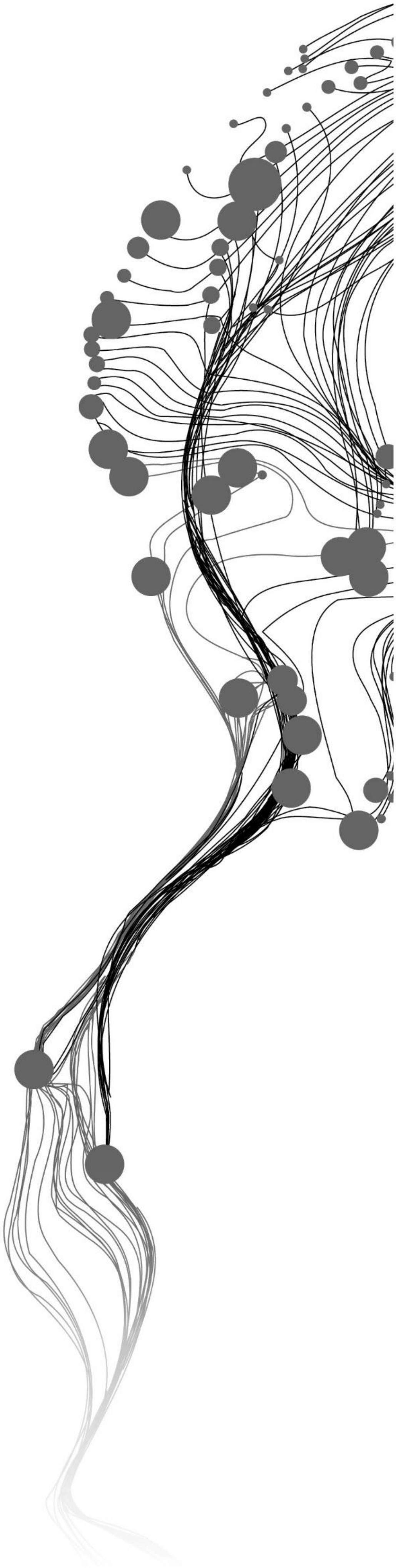
EVALUATION OF BICYCLE INFRASTRUCTURE AT ROUTE LEVEL IN ENSCHEDE, THE NETHERLANDS

YANNAN ZHANG
May, 2015

SUPERVISORS:
Ir. M.J.G. Brussel
Ing. F.H.M. van den Bosch
Dr. W. Zhang (CAU)



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YANNAN ZHANG

Enschede, the Netherlands, May, 2015

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SUPERVISORS:
Ir. M.J.G. Brussel
Ing. F.H.M. van den Bosch
Dr. W. Zhang (CAU)

THESIS ASSESSMENT BOARD:
Prof. dr. A. van der Veen (Chair)
Ing. G. Spaan (External Examiner, Enschede Municipality)

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ABSTRACT

Cycling becomes a preferred mode of sustainable transportation because of it is healthy for cyclists, eco-friendly and congestion-reduced. Enschede city has begun to promote bicycle usage by means of improving the bicycle network to make cycling the prominent mode for road users. Due to this, it is crucial to evaluate the existing infrastructure and improve the city-wide level of service. In this research, in order to assess the service level a so called Bicycle Level of Service (BLOS) index has been developed that combines scores of six indicators pertaining to the road section and the signalized intersection. A model of BLOS at route level has been also developed. Additionally a survey of cyclist route choice was held, gathering the reasons why people choose their specific routes in at the morning peak. With the survey conducted, the preferred routes composed a route set and these are processed in GIS. The Route BLOS (RBLOS) scores of the real routes and the shortest routes were compared.

In order to measure spatial variation in indicators along the segments, so called events were introduced and assigned to the real routes under a linear referencing system procedure. Subsequently BLOS scores at various levels were calculated combining all the events to obtain the so-called segment score of the real routes. To complete the entire network, these scores were extrapolated to similar segments of the network in the study area. Combined with the scores for signalized intersections, the dataset of the segment scores were built up as the calculation base of arbitrary RBLOS scores. It is achieved that the factors shortest distance and shortest travel time dominate the cyclists' routes choice at morning peak. The decreasing tendency of RBLOS scores of real routes with rising of the route distance was analyzed, and the service level of the study area was displayed. In the end, the recommendation of road segments improvement was given.

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Yannan Zhang

May, 2015

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1. INTRODUCTION

1.1. Background and Justification

To alleviate the negative impacts of transport systems such as congestion, air pollution and energy consumption, which are mainly caused by excessive use of vehicles, the concept of sustainable urban transport has been introduced. This has become a worldwide strategy to moderate these problems caused by over-motorized modes of transport. Sustainable transport provides a green transport idea with low-carbon emission, low fuel consumption and few externalities. Holden, Linnerud and Banister (2013) defined the concept of 'sustainable passenger transport' from four main dimensions: safeguarding long-term ecological sustainability, satisfying basic transport needs, and promoting intra- and intergenerational equity. The sustainability of the system is mainly measured by effectiveness and efficiency as well as the environmental impacts upon the public (Mihyeon, Jeon and Amekudzi, 2005). At present, cycling is promoted as an essential part of the strategy of urban planning and sustainable transport (Kirner Providelo & Penha Sanches, 2011). Therefore, the bicycle infrastructure should be well-developed to provide safe, comfortable and effective conditions for its users and so can support the sustainable transport policy.

Cycling is recommended according to its benefits to society as well as people's health. However there are still unsafe traffic factors due to the various service level of the infrastructure prolonging the promotion of cycling usage. In order to improve the suitability of bicycle infrastructure, the evaluation of the existing bicycle infrastructure should be conducted. In the research of Callister and Lowry's, there are various methods for assessing bicycle infrastructure, such as bicycle-compatibility index (BCI), bicycle-suitability assessment (BSA), bicycle level of service (BLOS), etc. Among these tools, the BLOS method derived from Highway Capacity Manual (2010) is the most recent and common way to calculate an index of bicycle suitability considering roadway attributes (Callister & Lowry, 2013).

The BLOS method indicates the comprehensive service level of bicycle infrastructure based on people's perception and using the measurable traffic and roadway factors that transportation planners and engineers use for other travel modes. Various models exist for assessing BLOS and can be divided into two classes—roadway segments and intersections. For instance, Jensen (2007) used a logit regression method supported by video production and questionnaire data to assess the BLOS for roadway segments considering people's perception. Moreover, the discontinuities of the bicycle lanes—left-handed losers, intersection inconsistencies and lapsing lanes are also taken into account (Krizek & Roland, 2005). Dowling, Flannery, Ryus and Venderhey et al. (2009) adopted a survey and video clip data with a regression method to evaluate the BLOS for segments and intersections respectively.

Most previous researches that calculate or estimate the BLOS of the bicycle infrastructure focused on the scale of segment and intersection, which insufficiently considers the route scale. That is, there is discontinuity for BLOS assessment in the bikeway network. Consequently, measurement of BLOS at route level is needed to evaluate the bicycle infrastructure. Thus, the route choices according to BLOS also could be compared with the traveller's preference. It also could be analysed how well the infrastructure is functioning and if it affects the route choices of passengers.

In addition, Geographic Information Systems (GIS) can be an analytical tool to support BLOS assessment by performing a series of spatial analytical operation using different indicators to measure BLOS.

1.2. Research Problems

The willingness of people using the bicycle instead of other traffic modes to travel is motivated to a large extent by how well the bicycle system is functioning. In order to improve bicycle suitability, factors such as safety, convenience and comfort are important and evaluation of the current bicycle system is necessary. The well-developed and most recent method is using BLOS index to characterize the bicycle suitability of the infrastructure.

For the sake of bikeway network improvement and allocation of resources, methods to measure the suitability at route level are needed. A number of models to measure BLOS are discussed in previous researches. However, they almost all are in segment or intersection scale which is focused on the scores of BLOS of the links or the junctions. There is need to explore other measures that could combine intersection BLOS with segment BLOS or BLOS continuity (Lowry, Callister, Gresham, & Moore, 2012). While lack of the methods of BLOS at route level makes it difficult to evaluate the bicycle level of service for the whole route within the network. Besides, the indicators like traffic volume, parking lot, width of lanes, pavement conditions and so on should be selected according to the local context. Thus, the main problem that should be prioritized is to develop the evaluation method of BLOS scores or to model it at route level.

In addition to the method adopted for BLOS modelling, the selection of reasonable pairs of origin and destination for assessment is another problem. The selected routes have to be in line with the characteristics of variety, and it is supposed to be easy to implement the route choice survey. After the modelling and quantifying the route BLOS, the issue of whether BLOS scores impact people's choice of routes for cycling could be tested, and conclusions can be drawn on how BLOS scores influence route choice.

1.3. Research Objectives

1.3.1. General Objective

The general objective of this research is to develop a method to evaluate bicycle infrastructure using route BLOS for Enschede, the Netherlands.

1.3.2. Sub-objectives

There are three specific sub-objectives derived from the general objective:

- To measure BLOS of bicycle infrastructure involving both segment and intersection BLOSs.
- To model the BLOS at route level and test route BLOS through survey.
- To build up the BLOS score dataset for optimal route analysis.

1.4. Research Questions

- **Sub-objective 1:** To measure BLOS of bicycle infrastructure of both intersection and segment.
  What attributes/factors dominate the BLOS?
  What are the characteristics of the bikeway network in Enschede?
  What are the proper factors for the assessment in Enschede?
  What are the methods of BLOS assessment in segment and intersection scale?

- **Sub-objective 2:** To model the BLOS at route level and test by survey.
  What model is appropriate to evaluate the BLOS at route level?
  What are proper routes selected to test the model?
  Which type of the survey should be conducted to test the model?
  What elements influence the route choice of cyclists?
  Do BLOS scores influence the route choice of cyclists significantly?
- **Sub-objective 3:** To build up the BLOS score dataset for optimal route analysis.
  What is the method to obtain the elementary section score?
  What is the method to digitize or symbolize the intersections?
  What is the standard of categorizing bicycle infrastructure?

1.5. Research Design

1.5.1. Hypotheses and Anticipated Results

The hypotheses are stated as follows.

- The bicycle level of service of the bicycle route influences the route choice of cyclists.
- The method of BLOS at route scale can model the bicycle level of service in a more realistic way.

The results are anticipated as follows.

- The method of the route BLOS is applicable to the bicycle system in Enschede.
- The difference between the model result and the preference of cyclists could be well-understood.
- The BLOS score dataset can be applied to the study area properly.

1.5.2. Conceptual Framework

The conceptual framework of this research is illustrated in Figure 1-1. All concepts are related to bicycle level of service, which is the core of this research. The requirements of friendly bicycle infrastructure occur in five aspects—directness, safety, comfort, attractiveness and coherence(CROW, 2007). These requirements could be reflected by physical attributes and cyclists' perceptions which contribute to section and intersection BLOSs. One section is a route portion where all attributes are consistent. Then these two BLOSs will be combined to the aggregate route BLOS and compared with the cyclists' route choice to test the route BLOS model and to find out if the route BLOS influences cyclists' choice significantly. At the same time, the section BLOS would be intersected with the actual network to get the elementary local score, and then integrated to the segment BLOS score for the future flexible application. For instance, any combination of the segments and the intersection BLOS score could be obtained for the routes that are not investigated.

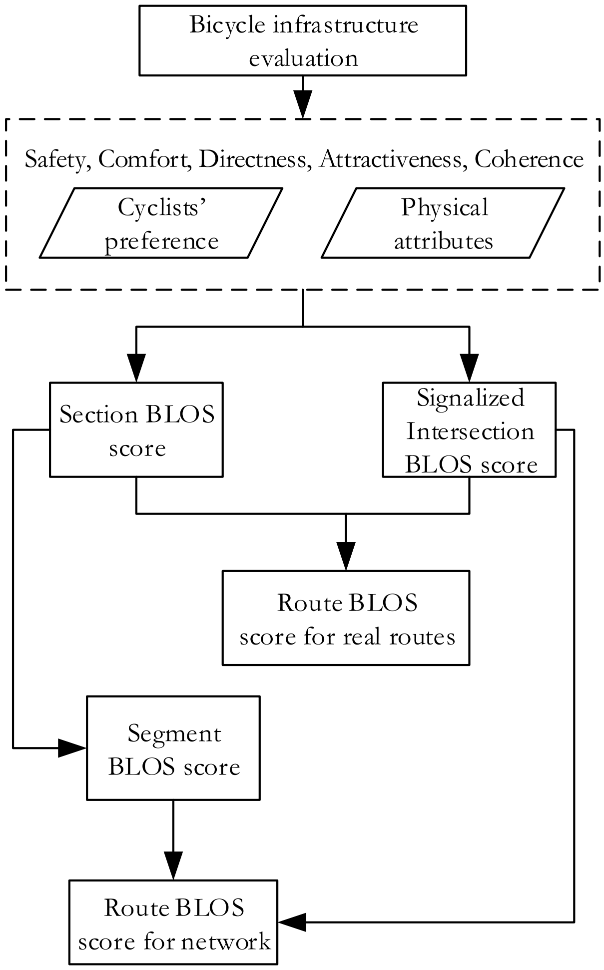


Figure 1-1 Conceptual Framework

1.6. Research Method

This research aims to develop a method to evaluate the bicycle performance by calculating the aggregate route BLOS for both section and intersection, and apply it to Enschede. In the first stage, the specific routes should be selected within the network to assess the route BLOS. This selection is conducted according to the result of the route choice survey. This survey would be executed by questionnaires asking cyclists with different age, gender and cycling frequency and to rank the reasons why they made such choices. Secondly, evaluating the service level is based on the indicators related to the requirements of the bicycle infrastructure. The data requirements of these factors mainly relate to the traffic flow, the widths of bicycle lane/track and driveway, pavement condition, vehicle speed, parked vehicle, intersections type, waiting time, etc. Thirdly with respect to the model of the route BLOS, it will be developed to combine the section and intersection parts to obtain the route BLOS. The model should fit the local situation of the Netherlands. The final phase deals with the problem of testing the route BLOS model with cyclists' route choice survey and analysing the travel behaviour of the travellers. The local-reflected elementary segment score will also be obtained to provide the dataset for applying scores to the whole network. Then the optimal route choice would probably be analysed. In addition, the improvement of the bicycle system may also be recommended for Enschede. The schema of this research is shown as figure 1-2.

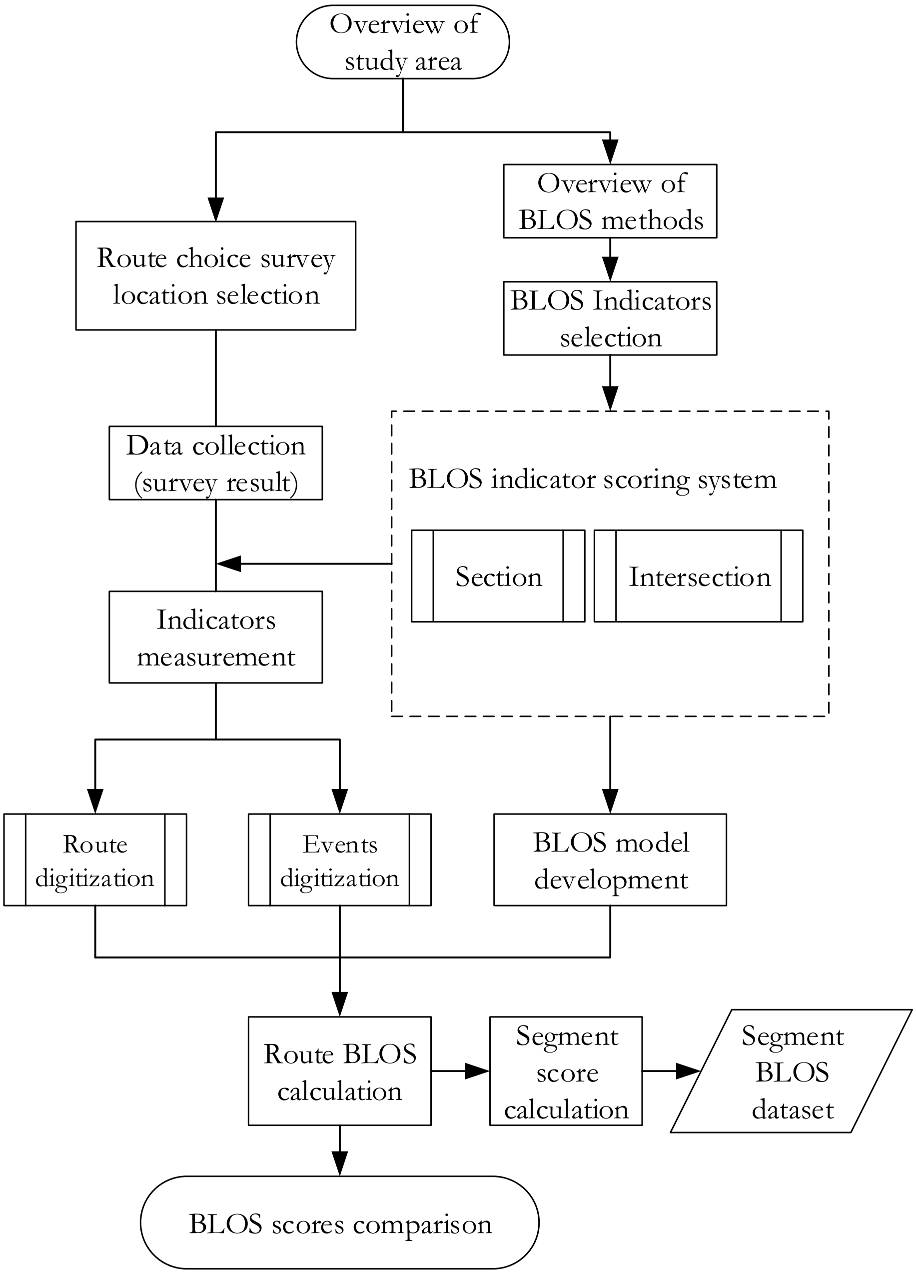


Figure 1-2 Research Schema

In the following chapters, it is going to be discussed how the questionnaire survey of route choice is conducted, how the route BLOS are modelled in calculation way and in the GIS, also the relation between the results of the survey and the models.

