81 m^2

Ratio: 1 : 7,11

Transit in the urban pattern

Average distance to station: 1162,94 m (st. dev.: 493,15 m)

Lines converging on station: 3 bus lines, 3 train lines

Underground/raised rails: no

Car movement and parking

Parking space: 278226,486582 m^2 ≈ 23554 cars

Parking space ratio: 278226,486582 / 4537605,237489 * 100 = 6,13%

Appendix I: Castricum (CAS)

Scale and density

Buildings in range: 10755

Connections

Figure I1: road use around Castricum. Source: Kadaster, 2020

Figure I2: public transit stops around Castricum. Source: RUG, 2018

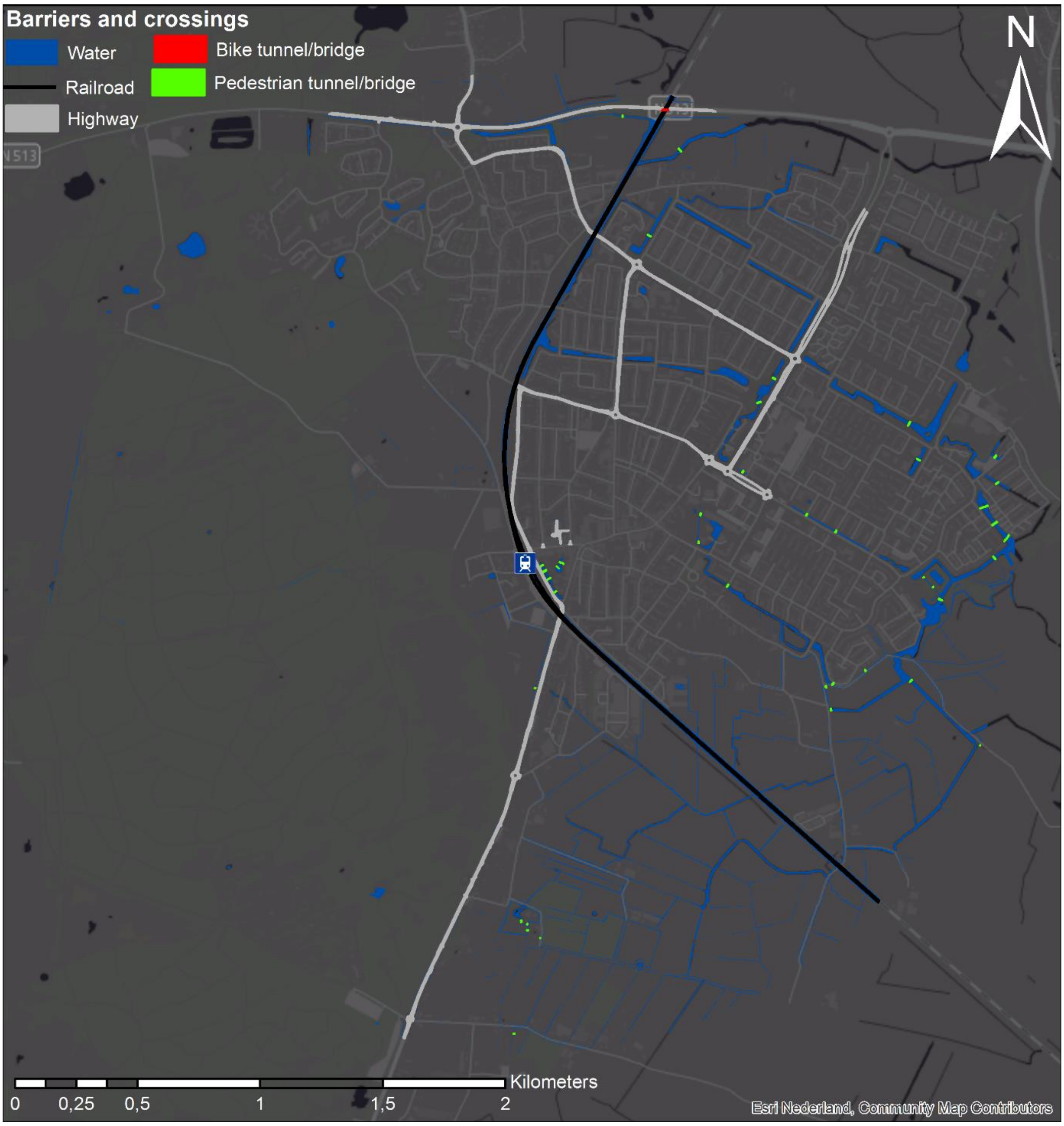

Figure I3: barriers and crossings around Castricum. Source: Kadaster, 2020

Pedestrian/cycling orientation

Bike parking space at station: medium capacity, open and closed spaces

Bicycle path surface area: 134607,21 m^2

Pedestrian path surface area: 775186,18 m^2

Ratio: 1 : 5,76

Transit in the urban pattern

Average distance to station: 1181,62 m (st. dev.: 473,53 m)