2. LITERATURE REVIEW

Several methods to evaluate the suitability of a bicycle system have been developed since 1987. Different indexes were used to represent how well the system is functioning. Most of them are shown in Table 2-1(Callister & Lowry, 2013). Besides, other methods were also introduced such as bicycle suitability score, bicycle interaction hazard score and compatibility of road for cyclists, etc.

Table 2-1 Roadway Attributes for Selected Bicycle Suitability Methods

	Method acronym, date					
Attribute[a]	BSIR, 1987	BSL, 1994	BSS, 1997	BCI, 1998	BSA, 2003	BLOS, 2010
Width of outside lane	x	x	x	x	x	x
Width of bike lane	—	—	—	x	x	x
Width of shoulder	—	—	x	x	x	x
On-street parking	x	—	—	x	x	x
Presence of curb	—	—	—	—	x	x
Vehicle-traffic volume	x	x	x	x	x	x
Number of lanes	x	—	—	—	x	x
Vehicle speeds	x	x	x	x	x	x
Percent heavy vehicles	—	—	—	x	—	x
Pavement condition	x	—	x	—	x	x
Elevation grades	x	—	—	—	x	—
Adjacent land-use	x	—	—	x	x	—
Storm drain grate	x	—	—	—	x	—
Physical median	x	—	—	—	x	—
Turn lanes	x	—	—	x	x	—
Frequent curves	x	—	—	—	x	—
Restricted sight-distance	x	—	—	—	x	—
Numerous driveways	x	—	—	—	x	—
Presence of sidewalks	—	—	—	—	x	—
Railroad crossing	x	—	—	—	—	—

Note: An x indicates the attribute is used for calculation and a blank entry indicates the attribute is not used for calculation. BCI = bicycle-compatibility index; BLOS = bicycle level-of-service; BSA = bicycle suitability assessment; BSIR = bicycle-safety index rating; BSL = bicycle-stress level; and BSS = bicycle-suitability score.
[a]Attribute names are sometimes slightly different in the source documentation for each method.

Source: (Callister & Lowry, 2013)

As we can see from the table, BSIR and BSA incorporate the largest number of variables. But the BLOS method has been updated as the most current one with refined roadway attributes fitting the urban situation. The definition of level of service was given in Highway Capacity Manual (2010) as "qualitative measures that characterize operational conditions within a traffic stream and their perception by motorists and passengers." Bicycle level of service(BLOS) index (Landis, Vattikuti, & Brannick, 1997) is one of the popular techniques to measure the comfort level of infrastructure, which considers the physical factors such as traffic volume, through lanes, speed limit, pavement condition, width, and heavy vehicles as well as the participant's perceptions of roadways (Rybarczyk & Wu, 2010)

The route BLOS needs the combination of the individual BLOSs as components. The American and Danish researchers have done some studies on the segment BLOS or the intersection BLOS. Regression methods are used to find the correlation of the predicted BLOS, which reflects the satisfaction or the suitability of the bicycle infrastructure, and the actual roadway properties. Besides, the researchers of the Netherlands also have done the studies for the quality of the bicycle paths.

2.1. Models of Road segment BLOS

2.1.1. BLOS model of Landis

The model was conducted initially by employing 150 bicyclists to ride around 30 roadway segments and rate each of them in Tampa, Florida(Landis et al., 1997). The participants ranged between 13 and over 60 years of age, with 47 percent being female and 53 percent being male. The range of cycling experience varied from 25 percent of the participants rode less than 322 km (200 miles) per year to 39 percent of them riding over 2,414 km (1,500 miles) per year(Dowling et al., 2009). The assessment was combined with the physical variables of the roadways such as the traffic volume, speed, vehicle types, pavement condition, proximity of cyclists to the vehicles stream, etc. The formula is shown as:

$$\mathrm{BLOS} = 0.589\ln\left(Vol_{15} / L\right) + 0.826\ln\left(SPD_P\left(1+\%HV\right)\right) + 0.019\ln(COM15 \times NCA) + 6.406 PC_5^{\,2} + 0.005 We^2 + 1.579 \quad (1)$$

Where:

Vol_{15}=volume of directional traffic in 15-minite time period;

L=total number of through lanes;

SPD_F=posted speed limit;

%HV=percentage of heavy vehicles

COM15=trip generation intensity of the land use adjoining the road segment (stratified to a commercial trip generation of "15"multiplied by the percentage of the segment with adjoining commercial land development);

NCA=effective frequency per mile of non-controlled vehicular access (e.g., driveways and/or on-street parking spaces);

PC_5=FHWA's 5 point pavement surface condition rating

W_e=average effective width of outside through lane, where $W_e=W_t+W_1-\Sigma W_r$

Where W_t=total width of paving between the outside lane stripe and the edge of pavement;

W_l=width of paving between the outside lane stripe and the edge of pavement

ΣW_r=width (and frequency) of encroachments in the outside lane;

$=W_p \times$%of segment with on-street parking $+W_g$

Where W_p=width of pavement occupied by on-street parking activity;

W_g=combined width and frequency factor of other encroachments

2.1.2. Bicycle LOS model (Version 2.0)

The model was developed form the model of Landis with over 250,000 miles of roads and streets varied from urban, suburban to rural area across North America (Sprinkle Consulting, 2007). It has been refined with a high degree of validity, including the case in Tampa, Florida in 2005 (Petritsch et al., 2008). The Model has been applied on over 400,000 miles of roadways throughout North America, which uses the same measure factors as the transportation planners and engineers used. It is also extensively used by numbers of states, regional, metropolitan and local transportation agencies across the United States and now is established in the new Highway Capacity Manual (Sprinkle Consulting, 2007).The formula is shown as:

$$\mathrm{BLOS}=0.507\ln(Vol_{15} / L_n) + 0.199 SP_t(1+10.38HV)^2 + 7.006(1/PR_5)^2 - 0.005We^2 + 0.760 \quad (2)$$

Where:

Vol_{15} = Volume of directional traffic in 15-minute time period

= (ADT × D × Kd) / (4 ×PHF)

Where:

ADT = Average Daily Traffic on the segment or link

D = Directional Factor
Kd= Peak to Daily Factor
PHF = Peak Hour Factor
SPt = Effective speed limit= 1.1199 ln(SPp - 20) + 0.8103
where:
SPp = Posted speed limit (a surrogate for average running speed)
HV = percentage of heavy vehicles (as defined in the 1994 Highway Capacity Manual)
PR5 = FHWA's five point pavement surface condition rating
We = Average effective width of outside through lane:
We = Wv - (10 ft × % OSPA) and Wl = 0
We = Wv + Wl (1 - 2 × % OSPA) and Wl > 0 & Wps= 0
We = Wv + Wl - 2 (10 ×% OSPA) and Wl > 0 & Wps> 0 and a bike lane exists
Where:
Wt = total width of outside lane (and shoulder) pavement
OSPA = percentage of segment with occupied on-street parking
Wl = width of paving between the outside lane stripe and the edge of pavement
Wps= width of pavement striped for on-street parking
Wv = Effective width as a function of traffic volume and:
Wv = Wt if ADT > 4,000veh/day
Wv = Wt(2-0.00025 × ADT) if ADT ≤ 4,000 veh/day, and if the street/road is undivided and unstriped
The bicycle level of service is categorized in to 6 classes according to the different scores shown in table 2-2.

Table 2-2 Bicycle Level-of-Service Categories

Level-of-Service	BLOS score
A	≤ 1.5
B	> 1.5 and ≤ 2.5
C	> 2.5 and ≤ 3.5
D	> 3.5 and ≤ 4.5
E	> 4.5 and ≤ 5.5
F	> 5.5

2.1.3. BLOS model of Jensen

The model of Jensen is based on the perception survey of 407 respondents who were shown video clips for 56 segments of roadways. These were rated by the cyclists reflecting a 6-point scale in Denmark (Søren Underlien Jensen, 2007). It utilized the SAS (version 8.1) software to set up the cumulative logit models and ordinal probit models. This previous American studies provides bases for this method. The utility function was used to predict the satisfaction of the cyclists. The form is shown as:

$$\text{logit}(p) = \alpha \begin{bmatrix} \text{very} & \text{satisfied=-1.3652} \\ \text{moderately} & \text{satisfied=0.3741} \\ \text{a little} & \text{satisfied=1.5512} \\ \text{a little} & \text{dissatisfied=2.4805} \\ \text{moderately} & \text{dissatisfied=3.8449} \end{bmatrix} + AREA \begin{bmatrix} \text{residential=0.0557} \\ \text{shopping=-0.3400} \\ \text{mixed=-0.0334} \\ \text{rural fields=-0.0196} \\ \text{rural forest=0.3369} \end{bmatrix} - 0.0005585 \cdot MOT$$
$$-2.3895 \cdot LBUF - 0.0004691 \cdot LBUF \cdot MOT - 0.0958 \cdot SPEED + 0.000421 \cdot SPEED^2 - 0.000002913 \cdot MOT \cdot SPEED$$
$$+0.0402 \cdot LBUF \cdot SPEED + 0.000002446 \cdot LBUF \cdot MOT \cdot SPEED - 0.001623 \cdot PED + 0.0000008309 \cdot PED^2$$
$$-0.09416 \cdot PARK + 1.7782 \cdot PATH + 1.3938 \cdot ULAN + 2.1596 \cdot RSHO + 0.2413 \cdot DBL - 0.2593 \cdot RBUF$$
$$+1.2694 \cdot SW - 0.6988 \cdot BUS + 0.6821 \cdot LANE \tag{3}$$

Where:

logit(p) = utility function of the cumulative logit model；
α= intercept parameter of the response level of satisfaction；
AREA = type of roadside development or landscape；
MOT = motor vehicles per hour in both directions；
LBUF = width of buffer area between bicycle facility and drive lane on the nearest roadside (m);
SPEED = average motor vehicle speed (km/h);
PED = passed pedestrians per hour on nearest roadside at 20 km/h riding speed；
PARK = parked motor vehicle on nearest roadside per 100 m;
PATH = width of bicycle path/track on nearest roadside (m);
ULAN = width of bicycle lane/paved shoulder (at least 0.9 m wide) on nearest roadside in urban areas (m);
RSHO = width of bicycle lane/paved shoulder (at least 0.9 m wide) on nearest roadside in rural areas (m);
DBL = width of nearest drive lane including bicycle lane/paved shoulder of less than 0.9 m width (m);
RBUF = width of buffer area between sidewalk and bicycle facility/drive lane (m);
SW = sidewalk dummy, sidewalk on nearest roadside = 1, no sidewalk = 0;
BUS = bus stop dummy, bus stop on roadway = 1, no bus stop = 0;
LANE = drive lane dummy, four or more drive lanes = 1, one to three lanes = 0.

2.2. Models of Intersection BLOS

2.2.1. BLOS model of Landis

The model provides the method to evaluate the degree of safety and comfort for the cyclists going through the signalized intersections in a research sponsored by the Florida Department of Transportation. It was conducted through Pearson correlation analyses and stepwise regression modelling of almost 1000 cyclists' perception responses. The results showed a high correlation with the average observations. It indicates that the factors- traffic volume, the width of the outside lane and the crossing distance are the key factors of the intersection BLOS for the through movement of cyclists(Landis et al., 2003). The formula developed is shown as:

$$\text{TM IntBLOS} = -0.2144 \cdot W_t + 0.0153 \cdot CD + 0.0066(Vol_{15} / L) + 4.1324 \tag{4}$$

Where,

TM IntBLOS = perceived hazard of shared-roadway environment through the intersection;
Wt = total width of outside through lane and bike lane (if present);
CD = crossing distance, the width of the side street (including auxiliary lanes and median);
Vol_{15} = volume of directional traffic during a 15-minute time period;

L = total number of through lanes on the approach to the intersection

2.2.2. BLOS models of Jensen

Jensen proposed these models in 2012(Soren Underlien Jensen, 2013). These models provide different types of intersections, roundabout and other kinds of crossings, using the same method of the BLOS model building for the segments. The survey of 95 intersections, including 46 signalized intersections, 23 roundabouts and 26 non-signalized crossings, with 200 respondents participating has been done after the orthogonal experimental design for the site selection in Copenhagen. The researchers attempted to identify the connections between road conditions and user perceptions through a cumulative logit model. The intersections are modelled relatively in various groups such as signalized intersections (straight ahead crossing one arm and left-turn crossing two arms), roundabouts (crossing one arm), and non-signalized intersections (crossing main road).

It's significantly influenced that the bicycle facilities affects the satisfaction. For instance, the satisfaction will increase 2 to 3 levels when the bicycle facilities exist such as the coloured bicycle lane or track rather than cycling on the roadway. Besides, the traffic volume would be another factor which has big impact on the satisfaction, especially the non-signalized intersections.

2.2.3. Conclusion of the segment and intersection models

The comparison of the main models of segment BLOS and intersection/arterial BLOS is revealed in table 2-3. According to the table, it can be seen that most of these models take advantage of the regression model to predict the cyclists' satisfaction through different factors. The US models have not used the cyclists' perception as one of variables, comparing to the Danish models.

2.3. Route BLOS models

2.4.1. BLOS model of Arterials

Petritsch et al. developed an arterial LOS model for cyclists based on a mix of video laboratory and field surveys for rating arterial sections. BLOS observations were obtained from 63 volunteers who rode the 20-mile course in Tampa, Florida in 2005. A total of 700 BLOS ratings were responded and the arterial BLOS involving both segments and the unsignalized intersections with combination of them. The form is shown as:

$$\text{BLOS Arterial} = 0.797\left(avsegLOS\right) + 0.131\left(unsig / mile\right) + 1.370 \quad (5)$$

Where

avseg LOS = distance-weighted average segment bicycle LOS along the facility, and

Unsig/mile = Number of non-signalized intersections per mile along the facility.

This model comes up with a combination of segment and intersection BLOS, but just simply integrates the number of unsignalized intersections which doesn't reflect intersection service level.

Table 2-3 Comparison of BLOS models

Study		Application areas	Method	Elements mainly involved	Application Pros & cons
Segment BLOS	Landis (1997)	Tampa, Florida	· A field survey of nearly 150 bicyclists riding a 27-km (17-mile) course in Tampa, Florida. · Participants were asked to evaluate the quality of the roadway links on a 6-point scale (A to F) as to how well they were served of each segment.	· Volume of directional traffic in 15mins · Total no. of through lanes · Speed limit · % of heavy vehicles · Pavement condition rating · Avg. effective width of outside though lane (on street parking) · effective frequency per mile of non-controlled vehicular access	· The classic method providing basis for studies of BLOS, which is a correlation between roadways factors and BLOS score · Applied only to Tampa, Florida
	Bicycle LOS model (version 2.0)	North America across urban, suburban and rural area	· Based on Landis model · Evaluate and reflect over 250,000 miles roads and streets by assessing the participant's perception of the physical road network with statistic precision.	· Volume of directional traffic in 15mins · Total no. of through lanes · Speed limit · % of heavy vehicles · Pavement condition rating · Avg. effective width of outside though lane (on street parking)	· Wide spread application varied from metropolitan to rural area has provided refinements and validation · Date requirements needs various kinds of traffic parameters which requires long-term observation, e.g. ADT, Directional Factor, Peak to Daily Factor, PHF · Suitable for North American
	Jensen (2007)	Demark	· Preference survey through video clips production · Cumulative logit models and ordinal probit models	· Rating of satisfaction · landscape · Motor vehicles' volume per hour in both directions · Width of buffer area between bicycle facility and nearest drive lane · Avg. motor vehicle speed · Passed pedestrians per hour on nearest roadside at 20 km/h riding speed; · Parking · Width of bicycle path/track on nearest roadside, bicycle lane/paved shoulder, buffer area between sidewalk and bicycle facility/drive lane; · Sidewalk, bus stop, drive lane dummy	· Derived from local Danish area considering the local context ; · Needs large amounts of cyclists perception response; high demand of the data
Intersection BLOS	Landis (2003)	Florida	· Pearson correlation analyses · Stepwise regression modelling of Perception responses	· Total width of outside through lane · Crossing distance, the width of the side street · Volume of directional traffic during a 15-minute time period; · Total number of through lanes on the approach to the intersection	· The factors consist with the one contributing to the segment BLOS · For signalized intersections
	Jensen	Denmark	· Preference survey through video shows and questionnaire · Cumulative logit models	· Rating of satisfaction · Type of the intersection and bicycle facility · Width of the bicycle facility · Waiting time · Presence of the zebra, bicycle signal · Circulating motor vehicle volume	· Derived from local Danish area considering the local context ; · Needs large amounts of cyclists perception response; high demand of the data

2.4.2. Bi-objective cyclist choice model

With the BLOS score of both segment and intersection combined, the route BLOS could be calculated. Ehrgott, Wang, Raith, and van Houtte (2012) proposed a bi-objective cyclist choice model including minimizing the travel time and maximizing the level of suitability. The segment and intersection BLOS values are calculated by the model of Landis.

The principle of the model is characterising each link (segment) the attributes-travel time and suitability - of the roadway along the route. The assumption of the model is that the cyclists choose the route rather than others only if the travel time is shorter without the suitability score sacrifice or if the suitability level is higher without the travel time extension, meaning the comparison only comes into effect when single factor changes.

The total travel time of the whole route can be calculated by adding the travel time of each link up sequently as given,

$$t(p) = \sum_{i \in p} t_i \tag{6}$$

Where t_i is the travel time for the link i of the route p.

2.4.3. Bicycle Environmental quality index

The BEQI measures 22 indicators to evaluate the bicycle service quality at both the intersection and street segment level, listed in table 2-4. Intersection-level assessment looks only at safety features that aim to protect cyclists from vehicle traffic, while the segment-level focuses on land use, traffic and design features as well as safety measures that increase visibility for cyclists(San Francisco Department of Public Health, 2010). This assessment is San-Francisco-specific method, which might provide reference for Enschede.

Table 2-4 BEQI indicators by domain

Intersection	Segment			
Intersection Safety	Traffic	Street Design	Land Use	Safety/Other
-Left turn bicycle lane -Dashed intersection bicycle lane* -No turn on red signs *relevant only at complex intersections with high traffic volumes and/or speeds	-Number of vehicle lanes -Vehicle speed -Traffic calming features -Parallel parking adjacent to bicycle lane/route -Traffic volume -Percentage of heavy vehicles	-Presence of a marked area for bicycle traffic -Bicycle lane markings -Bike lane width -Trees -Connectivity of bike lanes -Pavement type/condition - Driveway cuts - Street slope	-Line of sight -Bicycle parking -Retail use	-Bicycle/pedestrian scale lighting -Presence of bicycle lane signs

Source: San Francisco Department of Public Health, 2010

2.4.4. Quality indicator for Provincial bicycle path in the Netherlands

The method of quality indicator was developed and established by Noord-brabant in 2014, discussed with the cyclists and the NHTV (Nationale Hogeschool voor Toerisme en Verkeer)(Noord-brabant, 2014). It contains 8 sub-indicators to assess the performance of the bicycle infrastructure, including the physical attributes of the road and the traffic features.

This Quality indicators consist of sub-indicators with respect to traffic and technical characteristics, shown in table 2-5 (Breedte & Vri, 2014). These sub-indicators are weighted when calculating the total score-quality indicator- of the selected route. The weights were decided by the discussion.

Table 2-5 Quality sub-indicators

Traffic system indicators		
		Utilitarian network
Width	1-way cycle track	≥2m
	2-way cycle track	≥3m
	bicycle lane	≥1.75m
Priority at roundabouts	Inside the built-up area	In priority
	Outside the built-up area	Out priority
Obstruction-free zone		≥0.6m
Waiting time of crossing	Irregular	＜15sec
Technical indicators		
Area of hardening		score≥6
Pavement type		Closed pavement
Pavement colour	Inside the built-up area	Red
	Crossing	Red(incl. correct mark)
waiting times at crossing	In rush hour, workday	＜60sec

The object route was divided into multiple hectometres. These criteria were assessed for each hectometre. It would be assigned if the actual situation of the section meets it, otherwise 0. If the criterion is not relevant then it does not count. The final score of BLOS index can be calculated as follows:

$$\text{BLOS}=\frac{\sum_{i=1}\sum_{j=1} score}{\sum_{i=1} \max\ score} \times 0.1 \qquad (7)$$

Where,
i= the ith section of the route;
j= the jth indicator;
score= the value of the indicator;
max score= the sum of the value of indicators assigning 1 to all relevant indicators.
This method is adapted to the local context of the Netherlands. Therefore it could provide a reasonable reference for the context of Enschede comparing to other models. These indicators could be considered under the situation of Enschede.

3. CASE STUDY AREA

3.1. Enschede city

With its population of about 160,000, Enschede is the largest city of the province of Overijssel. It is one of the five nominees to become best Cycling City of the Netherlands in 2014. These five Dutch cities are well-known in the Netherlands for their bicycle use. Chosen from a long-list of 19 municipalities, these five municipalities compete to take over the title of current best cycling city's-Hertogenbosch, which was elected in 2011. In these five cities, Enschede is the third after Velsen and Zwolle (Enschede, nominee for best cycling city | Bicycle Dutch on WordPress.com, 2014). The municipality has proposed an agenda of cycling city by 2020 in March, 2012, which aimed to promote the bicycle use. Cycling policy of the municipality of Enschede—the bike vision—wants everyone to pick up the bike in 2020. The municipality is building a cycle network with preferred routes in the coming years, called bicycle streets where cyclists as prominent road users can make use of connections. These bicycle connections often run through the streets to the city centre and are direct routes with priority for cyclists, so that they can reach their destinations quickly and safely ("Enschede Fietsstad 2020," 2012) . Enschede has a relatively frequently used bicycle system with high-frequency use of cyclists and policy of promoting bicycle commuting, which provides convenient access to data collection so that the BLOS analysis would be well-founded and the model can be tested more achievably. The bicycle connections of Enschede are shown as Figure 3-1.

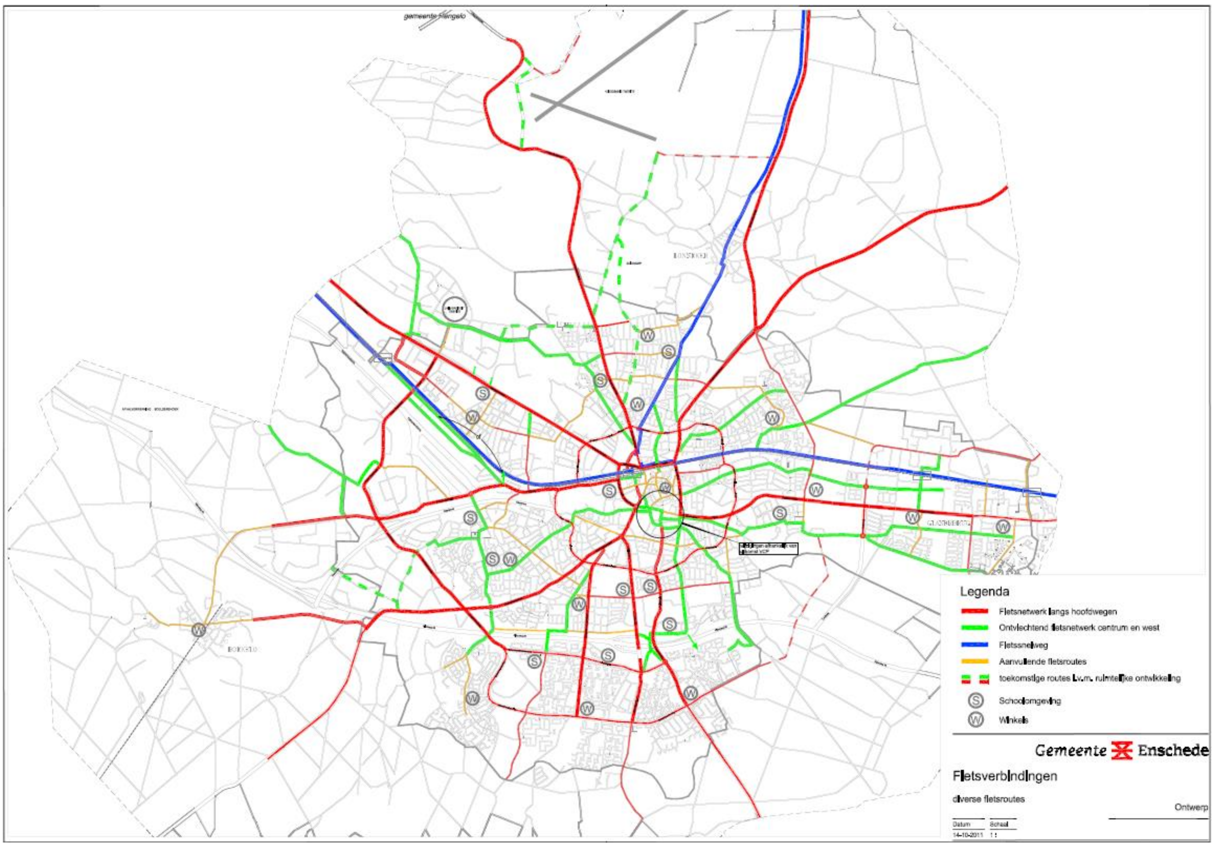


Figure 3-1 Bicycle connections

Source: Fietsvisie 2012-2012 (Gemeente Enschede, 2011)

3.2. Current situation of Bicycle facilities and bicycle vision

The old bicycle network Enschede consists of a primary and a secondary network (Gemeente Enschede, 2011). The primary network is the one along the main roads. The secondary network is denser and connects the residential areas between main roads. Because the primary network now are of attractiveness, safety and comfort mainly for the cars. The exhaust fumes and noise of cars make cycling along busy roads less attractive and unhealthy. There are many places where the bike and the car meet, causing a variety of potentially unsafe situations or conflicts. Moreover, there is often no enough space for all traffic types.

According to the bicycle vision of Enschede("Enschede Fietsstad 2020," 2012), the new bicycle network building is in process. Enschede has an effective bicycle network and the government is promoting the usage of bicycles resulting in existing bicycle network development, such as expanding and reconstruction, to make it more efficient.

The vision and mobility road safety plan of Enschede follow four main goals (Gemeente Enschede, 2011):

- Improve the external accessibility of Enschede Centre, Enschede-West and the Innovation Triangle
- Improve the internal accessibility through a modal shift to sustainable modes
- Contributions to an attractive city
- Improve road safety

To achieve these goals, the vision of cycling in Enschede for the period 2012 to 2020 is recorded. This vision was developed in close cooperation with the sounding board Bicycle Vision which were the following parties represented: Department of Enschede Cyclists, Urban Older Traffic Council, Regio Twente, Twente University (Department traffic & Transport) and Police Twente.)

3.3. Study area

The southern part of Enschede becomes the focus of the recent plan for the bicycle usage promotion. The new network connecting the neighbourhoods used to be the secondary network developed has been planned to be completed by 2017. Therefore, it's good to take such an area like the figure 3-2 shows as the study area to observe if the new network will fits the public's needs in the near future.

Figure 3-2 Study area

Source :TOP10-NL-2012, 2012

4. METHODOLOGY

The municipality of Enschede has proposed an agenda of cycling city by 2020 to increase the proportion of cyclists in trips of up to 7.5 km (Gemeente Enschede, 2011). The new network is aimed at the densification of the non-stop connections of cycling to the residential areas. This chapter explains the indicator selection, data collection and BLOS calculation method for offering certain reference to the new cycling network realization in the assessment of the current bicycle system.

4.1. Overview of the study methodology

To achieve the BLOS at route scale, the service level of segments and intersections needs to be evaluated first. Drawing on the assessment method applied in Denmark, Noord-brabant of the Netherlands and the USA, the criteria and the indiators of the BLOS index have come up considering the local context of Enschede.

Firstly, the survey sites are selected and the questionnaire are designed to collect route choice preference of the cyclists. The questionnaire consists of the questions asked for the cyclists' preferred routes as well as the reasons of their choices. Meanwhile, the indicators that form the BLOS score are initially identified. Secondly, the route BLOS (RBLOS) scores are calculated for the selected routes and reflected to the actual network as an elementary or local score, to aquire the dataset as the basis of other routes which are similar and not investigated. Thirdly, a comparison of the cyclist' choices and the result of the RBLOS modeling could be analysed and reveals if there is difference between the reality of route choices and the model result, for example, people choose the routes with better BLOS. Besides, the route choice behavior will be analysed and understood.

4.2. Route BLOS Indicators

The BLOS score is composed of BLOS indicators related both to the road segments and intersections, based on the previous research and the design principles of the infrastructure. These indicators are initially identified as shown as in table 4-1, according to the common selection of previous researches, the local context and the limitation of data such as the noise distribution, planting, unsignalized intersections, accident rate, etc. It is also practical to add other indicators in the future.

Table 4-1 Indicators of Bicycle level of service index

	Indicators	Specification
BLOS indicator	Width	Sharing road
		Bicycle lane
		Bicycle path
	Vehicle traffic volume and speed limit	AADT
	Pavement	Condition
		Colour distinguishing and marking
	Waiting times at signalized intersection	Weekdays
	On-street parking	Type
	Number of intersections	Signalized

These indicators are taken into consideration most commonly as they are the basic element for service level assessment which could be seen as a base set. Due to the main objective of developing the evaluation BLOS model and the data limitation, these indicators have the priority to be modelled initially.

4.3. Scoring method of each indicator

For each indicator, the scoring adopted a 6-points ranking system consistently to make it comparable to the traditional A-F scoring method. The scoring standard derives from the bicycle facility design principles of Enschede. The worst situations are assigned "6", the best ones are "1". The moderate cases are interpolated to be scored.

4.3.1. Bicycle facility type

The 4 types of bicycle network facilities in the urban area of Enschede are considered, as shown in table 4-2. Comparing to the sharing road, people cycling on the bicycle lane or path would feel safer due to the clear boundary between the car lane and bicycle lane.

Table 4-2 Scoring of facility type

Facility type	Typology	score
Sharing road		6
Bicycle lane (dashed)		4
Bicycle lane(striped)		3
Bicycle path	 	1

Source: Fietsvisie 2012-2012 (Gemeente Enschede, 2011)

4.3.2. Bicycle facility width

According to Fietsvisie 2012-2012 (Gemeente Enschede, 2011), bicycle lanes have frequently been constructed with a width of just 1.50 m in recent years, often with the gutter and marking between bicycle and car lanes included. It makes the effective width of the bicycle lane even less. It probably leads to dangerous situations that the overtaking cyclist makes use of the car lane due to the limited width of the bicycle lane.

Table 4-3 Scoring of facility width

Facility type		Width	score
Sharing road		-	6
Separate bicycle lane with marking		<1.75m	6
		1.75 to 2.0m	3
		>2.0	1
Bicycle path	One-way	<2.5m	6
		2.5 to 3m	3
		>3m	1
	Two-way	<3m	6
		3 to 3.5m	3
		>3.5	1

4.3.3. Pavement condition

The smoothness of the pavement influences the comfort of cycling feeling. In addition, the well maintained painting and traffic marking are important.

Table 4-4 Scoring of pavement condition

Pavement condition	Colour distinguished and well-marked	Score
Non-closed pavement	No	6
Non-closed pavement	Yes	4
Closed pavement	No	2
Closed pavement	Yes	1

4.3.4. On-street parking

Vehicles parked along a road next to the bicycle lane make a road less bike-friendly. Parked cars not only force cyclists further into the car lane, they also can move unpredictably into the path of bicyclist. Parallel parking includes the hazards of doors opening.

Table 4-5 Scoring of in-street parking type

Type of parking	Score
Parallel	6
Island	4
Back (in angled)	3
None	1

4.3.5. Vehicle traffic volume and speed limits

The vehicle traffic volume impacts on the service level mainly in terms of safety and comfort, specifically the possibility of accidents, psychological effect or noise, etc. According to the design requirements, the evaluation of traffic volume is shown as follows(Gemeente Enschede, 2011).

Table 4-6 Scoring of traffic volume and speed limit

Facility type	AADT(pcu/day)	Speed limit (Km/h)	score
Sharing road	-	-	6
Bicycle lane	>10000	50	6
		30	5
	5000 to 10000	50	4
		30	3
	2500 to 5000	50	2.5
		30	2
	<2500	50	1.5
		30	1
Bicycle path	-	-	1

4.3.6. Average waiting times at signalized intersections

The average of waiting time on weekdays is between 40 and 80 sec(Gemeente Enschede, 2012).

Table 4-7 Scoring of waiting time at intersections

Waiting times (sec)	Score
>60	6
40 to 60	4
20 to 40	2
<20	1

4.4. Data collection

4.4.1. Survey principles in Enschede

The data collection was divided into two phases. The first one deals with the route choice data from the cyclists and the second one with the physical properties of the bicycle infrastructure. The bicycle route choice data of the practical situation is required to address the selection of the bicycle route for the route bicycle level of service. The big organizations have higher density of the respondents, in which the result can be gathered more efficiently.