Lines converging on station: 4 bus lines, 4 train lines

Underground rails: no

Car movement and parking

Parking space: 196388,562935 m^2 ≈ 16625 cars

Parking space ratio: 196388,562935 / 2587535,173854 * 100 = 7,59%

Appendix J: Heiloo (HLO)

Scale and density

Buildings in range: 11370

Connections

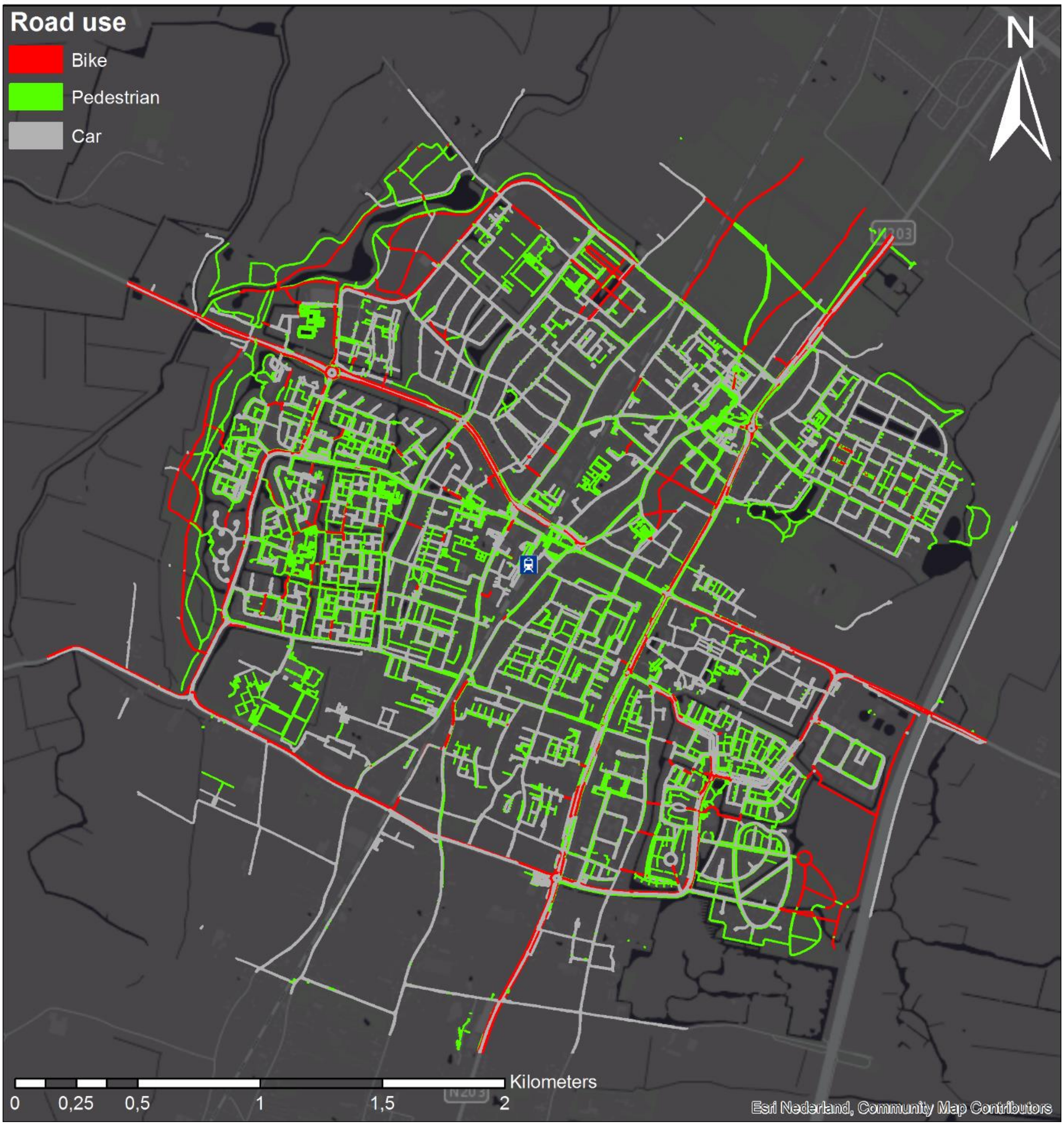

Figure J1: road use around Heiloo. Source: Kadaster, 2020

Figure J2: public transit stops around Heiloo. Source: RUG, 2018

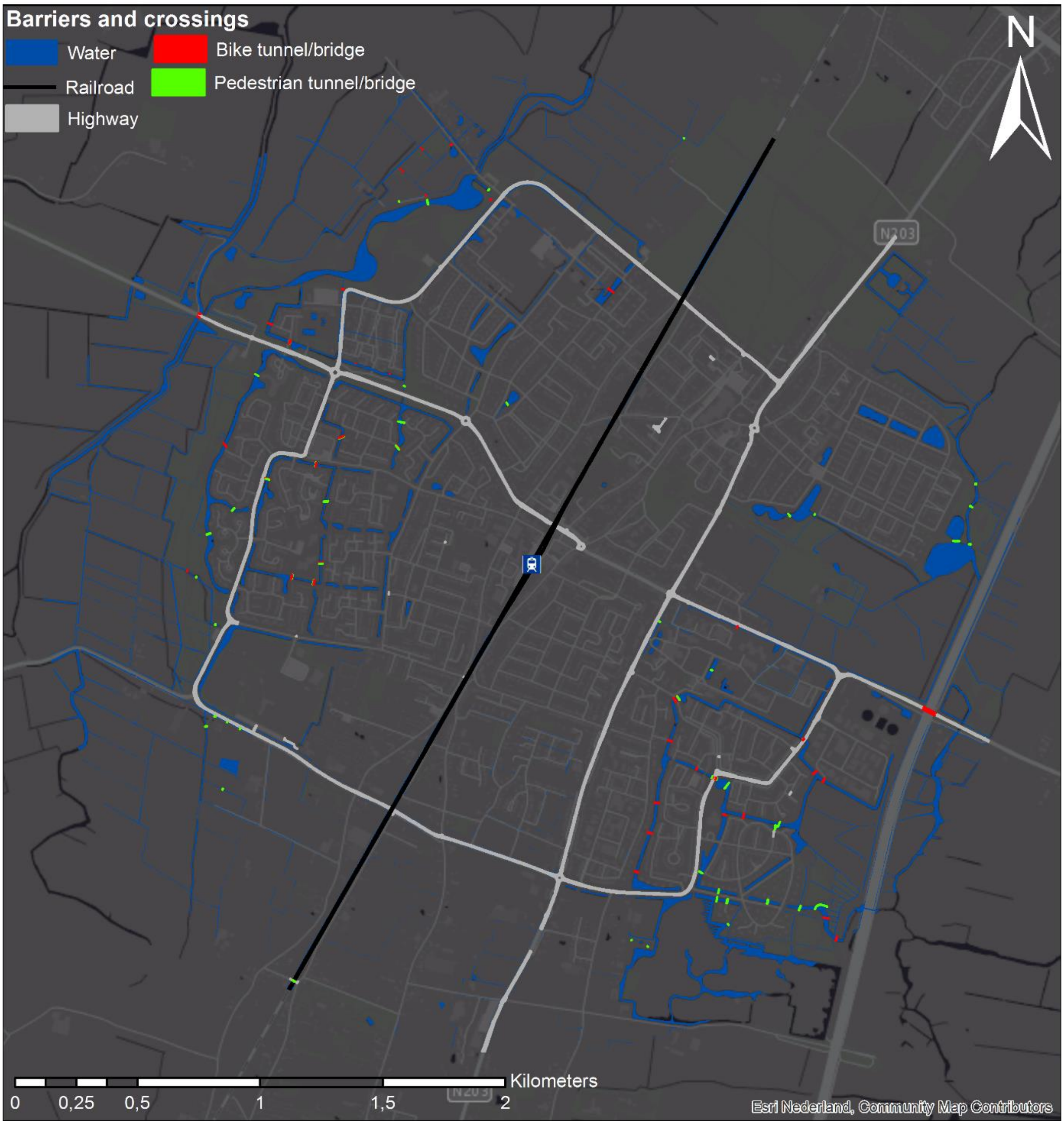

Figure J3: barriers and crossings around Heiloo. Source: Kadaster, 2020

Pedestrian/cycling orientation

Bike parking space at station: small capacity, open space

Bicycle path surface area: 183222,31 m^2

Pedestrian path surface area: 493813,11 m^2

Ratio: 1 : 2,7

Transit in the urban pattern

Average distance to station: 901,88 m (st. dev.: 389,39 m)

Lines converging on station: 1 bus line, 3 train lines

Underground rails: no

Car movement and parking

Parking space: 241940,576813 m^2 ≈ 20482 cars

Parking space ratio: 241940,576813 / 2952480,179355 * 100 = 8,19%

Appendix K: Alkmaar (AMR)