According to the investigation by the municipality of Enschede in 2011, the commuting or home-study/school travel and private travel (family, shopping, sports, etc.) are the main types of movements. Moreover, the commuting one accounts for the highest proportion (Gemeente Enschede, 2011).

Table 4-8 Main objectives for the use of the bicycles as a means of transport among cyclists

	Main purpose	2ndmost important purpose	Additional (main or after main purpose)
Commuting or home-study/school travel	49%	15%	64%
Business travel(customer visits, delivery)	1%	4%	5%
Children drop-off(school)	5%	9%	14%
Private (family visits, shopping)	43%	46%	89%
Other (recreational, sports)	2%	7%	9%
No 2nd most important target named		19%	

Table 4-8 shows the different proportions of cycling use based on different trip purposes. Thus, the main purpose of travel – commuting provides the basis for the Origins or Destinations selection for collection of cyclists' route choice perceptions. Also, cycling is the preferred mode in cases when the trip length in the city below 7.5 kilometres (Gemeente Enschede, 2011).

The data can be classified into two parts consisting of physical roadway attributes and the route choice perception, which would be collected from the municipality of Enschede or the field and the cyclists who travel for the commute purpose. Because these organizations like the hospital are trip attraction sites that intensively attract cyclists from neighbouring areas.

4.4.2. Survey locations

In order to identify the normal route choice of the commuting cyclists, the surveys of route choice are conducted in two different places: the hospital Medisch Spectrum Twente and the offices of the Municipality. Because these target groups cover a large range of cyclists that have the trip purpose of commuting, which accounts for the greatest portion of bicycle use, they also may vary by different ages from the youth to the elderly. What's more, it is most likely to acquire sufficient sample size. The surveys are collected by means of a questionnaire. It is expected that at each organization a minimum number of 50 participants is willing to answer the questionnaire.

According to the bicycle vision 2020 (Gemeente Enschede, 2011) and the opinion of the expert from the transport department of the municipality, Mr. Gerran Spaan, we have focused the route data collection on the southern part of Enschede resulting from fact that the new non-stop bicycle network will be developed in the southern part of the city specifically.

1. The Medisch Spectrum Twente

The questionnaire consists of two parts. 100 questionnaire forms and a map were handed out in the closed bicycle shed of the hospital in the early morning of Tuesday 16 December 2014 from 7:45 to 9:15 am, as this is the peak hour for commuting cyclist to arrive at the hospital. Firstly, the survey filters the respondents who live in the certain postcode areas to meet the needs of the study area, which is the southern part of Enschede. Secondly, the questions are directed at route preference information, adapted considering the suggestions of human resource staff Mr. Gerrit van der Kolk. The questions in this part deal with the age, cycling frequency of the respondents, the normal route they take and the importance of the driving forces of their route choices.

The questionnaire consisted of questions such as the normal and alternative routes the respondents take to the destination and the reasons why they made that choice. Simultaneously information on the riding experience was gathered, etc. (for the questionnaire form see the appendix B)

2. The Enschede Stadskantoor

The survey was conducted from 7:30 to 9:00 am on January 6th, 2015 similarly as it had been done in the hospital with the important contribution from the policy advisor Mr. Gerran Spaan, from the urban development and policy department of Enschede Municipality. 100 questionnaire forms were distributed to the staff entering the bicycle shed who had made a trip originating from the southern part of Enschede during the morning peak. The questionnaires are in the same way asking cyclists their commute route choices as the one processed with the hospital (for the questionnaire form see the appendix C).

4.4.3. Physical data collection

This collection process started after the acquirement of the route choice of the survey respondents, referring to the route set. The physical data was derived using aerial photos, thematic maps and research reports from the municipality and by field visits. With regard to the typology, width, pavement condition and the on-street parking attributes of the bicycle facility, aerial photos from the geographic information system of Enschede municipality were mainly investigated. Few routes were measured from the field. The measure accuracy along the routes is 10m. For the measures of intersections, it was set basically at the centre.

With regards to other indicators such as the vehicle traffic volume and speed limits, waiting time at intersections and the occurrence frequency of the unsafe sections of the roads, the data sources used are the combination of the thematic maps and the research report of the bicycle vision 2012-2020(Gemeente Enschede, 2011). Figure 4-1 shows all the signalized intersections in Enschede, the research report provides the average waiting time for cyclists at each intersection. Figure 4-2 displays the different road categories, which can be referred to the speed limits. What is more, there are counting spots for vehicle traffic volumes in the network and these were combined with the speed limits as one indicator.

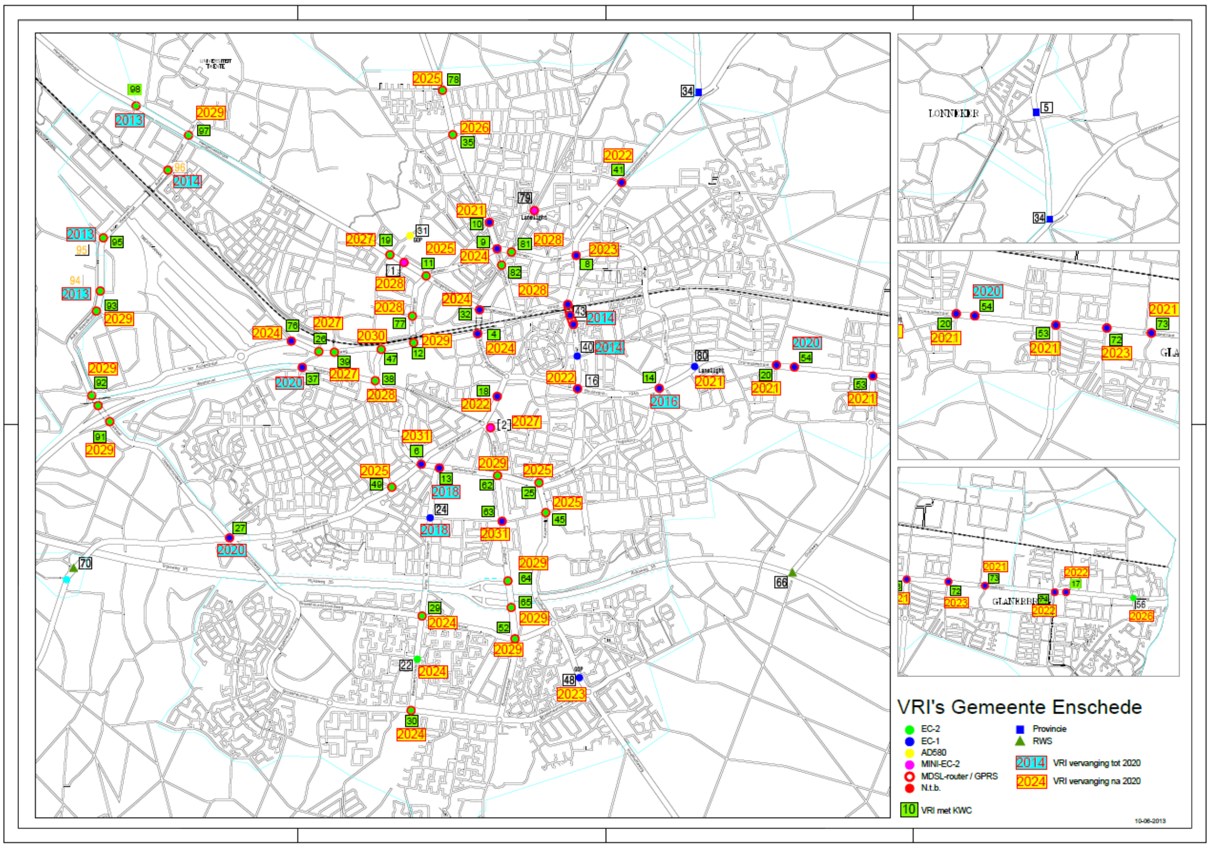


Figure 4-1 Intersections of Enschede

Source: Fietsvisie 2012-2012 (Gemeente Enschede, 2011)

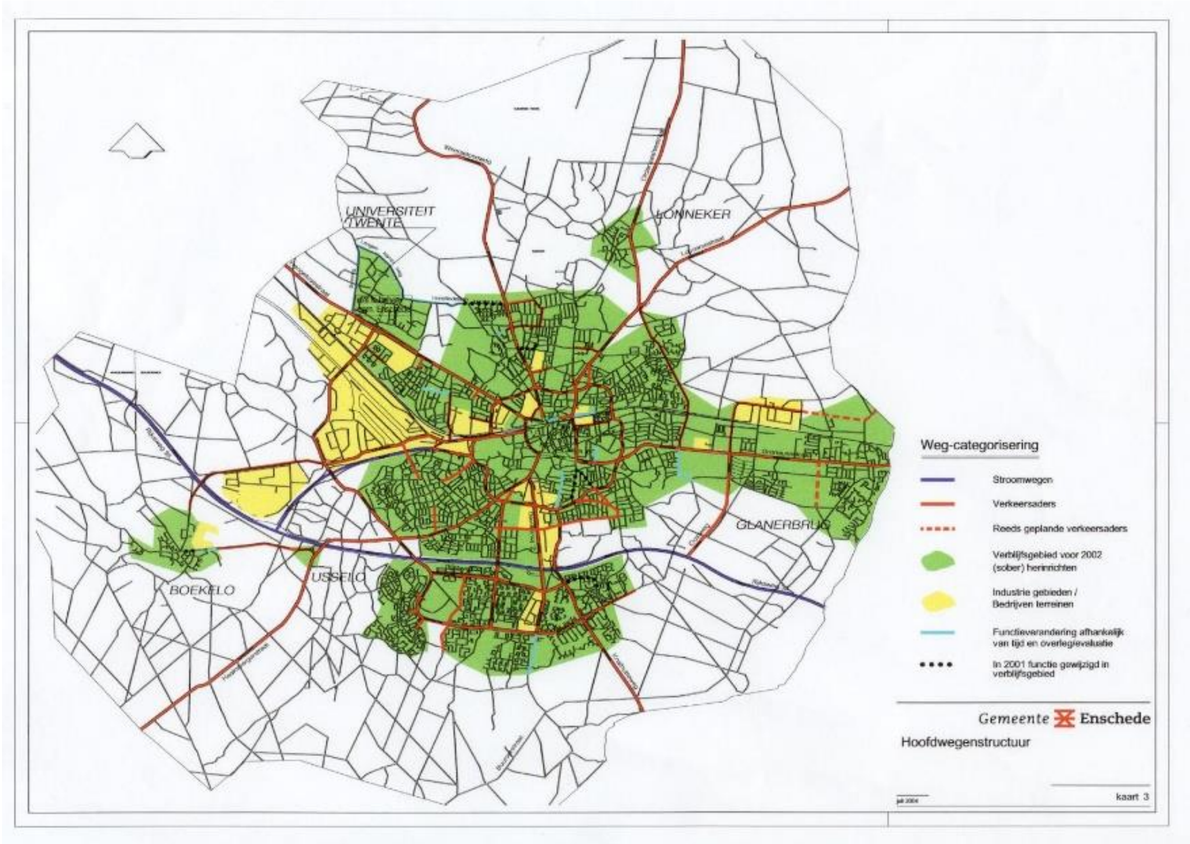


Figure 4-2 Roads categories of Enschede

Source: Fietsvisie 2012-2012 (Gemeente Enschede, 2011)

4.5. Calculation method of route BLOS

All the target routes are divided into short portions and assessed by each indicator using scores from 1 to 6 to make the scale consistent ("1"-"best", "6"-"worst"). All scores are under this 6-points system. The principle by which we divide the route into portions is based on the positions where the attributes of the roadway suddenly change. Sections are defined as parts of routes where any one of the indicators changes its value. As the waiting time at signalized intersections/traffic lights is considered, these intersections would also be a type of the division points. A route has m linear portions and n signalised intersections.

4.5.1. Local BLOS score

All indicator values are same or consistent within one section, so does the localBLOS score. The BLOS score of each section (LocalBLOS), including the types of both road segment (lineBLOS) and signalized intersection (PointBLOS) , is calculated by a weighted summation of different scores of the various attributes,

$$Local\text{BLOS} = \sum_{1}^{n} S_k . w_k \qquad (11)$$

Where,

s_k is the score of the kth indicator(Roadway attribute) of BLOS index;

w_k is the weight of each indicator (0< w_k <1), the weighting method is equal-weight in this study. But it can be adjusted in the future.

In this case, the LineBLOS and PointBLOS are obtained by,

$$\begin{aligned} & Line\text{BLOS}=\frac{1}{5}(\text{FT+WD+PT+PV+VS}) \\ & Point\text{BLOS} = \text{WT} \end{aligned} \tag{12}$$

Where,
FT=Facility type
WD=Width
PT=Parking type
PV=Pavement condition
VS=Volume and speed limit indicator
WT=Waiting time
In this case, LineBLOS is the average BLOS score of the 5 line-event attributes (Facility type, width, etc.) of the segments, and PointBLOS indicates the Waiting Time at the traffic light.

4.5.2. Route BLOS score

The route BLOS (RBLOS) is the combination of all attributes of the roadway along the route. It is calculated based on the localBLOS by means of travel time-normalization. The route BLOS score also ranges from 1 to 6, as it is based on the other indicators that fall in this range.
The Route BLOS is calculated as formula 13 shown.

$$\begin{aligned} \text{RBLOS} &= \frac{1}{6}\sum(\text{FT+WD+PT+PV+VS}) * w_i + \frac{1}{6}\sum \text{WT} * w_j \\ &= \frac{5}{6}\sum\left(\frac{\text{FT+WD+PT+PV+VS}}{5}\right) * w_i + \frac{1}{6}\sum \text{WT} * w_j \\ &= \frac{5}{6}\sum Line\text{BLOS} * w_i + \frac{1}{6}\sum Point\text{BLOS} * w_j \end{aligned} \tag{13}$$

Where,
w_i = Weight of the ith segment= $\frac{\text{Cycling time}}{\text{Total travel time}} = \frac{\text{CT}}{\text{TT}}$
w_j = Weight of the jth traffic light= $\frac{\text{Waiting time}}{\text{Total travel time}} = \frac{\text{WT}}{\text{TT}}$
We treat the importance of these 6 attributes as the same importance in this study, meaning each attribute gets “$\frac{1}{6}$” weight for its importance.

4.6. Extrapolation of BLOS score to the network

The appearance, properties and design standards of the bicycle facilities are often similar or even same within different areas of the city. Particularly in certain coherent residential areas that are planned and constructed simultaneously, the characteristics of the bicycle networks are almost homogeneous. Therefore, it is possible that the representative BLOS score obtained by the GIS model can be assigned to the same type of the bicycle route to evaluate the bicycle infrastructure for the whole network of Enschede, referring to the calculated BLOS score from the measured routes.

With the preferred routes taken as the sample, the score of each section of the network (polyline) in the GIS system would be required and could be applied flexibly to the whole network or any routes.

The undefined segments are assigned LineBLOS according to the category they fit in GIS. It is called segment BLOS score.

4.7. Comparison of the model results and realistic route choices

The general service level of the selected routes can be obtained through the statistical outcome of all BLOS scores, such as the mean score. The RBLOS comparison between the selected real routes from respondents and the routes of shortest distance and travel time will indicate if cyclists do choose the route taking the BLOS into account, in order to provide reference to the policy making of the municipality.

To calculate the RBLOS score of the shortest routes, the LineBLOS and the PointBLOS scores are compensated and stored in a centerline table and a turn table relatively. They are accumulated along with the shortest routes analysis. The final RBLOS score of the shortest routes are figured up in the same way as formula 13 shown.

What is more, it would be found if there is RBLOS difference between the routes with different travel distance. The difference refers to the preferred reasons of making route choice for each group with various distance through comparing these RBLOS scores, for example, cyclists living within varied distance have varied considerations.

5. GIS MODELING OF ROUTE BLOS

The BLOS score calculation is accomplished and processed by means of a GIS model. The process is somewhat complex and falls into two parts, calculation of BLOS from the sample route sets and reflection to the actual bicycle network. The physical data collected from the field and the municipality are processed in the GIS using the ArcGIS extension Roads and Highways. This is a tool providing the environment to store and manage the attributes along the roadway. Below is the explanation of BLOS and Linear Referencing and how they can be computed together in a GIS model.

5.1. Linear Referencing System

There are a number of computational steps to create BLOS for routes on a city-wide network. The BLOS score calculation is based on a Linear Referencing System (LRS). The LRS stores data utilizing relative positions along the existing line features. The logic model is shown in figure 5-1. In this GIS model, the routes are derived from the original bicycle network, combining each portion to the whole route with directions based on the linear referencing. For this GIS model, the centerline is the polyline feature class that stores the geometry providing the backbone of all the possible routes that we may create. While first selecting centerlines to create a route, a 0 measure is fixed to delineate a direction. These network centerlines are then connected to the routes by the centerline sequence table. The routes are created from the network centerlines by the Centerline sequence table which is auto-generated to indicate its relationship with the centerlines. This connection works in terms of the identifiers. For instance, the centerlines link to the centerline sequence table with the RoadwayIdGuid, which is a system-generated globally unique identifier (ID) that the Roads and Highways internally uses to map centerlines to routes (Esri, 2014). Similarly, the centerline sequence table connects the routes by RouteID generated immediately when routes are created. Without these identifier connections, the GIS model could not process multiple routes at the same position due to the overlap problem of same spatial position.

In this GIS model (shown in Figure 5-1), the routes are associated to the centerlines with a many to many relation. That is to say, one route can be created from 1 to many centerlines and one centerline can constitute 0, 1, or many routes. In figure 5-1, "M" represents the "many". It is not possible to achieve a many to many relationship directly in a relational database, therefore the intermediate table centerline sequence table is created to convert "M to M" relationship to another form "1 to M and M to 1" indirectly. The road physical attributes (line or point events) as the indicators for BLOS evaluation are expressed in terms of event tables, linking to the routes by RouteID and measures under the linear referencing system. Thus, the events tables of any route are independent to those of the other routes, even if they share a common portion with others. There are two kinds of events, line events and point events. The measures vary by the event type. For instance, the line events such as the width or the facility typology requires a "from/to" measure to specify their locations. For the point events like the waiting time at the intersections in this case, it is just the measure needed to identify where they are located in the bicycle network.

The data administration and management would benefit from this dynamic segmentation process due to the fact that it is only reloading updated events tables instead of merging or splitting the network centerlines according to the attributes of the roadway changes.

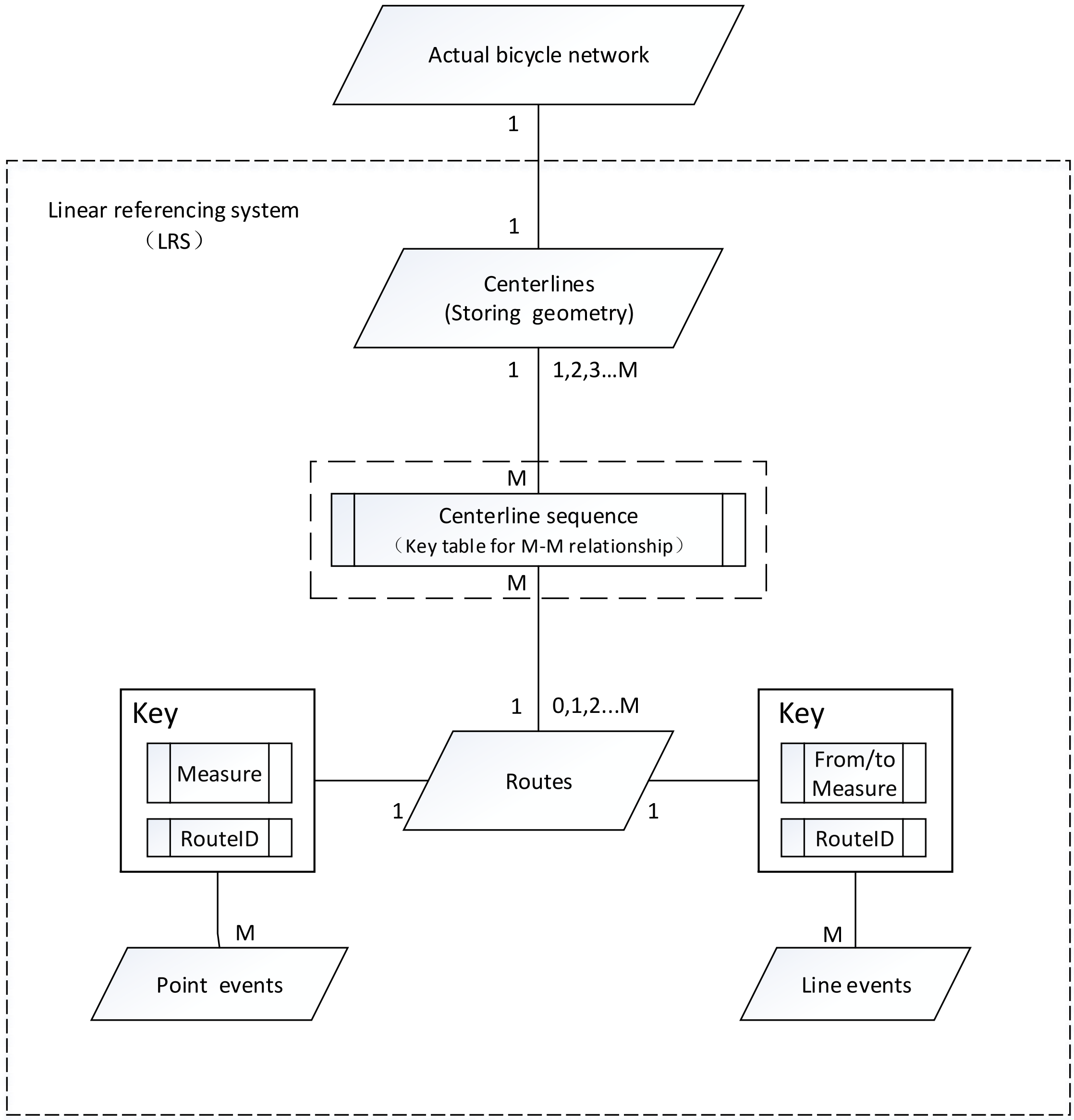


Figure 5-1 GIS logic model of routes info storing and management

5.2. Route set geometry digitalization

All the preferred routes of cyclists are digitized in the linear referencing system. The map (figure 5-2) below demonstrates the visualization of the route set from the questionnaire feedback after the route digitization, containing all the routes the cyclists take from where they live to their work place in the morning peak. The routes are digitized under the linear referencing system. The MST and the Stadskantoor are set as the start point, namely the 0 points, so the routes near these two positions are more frequently overlapping than routes further. Therefore these routes might share the same measure to a large extent.

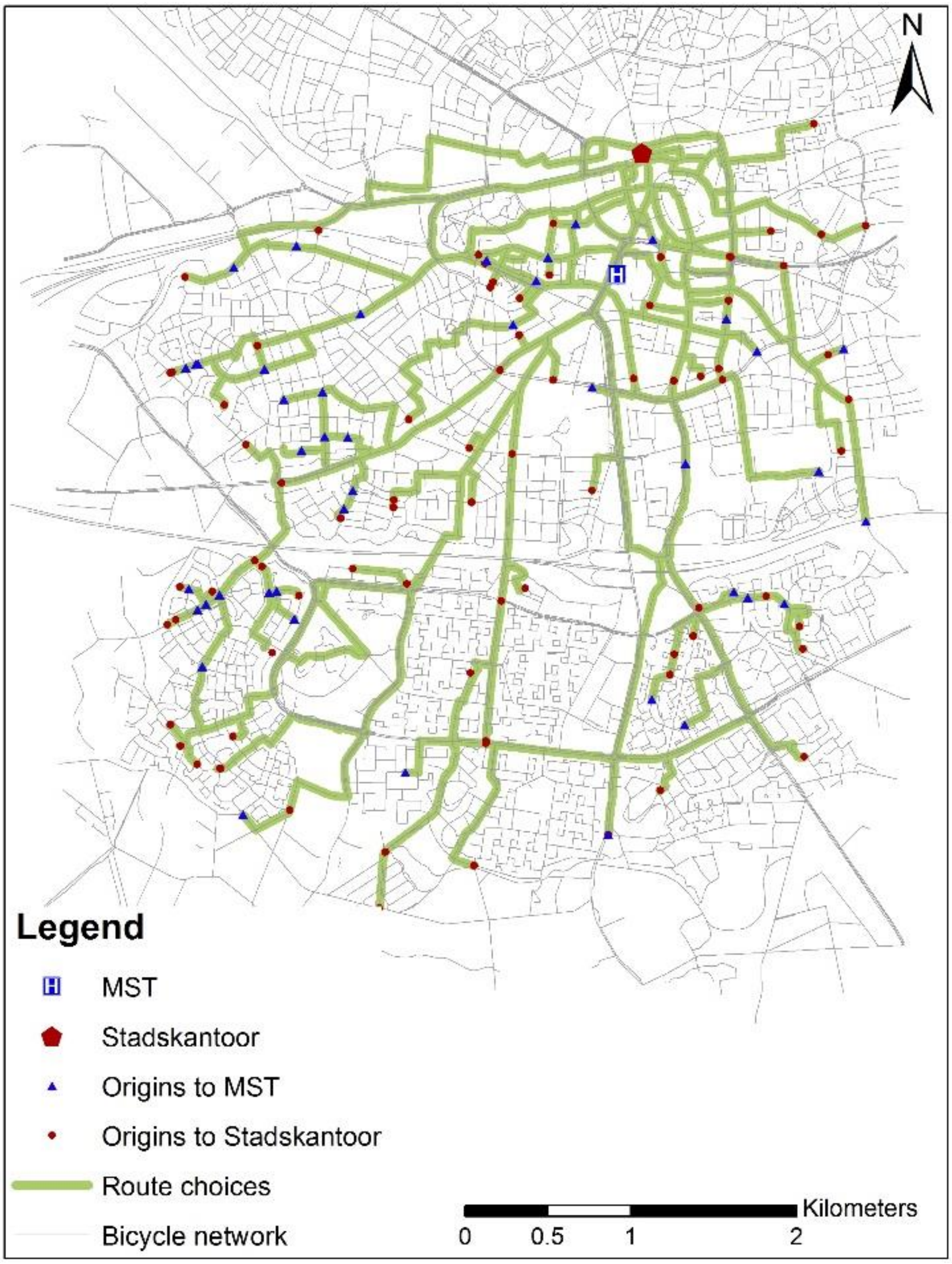


Figure 5-2 Routes choice of respondents

5.3. Data processing schema

Figure 5-3 represents the conceptual model of the data processing to achieve the final route BLOS score of the route set from the survey, as well as the flexible elementary segment BLOS score that can be applied to the whole network in any combination.

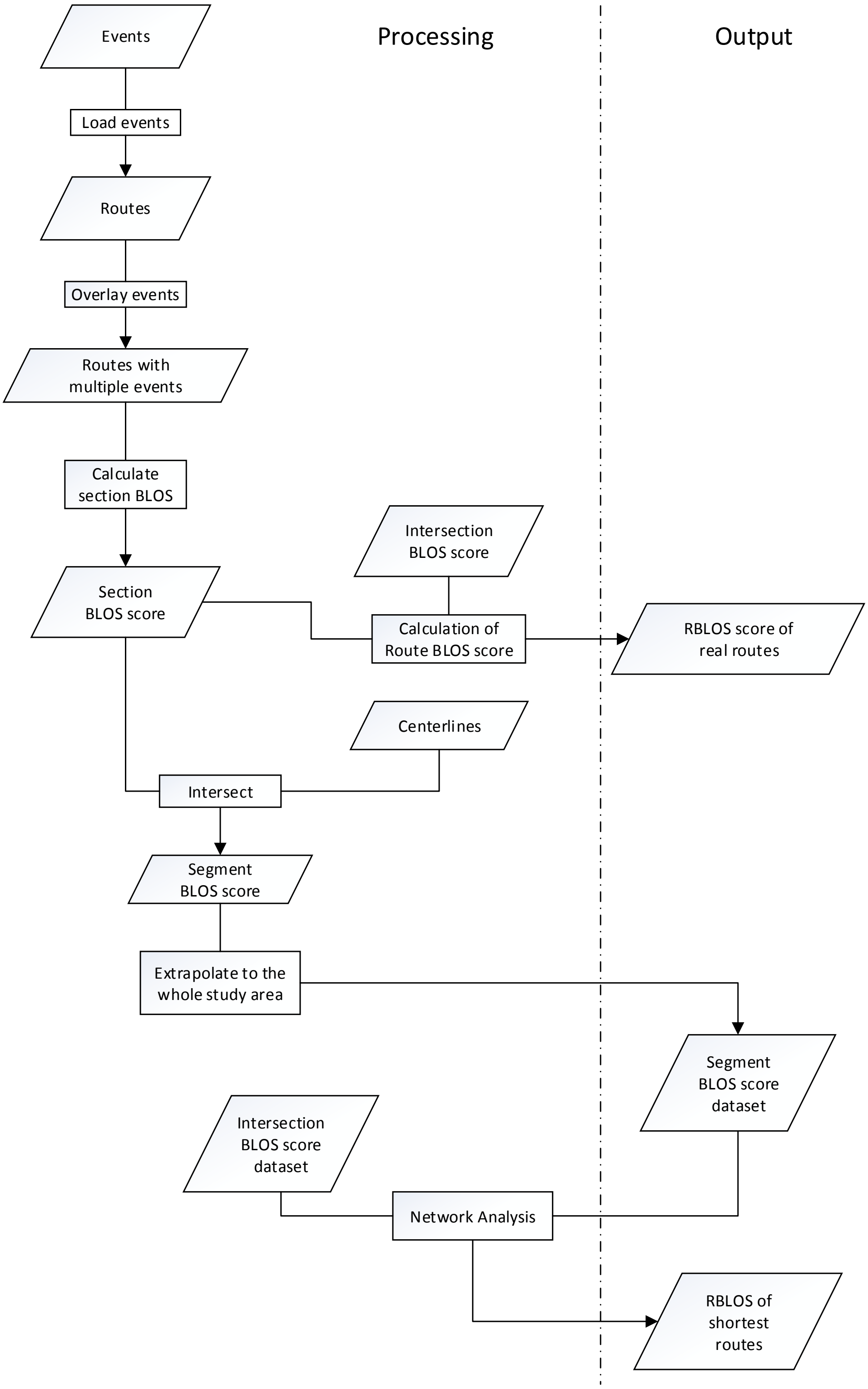


Figure 5-3 Conceptual process model

Firstly, the events are aligned to each route by the connection keys-measures and RouteID under the linear referencing system. In this phase, each kind of event is measured and arranged by the values of the indicator and its corresponding linear measures by means of tables, which means each route is digitized with the events (all the evaluating indicators) from the 0-point measure up to the end. As a result, each indicator has a table indicating the measures and the events of all routes coded by RouteID for the whole

route set and EventID for each route. There would be the cases of same measures and events or just same events among different routes due to the fact that these routes share the same portion.
Secondly, these attributes of each route need to be overlaid according to their RouteID. This creates an overlaid multi-event table for all routes obtained out of the multiple event tables.
Thirdly, the section and the intersection score are computed relatively from the overlaid event table and according to the method demonstrated in section 4.5.2 the whole route BLOS score is calculated, which is the first output. Then the comparison between these BLOS score on route level and the actual route choice of the respondents is made.
Fourthly, the section score is intersected with the bicycle network centerlines to get the output of sub-segment scores. As defined in 4.5.1, the section is the portion where the value of any of the events change. The intersecting process of those two features could be understood as using intersections of the centerlines as cut points to divide the routes composed by continuous sections. Finally, the sub-segment score composed to the segment score through the weighted mean method, as illustrated in figure 5-4. S1, S2 and S3 represent the different scores.

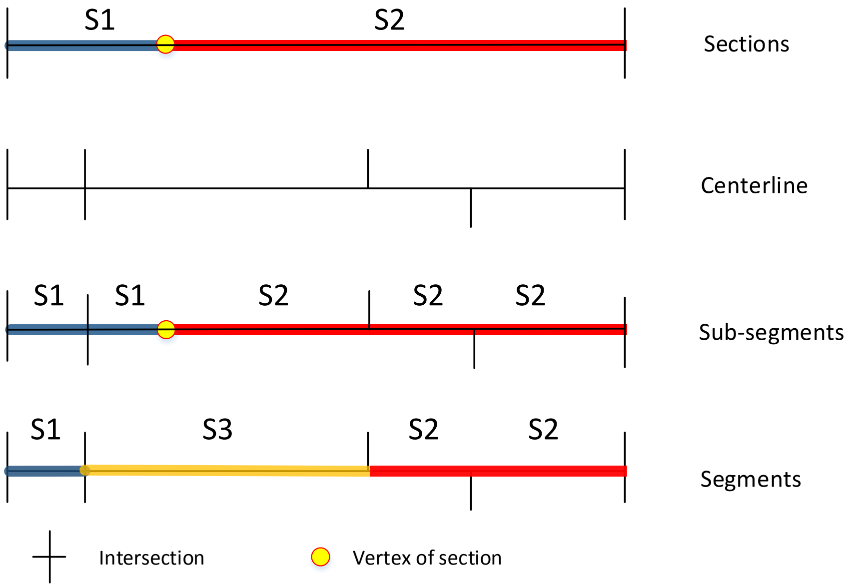


Figure 5-4 Intersect process of segment score acquirement

When the processing is complete, these segment scores compose the dataset in terms of local score, which is convenient to extrapolate to the other segments without measuring but with similar conditions or in similar performance. The segment LineBLOS would be acquired by integrating the local sub-segment LineBLOS scores based on the CenterlineID. Hence, this segmentation of the section score makes it flexible to evaluate the bicycle level of service in any combination when the intersection score is added. Thereby it is possible to analyse the optimal route with the highest level of service. In addition, this GIS model could avoid redoing the segmentation caused by the roadway attributes changes. It simplifies the digitization and segmentation process of attributes along the road by means of updating and reloading the event tables. It is also flexible to adjust the route layout according to the actual development of the roads.