Scale and density

Buildings in range: 19376

Connections

Figure K1: road use around Alkmaar. Source: Kadaster, 2020

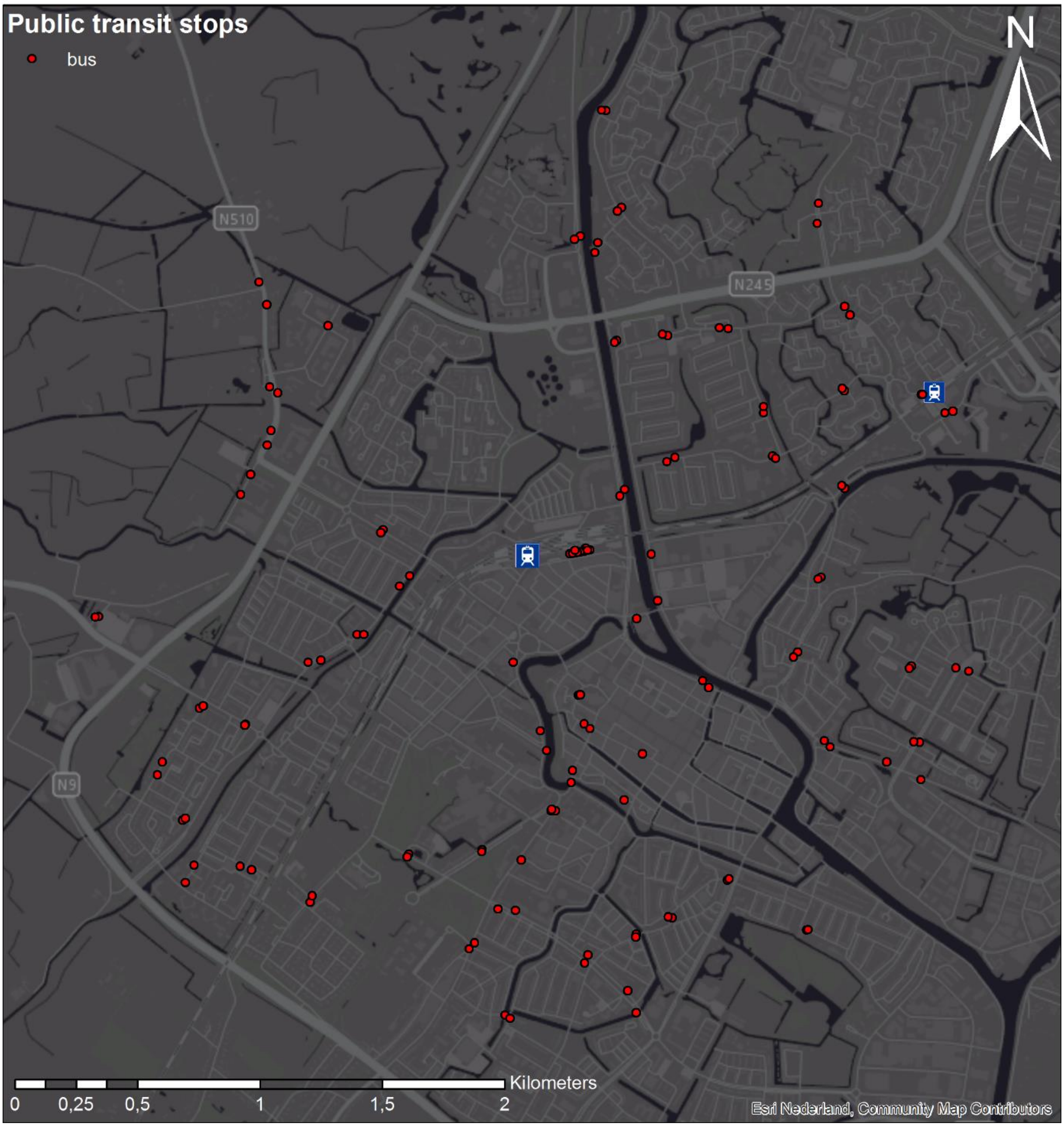

Figure K2: public transit stops around Alkmaar. Source: RUG, 2018

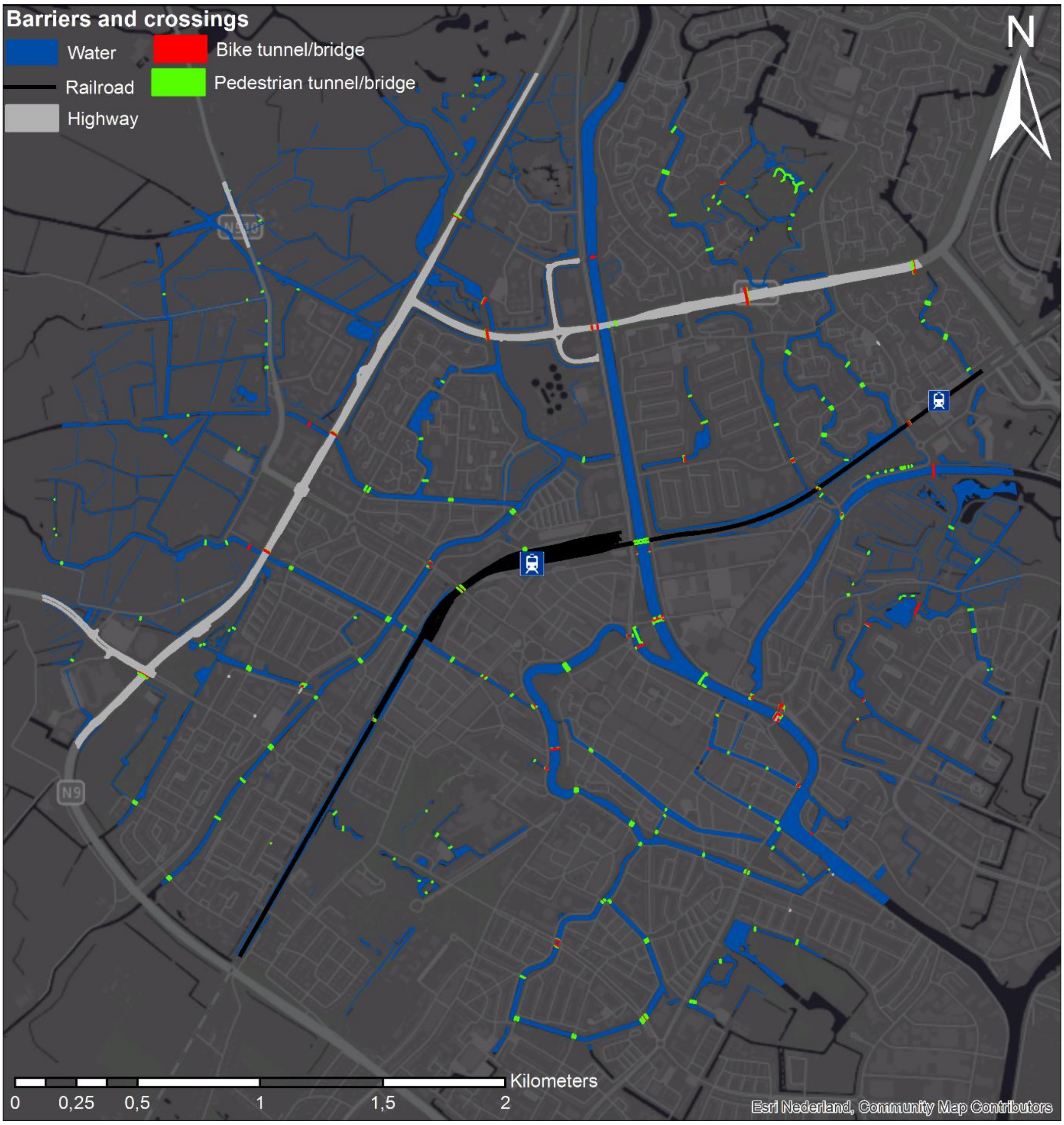

Figure K3: barriers and crossings around Alkmaar. Source: Kadaster, 2020

Pedestrian/cycling orientation

Bike parking space at station: medium capacity, open and closed spaces

Bicycle path surface area: 255882,11 m^2

Pedestrian path surface area: 1442682,72 m^2

Ratio: 1 : 5,64

Transit in the urban pattern

Average distance to station: 1206,38 m (st. dev.: 504,44 m)

Lines converging on station: 22 bus lines, 1 night bus line, 4 train lines

Underground rails: no

Car movement and parking

Parking space: 425319,862225 m^2 ≈ 36006 cars

Parking space ratio: 425319,862225 / 4691134,450445 * 100 = 9,07%

Appendix L: Alkmaar North (AMRN)