5.4. Network analysis

The RBLOS scores of the real routes indicated by the respondents will be compared with two route types. One set of routes based on actual shortest distance and another based on travel time.

5.4.1. Travel impedance

- Length impedance

The actual length of the segments will be used to generate the shortest distance routes with the help of network analysis. For this purpose, the length attribute is used as impedance (unit: meters).

- Time impedance

Here two elements are involved: a. the time it takes to traverse a segment, b. the time involved to cross the intersection lights. The travel time to traverse the segments is computed using the average cycling speed of 15km/h(Gemeente Enschede, 2011). The time involved at the traffic light is based on the average waiting time (Gemeente Enschede, 2011) at particular crossings (left, right and straight forward) and for some cases 0 (right turn). For this purpose, the time attribute is used as impedance (unit: seconds).
Basically all the traffic light crossings in the network are modelled using 'complex' segments compositions instead of simple segment crossings, as shown in figure 5-5 a-d. 5-5 a shows the simple crossing and 5-5 b-d show the complex crossing with respectively a turn to the right, left and straight. The simple and complex crossings can be modelled with the help of the so-called turn table. In the turn table, the segments are administrated whom are involved in the turns together with the impedance. For example, the turn shown in 5-5 c involves 4 segments and waiting time to make a left turn will be set to e.g. 30s. In this way all potential turns at traffic lights are modelled.

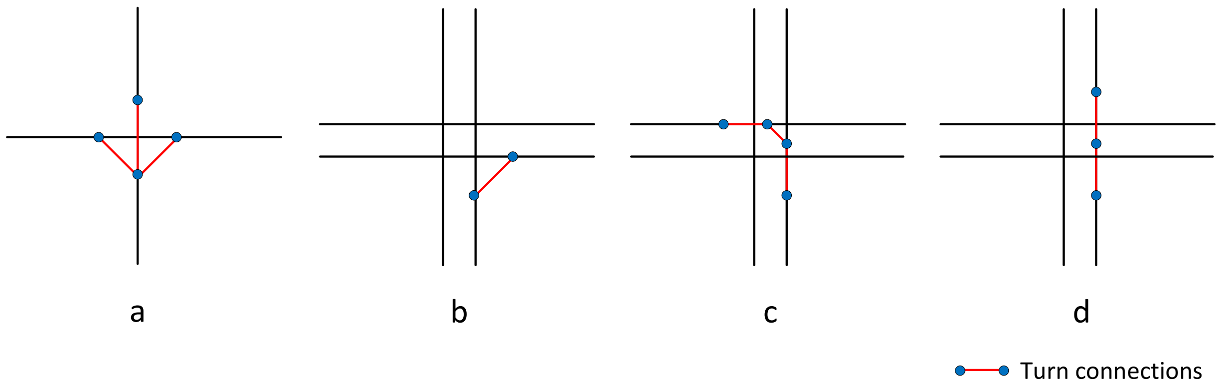


Figure 5-5 **Modelling of intersections**

Therefore, the 27 traffic lights in the study area were defined in terms of turns in the network analysis process. In this case, all possibilities of turns for each traffic light are digitized with the waiting time based on the specific type of the traffic lights.
In the process of shortest routes seeking, the compensated LineBLOS and PointBLOS are accumulatively added up. The RBLOS of these shortest routes, including both distance and travel time are achieved after the routes are found out.

5.5. Conclusion

To sum up, this model is flexible for evaluating the bicycle system. With this GIS model, we are able to:

- Visualise the single roadway attributes to make local improvement of bicycle facilities.
- Visualise the comprehensive service level of the existing and the updated network based on the various attributes which can be flexibly adjusted.
- Adapt the BLOS calculation to any route of any O-D pair needed within the whole bicycle network. For example, we can analyse the potential route required to be improved to see the service level before and after the improvement at certain positions or on specific attributes.

6. RESULTS AND DISCUSSIONS

This chapter illustrates the results of the survey and the BLOS scores calculation, including the section scores, segment scores and route scores. The RBLOS scores contains the scores of the real routes and the shortest routes. At the end, these route scores are compared.

6.1. Survey results

100 questionnaire forms were handed out to each organization (see appendices A and B). 45 were collected from the hospital MST and 81 from the municipality Stadskantoor. 122 out of the collection were found valid on route sketching and preference ranking of route choice reasons.

With the survey result acquired, we can find the most important reason for taking the respondent route by looking at the frequency of the answers over the whole sample; see table 6-1. The most frequent mentioned reasons are taking the shortest distance and travel time. We can see the total counts of the frequency is over 122 due to the "double counts"- more than 1 reason are chosen as the 1st choice.

Table 6-1 Frequency of the first reason preference

Route choice reason	Frequency
Shortest distance	64
Shortest travel time	42
Most safe	12
Most comfortable	17
Other	8
Total	143

The table identifies that the reason most people considered the most important is the shortest distance and the second-ranked is the shortest travel time. Then most comfortable, most safe and other reasons are following respectively. Therefore for the going-to-work cycling group, the reason of "shortest routes" account for biggest proportion when they make route choice. For the "other" options of the route choice reasons, the respondents mention mainly "cross the bus lane as few as possible", "avoid vehicle exhaust", "drop the children", "least traffic lights", "habit", "keep speed" and "most quiet", etc.

To specify the internal distribution of the route choice reasons (as 1st and 2nd reason) over the different respondents groups, the respondents are categorized by gender, age and how many days the respondents cycled per week, gathered as follows in table 6-2, and the same is given in table 6-3 in percentages over the totals per respondent group. This to be able to identify if cyclists in different groups prefer a different reason for a route choice.

Table 6-2 Distribution of preferred reasons for different groups

Reasons of route choices		Gender		Age			No. of cycling days per week			
		Male	Female	<=35	36-50	51-65	2	3	4	5
Total respondents		44	78	12	57	53	4	20	38	60
1st reason	Shortest distance	24*	40	5	24	35	0	13	18	33
	Shortest travel time	17	25	2	25	15	4	8	11	19
	Most safe	3	9	1	3	8	0	2	5	5
	Most comfortable	4	13	2	8	7	0	3	4	10
	Sum	48	87	10	60	65	4	26	38	67
2nd reason	Shortest distance	14	27	1	20	10	2	4	10	15
	Shortest travel time	15	26	6	15	20	0	8	13	20
	Most safe	6	11	1	7	9	1	2	5	9
	Most comfortable	4	10	1	9	4	1	1	3	9
	Sum	39	74	9	51	43	4	15	31	53

*Remark: These counts of respondents are potential overestimated because the corresponding reason may be selected more than 1 time.

The sum of frequencies per reason per group can be higher than the total number of respondents because some respondents choose two or more choices as 1st reason (or for the 2nd reason). It can also be lower because respondents choose "others" or did not choose at all.

Table 6-3 Selection percentage of each reason for different groups

Reasons of route choices		Gender		Age			No. of cycling days per week			
		Male	Female	<=35	36-50	51-65	2	3	4	5
1st reason	Shortest distance	55%*	51%	42%	42%	66%	0%	65%	47%	55%
	Shortest travel time	39%	32%	17%	44%	28%	100%	40%	29%	32%
	Most safe	7%	12%	8%	5%	15%	0%	10%	13%	8%
	Most comfortable	9%	17%	17%	14%	13%	0%	15%	11%	17%
	Sum	109%	112%	83%	105%	123%	100%	130%	100%	112%
2nd reason	Shortest distance	32%	35%	8%	35%	19%	50%	20%	26%	25%
	Shortest travel time	34%	33%	50%	26%	38%	0%	40%	34%	33%
	Most safe	14%	14%	8%	12%	17%	25%	10%	13%	15%
	Most comfortable	9%	13%	8%	16%	8%	25%	5%	8%	15%
	Sum	89%	95%	75%	89%	81%	100%	75%	82%	88%

*Remark: These percentages are potential overestimated because the corresponding reason may be selected more than 1 time.

According to the result in table 6-3, the preference of route choice reasons of different groups can be compared to some extent. It tells us that the majority of the male group selects the reasons shortest distance and travel time as the 1st choice (94% over 109%) and 66% over 89% of men select them as 2nd reason, whereas within the female group (respectively 112% and 95%) for both reasons and around 30% choose "most safe" and "most comfortable". For these percentages, it is assumed that the overestimation part is distributed to each reason equally.

Looking at age and number of weekly cycling days, they do not have an obvious influence on the preferred reasons within these groups. This can be explained by the variation on the age composition. For example, this survey excludes the non-working population, and the survey was only in one mooring per for each organization.

6.2. Individual BLOS indicator visualision

Each indicator which contribute to the BLOS values are projected onto the real routes and displayed in figure 6-1.

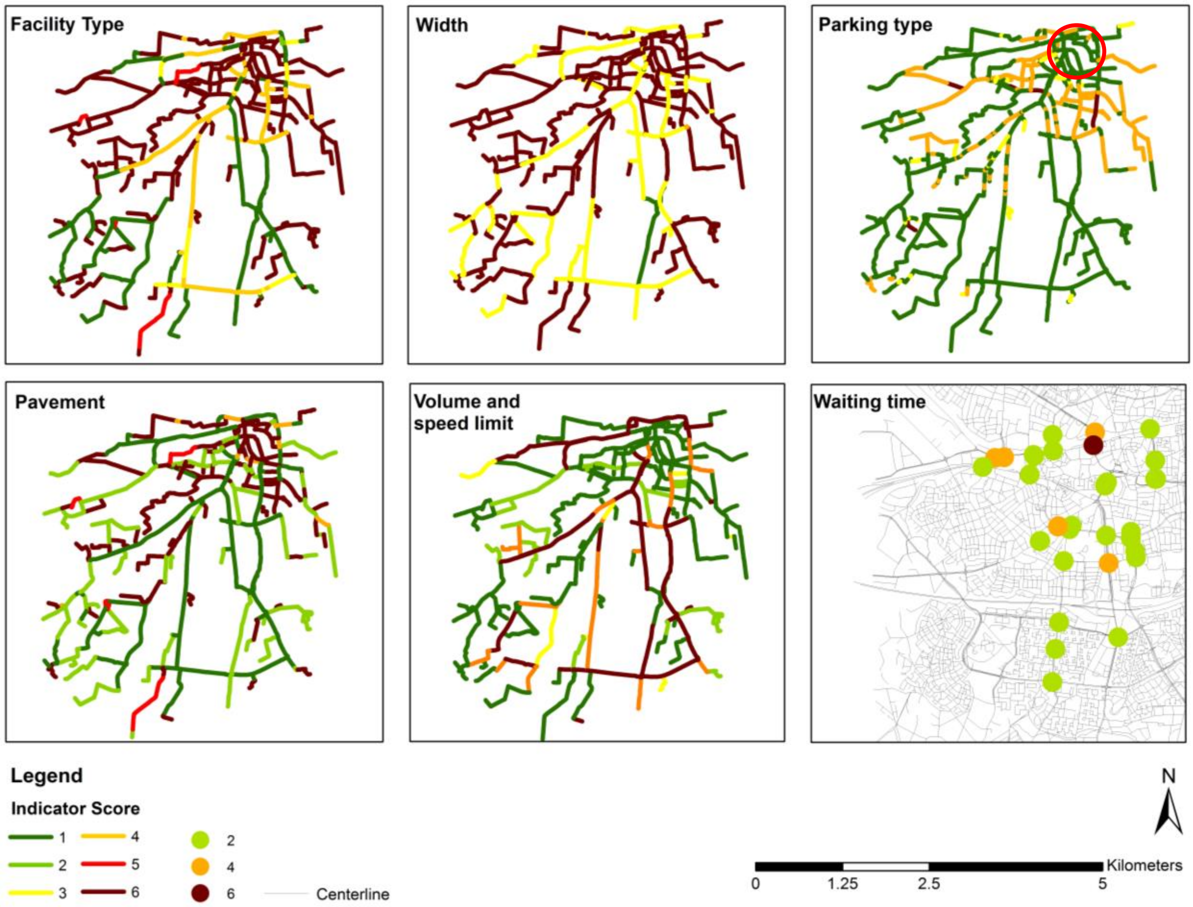


Figure 6-1 Rated values of the different indicators projected on the real routes

In terms of these investigated routes, the spatial distribution of the individual indicators is shown. For the indicators facility type, pavement and width, the road sections have relatively higher scores in the city centre area (located in the red circle of figure 6-1c) rather than the ones in outer areas (higher scores mean lower service levels). This visualization enables the municipality to prioritize local road improvements (e.g. the pavement).

The section lineBLOS score (the section starts and ends where any indicator changes, see 4.5) is a construct of the individual indicator values (average of line indicator values, see 4.5.1). The section LineBLOS scores are shown in figure 6-2.

The section LineBLOS score will be used for a) deriving the RBLOS scores of real routes and b) extrapolation of BLOS scores for all road segments in the study area. In section 6.3, RBLOS scores for real routes are discussed. In section 6.4, the extrapolation will be discussed.

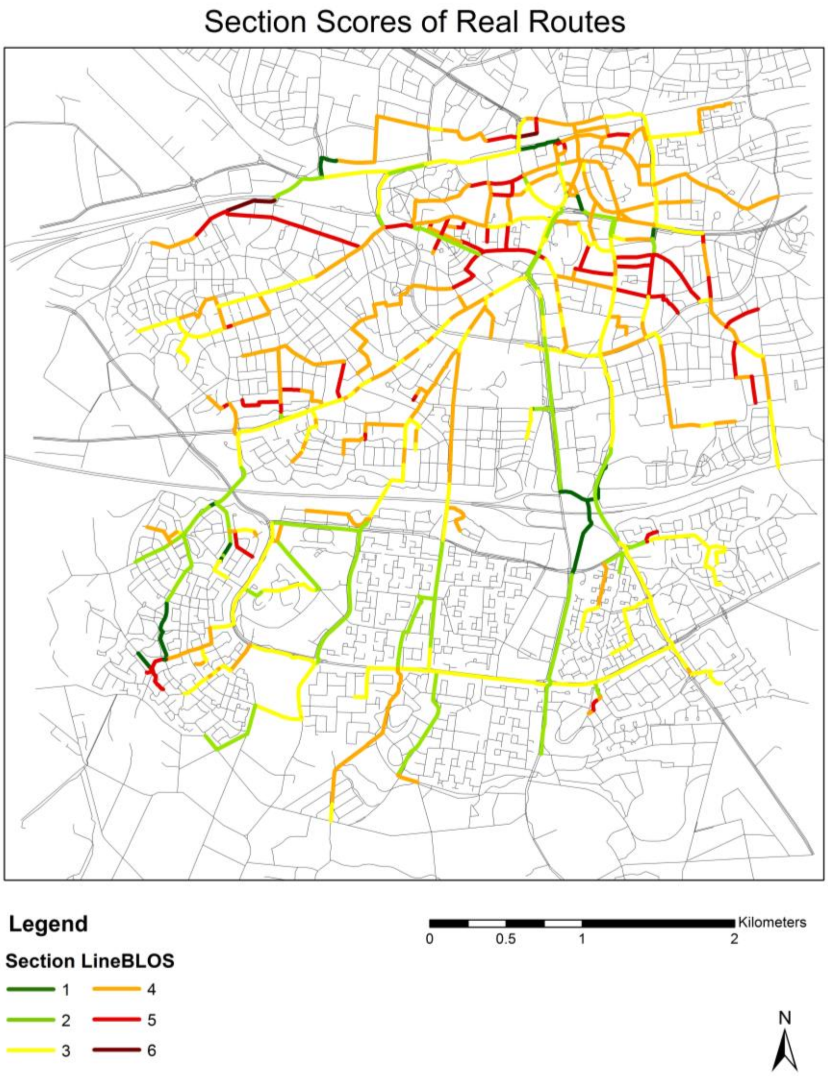


Figure 6-2 Section LineBLOS scores of real routes

6.3. RBLOS scores of real routes

The RBLOS values of the 122 real routes are calculated in the way illustrated in 4.5.2, and based on the combination of overlaying result of individual indicator values (section LineBLOS) and the PointBLOS scores at signalised intersections. The result is shown in figure 6-3.

The average and median of the RBLOS for the routes are 3(2.6) and 2(2.4). The standard deviation is 0.48, minimum of 1.4 and maximum of 3.9.

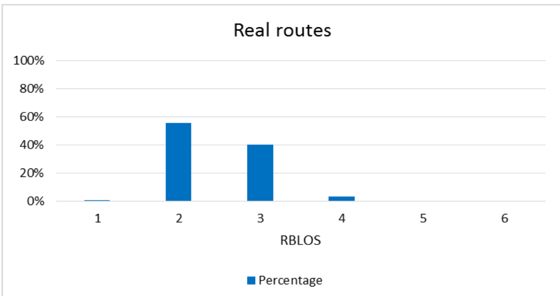


Figure 6-3 Distribution of each RBLOS class of real route set

We can see from the chart that the RBLOS scores of most routes the respondents chose are around 2 or 3 points. There is no route scoring 5 or 6 points which means no case of very bad performance at route level within the real routes.

6.4. Segment LineBLOS extrapolation

6.4.1. Segment LineBLOS at real routes

For the extrapolation of the LineBLOS scores, the network model is used. The section LineBLOS score is the basis to acquire the segment LineBLOS scores by intersecting section lineBLOS scores with the actual network segments from the network model (see 5.3). The segment LineBLOS scores are shown in figure 6-4.

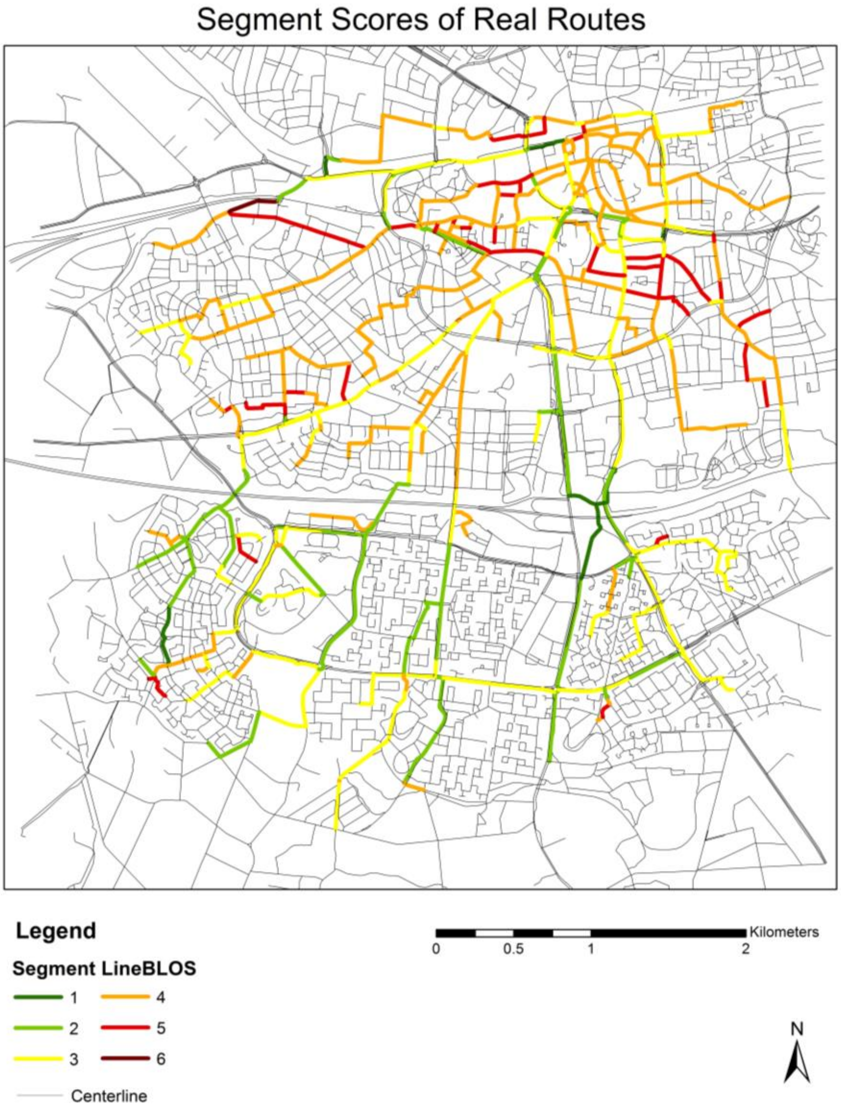


Figure 6-4 Segment BLOS score of the real route

Within the route set, it can be seen from figure 6-4 that, in general the segment BLOS scores of the sections close to the centre or in centre area are higher than the southern outskirts'. This means the service level of the outskirt road segments generally performs better than the central ones.

6.4.2. Road segments BLOS classification

The segment LineBLOS scores are assigned to non-classified road segments on the base of similarity of their characteristics compared with the defined road segments. This process is based on the typology as shown in table 6-4. Thus, the LineBLOS of road segments which are not investigated in the study area are populated to be able to cover the whole study area.

Table 6-4 Classification of LineBLOS

Representative LineBLOS	Typology	Specification
1		• Bicycle path • Wide • No parking • Closed/colored pavement
2		• Path • No parking • Closed/colored pavement
3		• Path • Low width • No parking • Closed/colored pavement
		• Dashed lane • No parking • Closed/colored pavement
		• Striped lane • No parking • Non-closed/colored pavement
		• Sharing road • No parking • Closed pavement

		• Sharing road • No parking • Non-closed pavement
4		• Dashed lane • Island parking • Closed pavement
		• Sharing road • Island/Back parking • Closed pavement
		• Sharing road • Island/Back parking • Non-closed pavement
5		• Sharing road • Dense island parking • Non-closed pavement
6		• Sharing road • Parallel parking • Non-closed pavement • High volume & speed limit

The extrapolation output of the representative LineBLOS is illustrated in figure 6-5. This makes it possible to derive the RBLOS scores on the base of shortest route analysis.

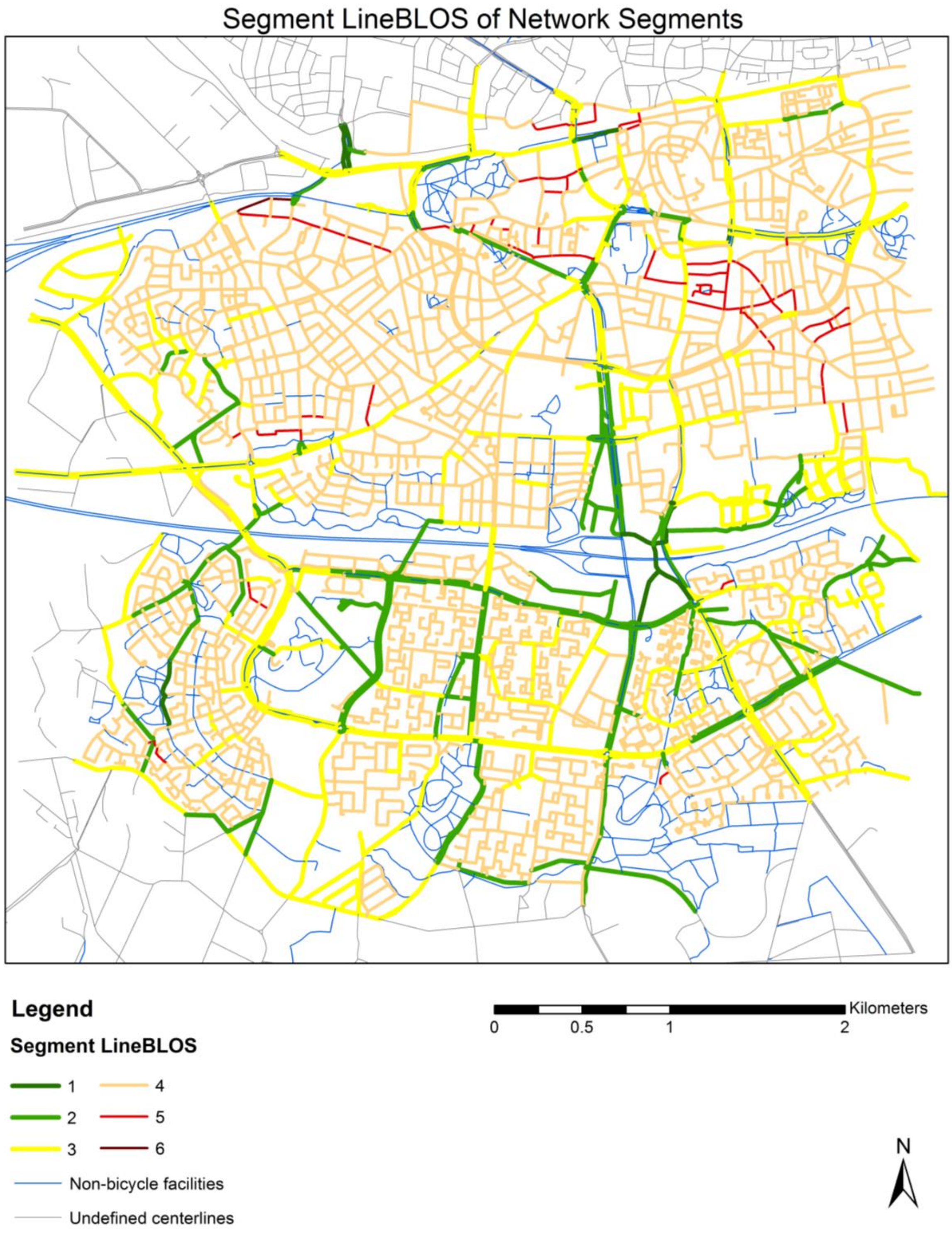


Figure 6-5 Segment LineBLOS of road network segments

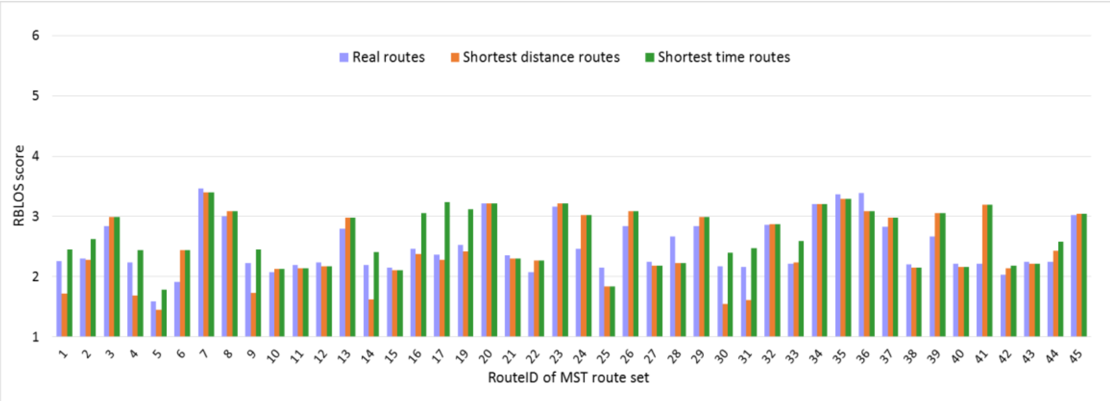
6.5. RBLOS comparison

Based on the shortest route analysis, the shortest routes in terms of both distance and travel time are generated. With this analysis, the RBLOS scores of the shortest routes can be derived and compared with the scores of the real routes RBLOS.

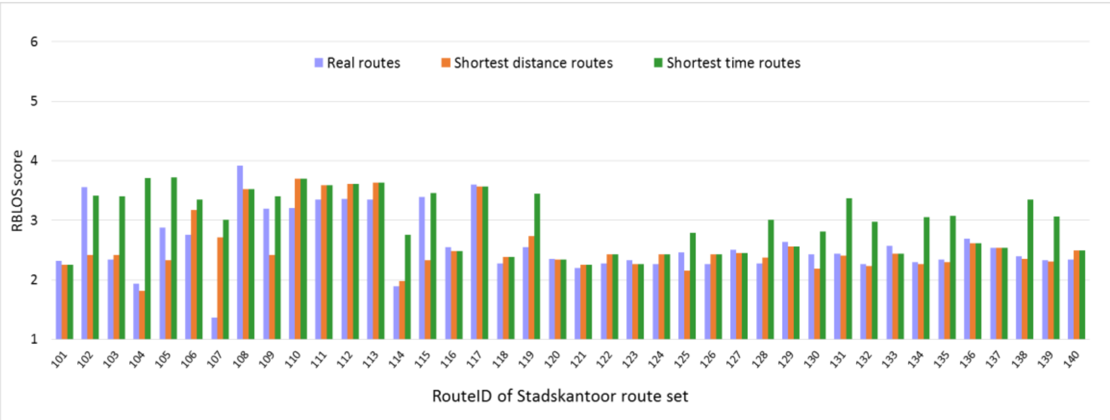
A remark in this context must be given. When the system seeks for shortest routes, the difference of length or time cost between two routes is "absolute", for example, it is possible that two totally different routes have only 1-meter (or second) long difference. In the analysis, the shorter one is going to be highlighted but a cyclist could select the other one in fact. In addition, the cyclist's habit of route choice may also exert impact on their sense of distance/travel time.

6.5.1. RBLOS score comparison of various type of routes

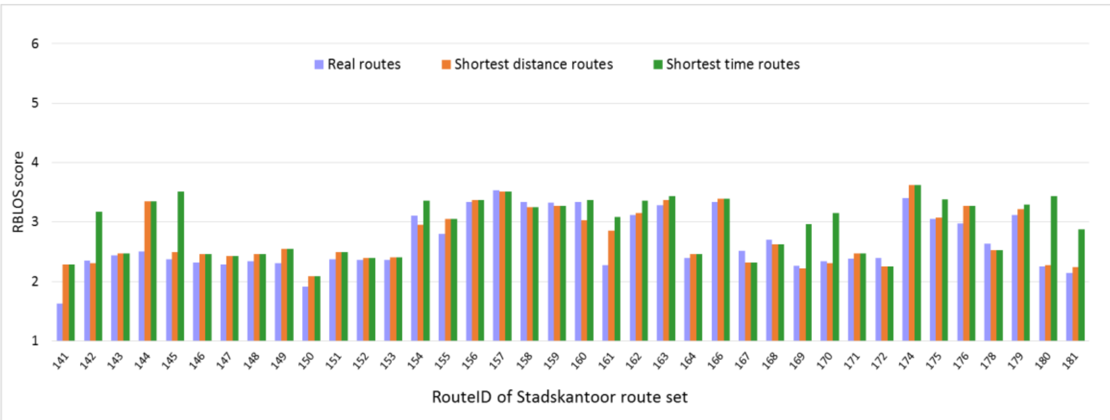
The RBLOS scores of different type of routes (122 O-D pairs, including both the Stadskantoor and MST) are calculated and the frequency distribution of them can be compared. Figure 6-6 shows the variation of RBLOS scores over different kinds of route set. The average RBLOS scores of real routes, shortest distance routes and shortest time routes are relatively 2.6, 2.6 and 2.9.



a.



b.



c.

Figure 6-6 RBLOS scores of real, shortest distance and shortest time routes

Figure 6-7 shows how the scores values distributed to each of the 6 levels.

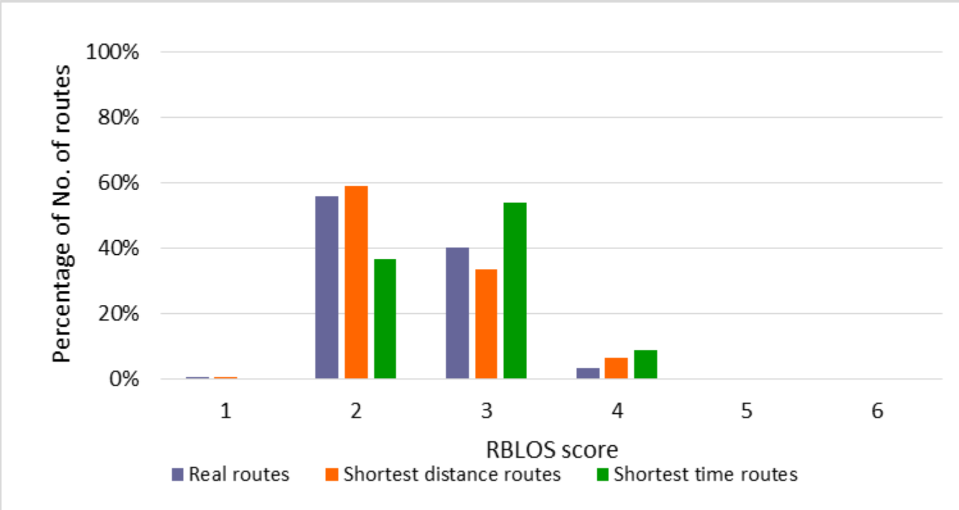


Figure 6-7 RBLOS score distribution of different type of routes

As result of the equal average scores of the real routes and the shortest distance routes, it is implicit yet whether cyclists consider service level or not. If the cyclists care much more about the service level, the average RBLOS score of the real routes is expected to be lower than the shortest routes'.

It can be seen in figure 6-6 and 6-7 that the RBLOS scores of all routes groups are roughly concentrated at 2 or 3 points. Based on the RBLOS score of the whole set shown in figure 6-6 and 6-7, the RBLOS score of the real routes and the routes of shortest distance are similar and similarly distributed to each level.