Scale and density

Buildings in range: 18981

Connections

Figure L1: road use around Alkmaar North. Source: Kadaster, 2020

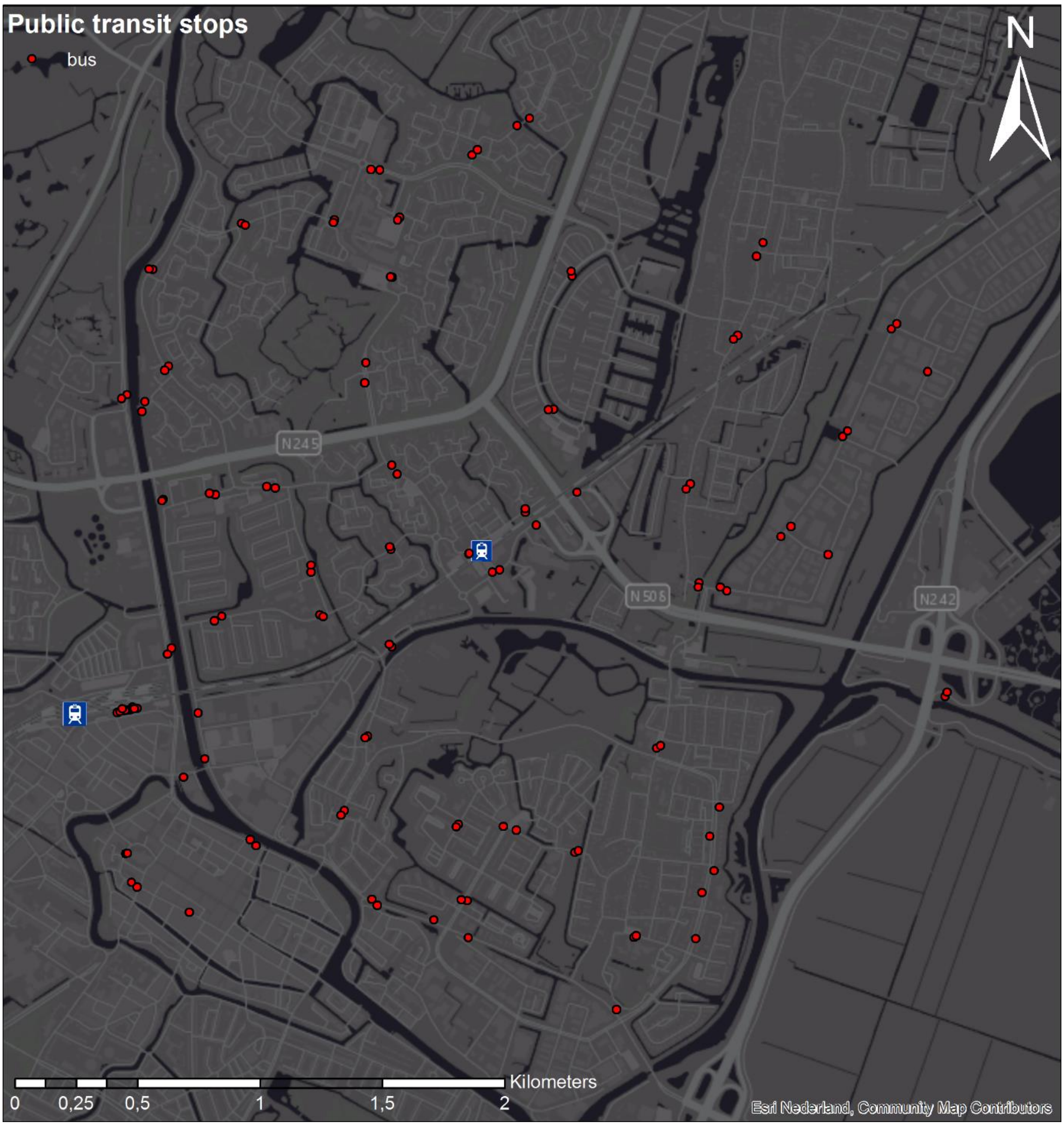

Figure L2: public transit stops around Alkmaar North. Source: RUG, 2018

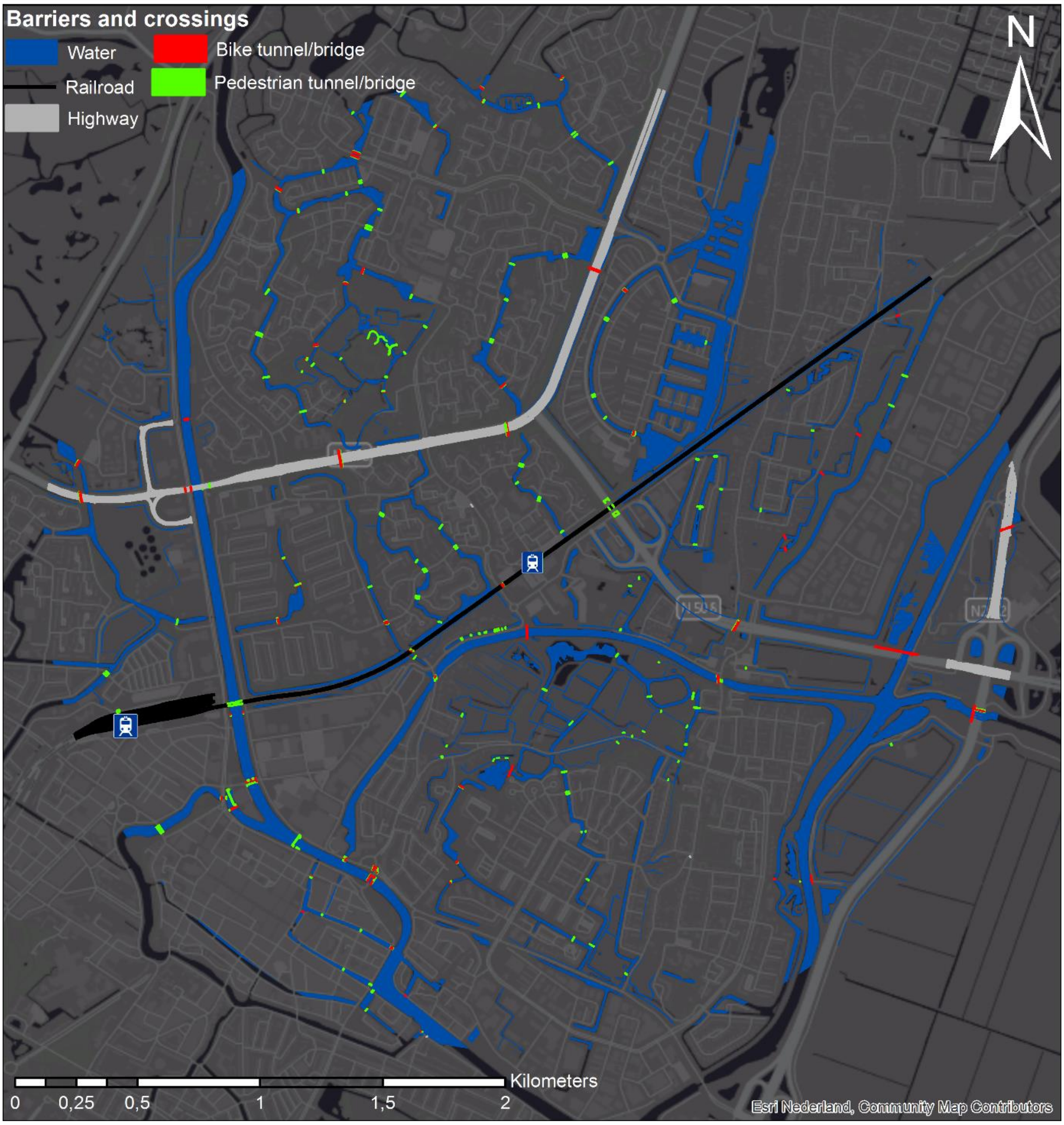

Figure L3: barriers and crossings around Alkmaar North. Source: Kadaster, 2020

Pedestrian/cycling orientation

Bike parking space at station: small capacity, open and closed spaces

Bicycle path surface area: 336560,04 m^2

Pedestrian path surface area: 1316051,12 m^2

Ratio: 1 : 3,91

Transit in the urban pattern

Average distance to station: 1356,2 m (st. dev.: 444,94 m)

Lines converging on station: 2 bus lines, 3 train lines

Underground rails: no

Car movement and parking

Parking space: 389484,802314 m^2 ≈ 32972 cars

Parking space ratio: 389484,802314 / 4565377,601699 * 100 = 8,53%

Appendix M: Heerhugowaard (HWD)

Scale and density

Buildings in range: 15934

Connections

Figure M1: road use around Heerhugowaard. Source: Kadaster, 2020

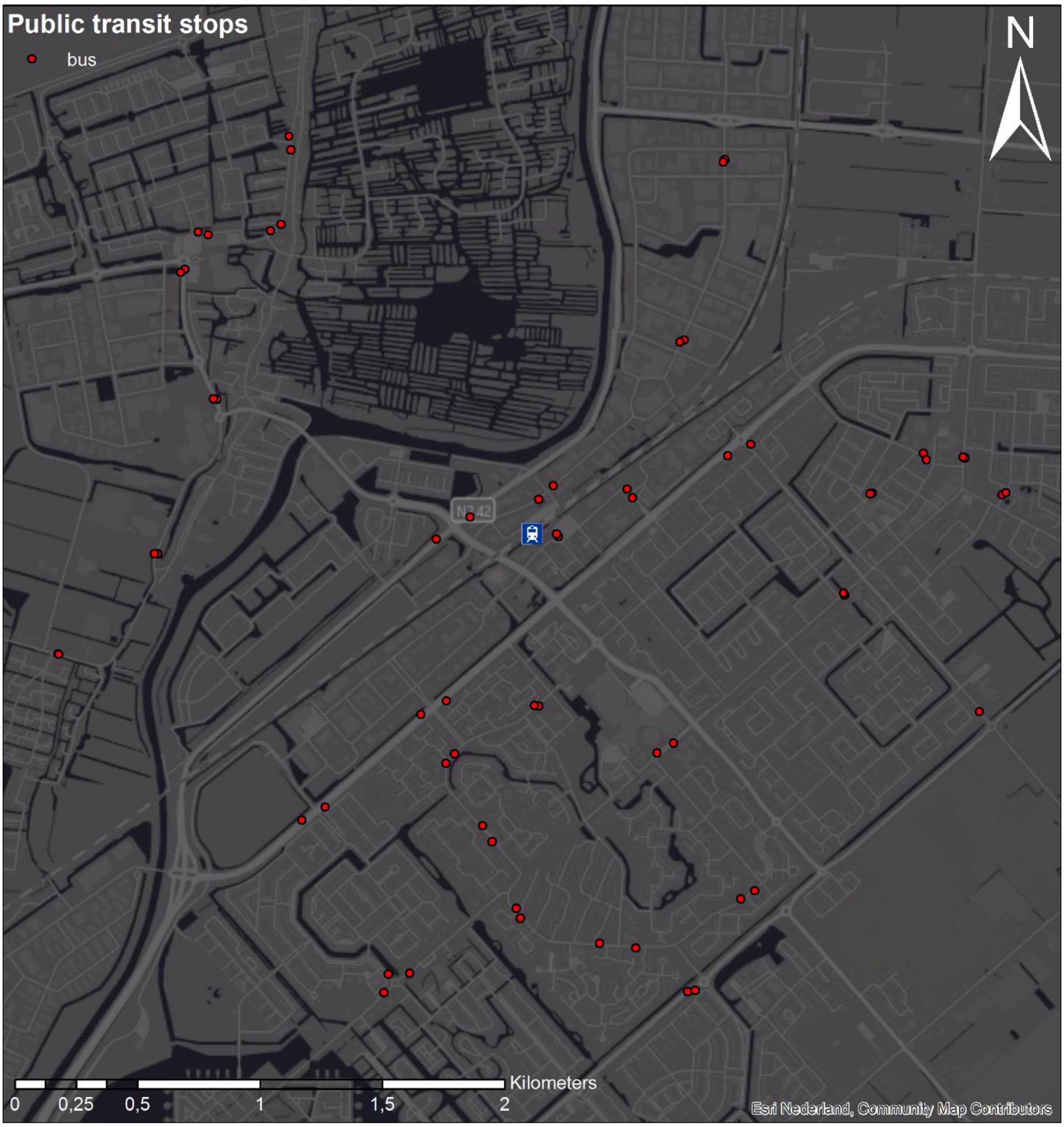

Figure M2: public transit stops around Heerhugowaard. Source: RUG, 2018

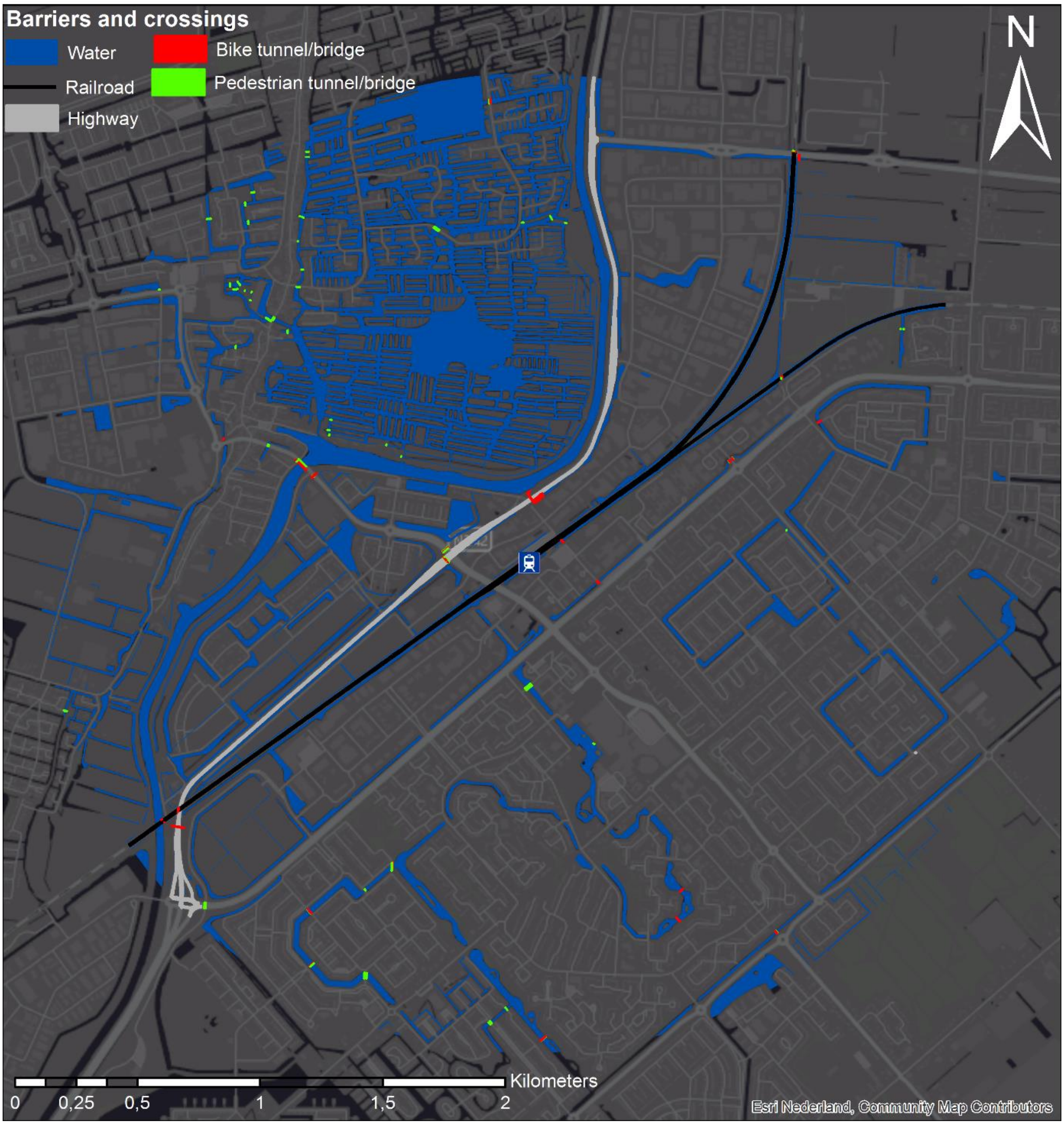

Figure M3: barriers and crossings around Heerhugowaard. Source: Kadaster, 2020

Pedestrian/cycling orientation

Bike parking space at station: medium capacity, open and closed spaces

Bicycle path surface area: 257879,18 m^2

Pedestrian path surface area: 910328,18 m^2

Ratio: 1 : 3,53

Transit in the urban pattern

Average distance to station: 1347,26 m (st. dev.: 425,39 m)

Lines converging on station: 3 bus lines, 3 train lines

Underground rails: no

Car movement and parking

Parking space: 303954,628924 m^2 ≈ 25732 cars

Parking space ratio: 303954,628924 / 3647714,640406 * 100 = 8,33%