There are 45 respondents that took the exactly the same routes as the shortest distance routes. Another 15 real routes are almost the same as the shortest distance routes. There are 46 real routes that are the same as the shortest time routes, but 41 out of them are also the shortest distance routes in fact. It can also be concluded from figure 6-8 to 6-11 that the real routes coincide to a large extent with the shortest distance routes rather than the shortest time routes. All these routes are visualised in two separate groups with different destinations- the Stadskantoor and the MST.

1. **Routes to Stadskantoor**

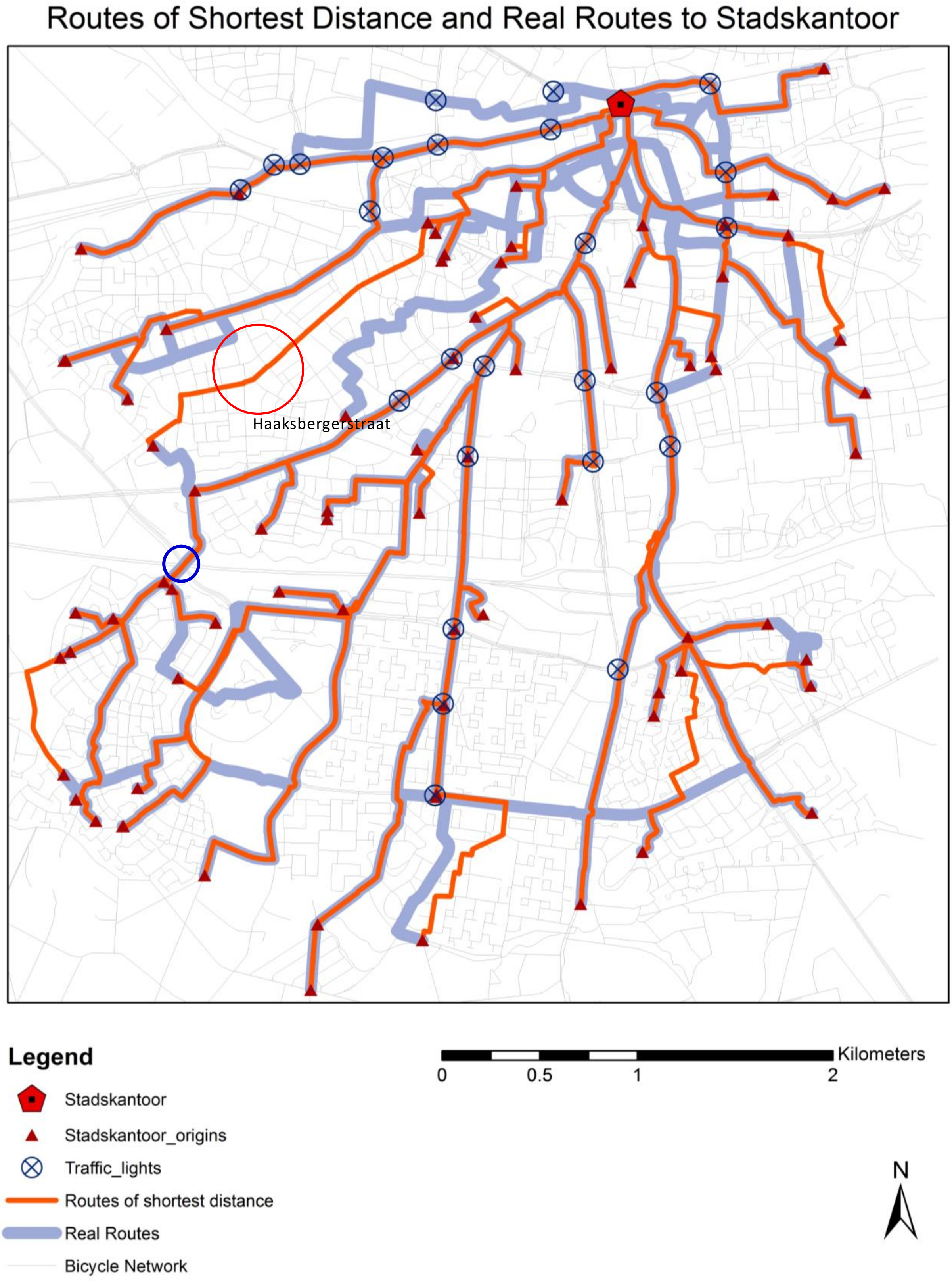


Figure 6-8 Comparison of shortest distance routes and real routes

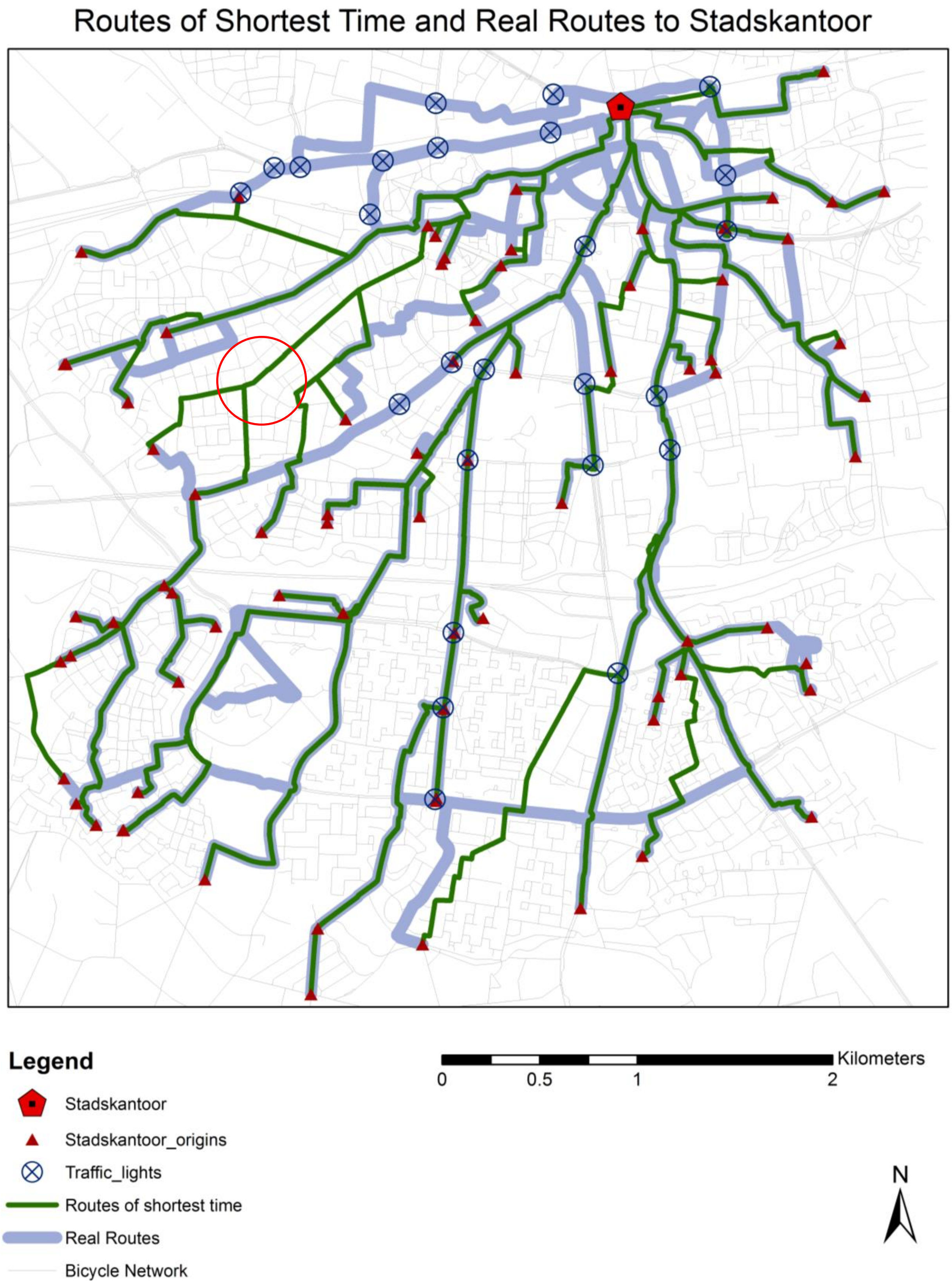


Figure 6-9 Comparison of shortest travel-time routes and real routes

2. Routes to MST

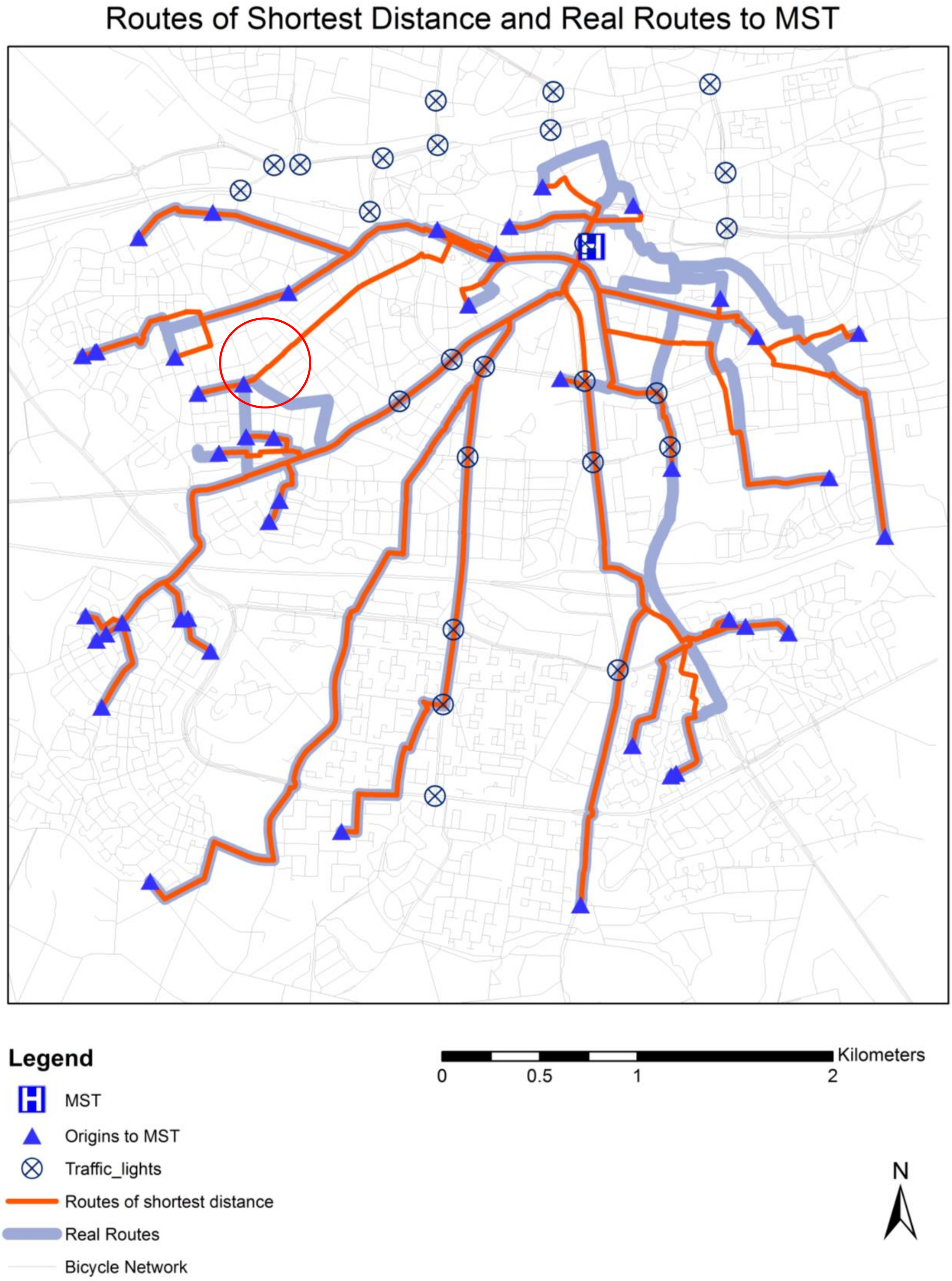


Figure 6-10 Comparison of shortest distance routes and real routes

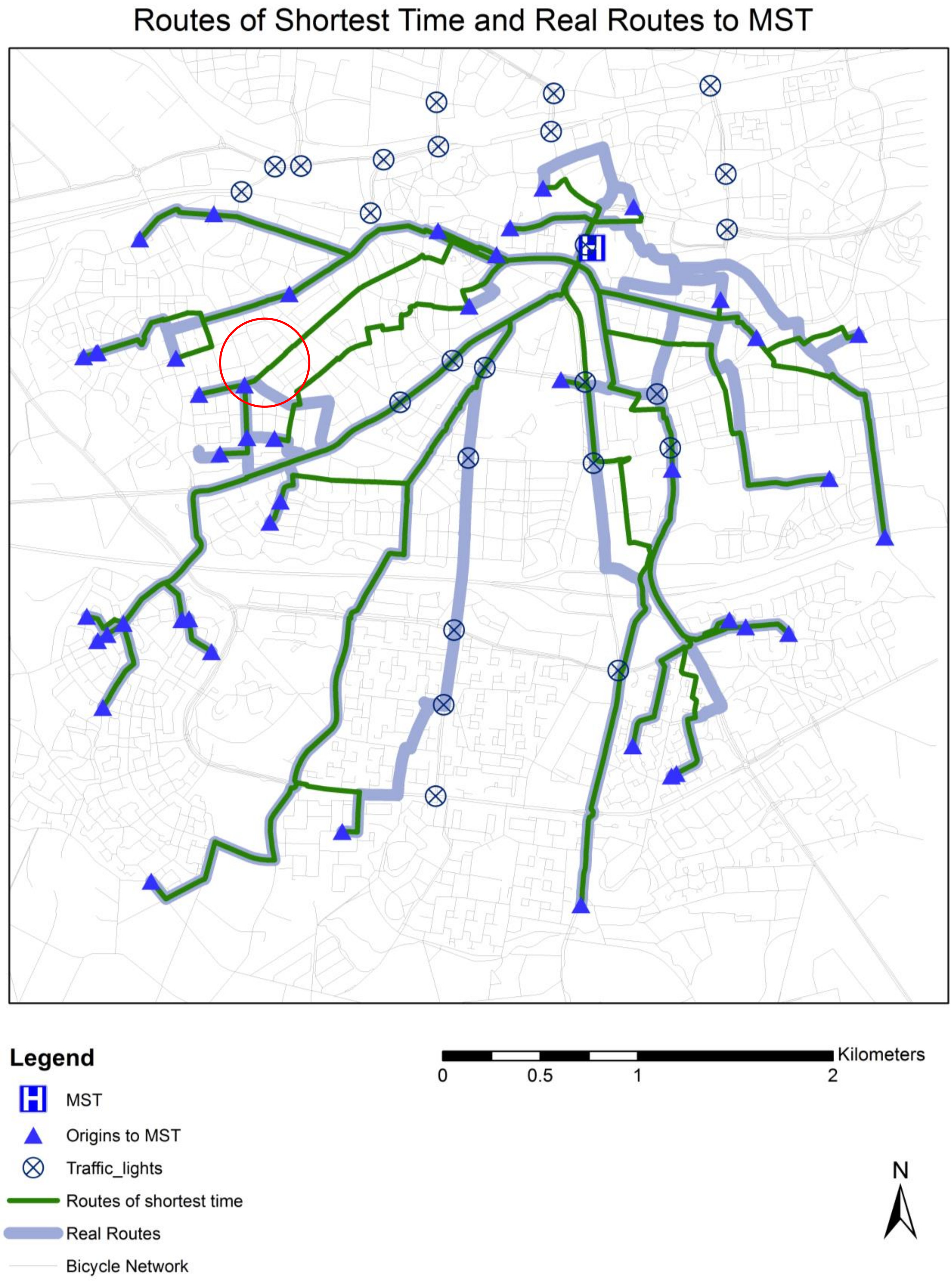


Figure 6-11 Comparison of shortest travel-time routes and real routes

It can be seen from these maps (Figure 6-8 to 6-11) that the real routes coincide a lot with the shortest distance routes. These kinds of overlaps occur much less in case of comparing real routes with the shortest time routes. That explains their average RBLOS scores are equal (2.6 for both real routes and shortest distance routes, 2.9 for shortest tine routes). What is more, it can be interpreted that the difference between the routes of shortest distance and time is mainly caused by cyclists avoiding traffic lights (waiting at the traffic lights) in the case of shortest time routes. Traffic lights mostly are located along the main roads. Therefore shortest time routes make more use of local neighbourhood roads, which have higher BLOS scores in terms of intensive parallel parking the brick pavement to a large extent.

Most people living in southwest Enschede are forced to make use of the westernmost passageway over the A35, marked in blue circle in figure 6-8, and the main radial arterial road Haaksbergestraat to the centre. What is interesting, several road segments (Usselerweg and Zweringweg) occur frequently in the route set of shortest distance or shortest time as marked by red circles (figure 6-8 to 6-11), but not in the real route set. These road segments form the alternative that cyclists can use to avoid the two traffic lights located in Haaksbergerstraat. In addition, this portion has Segment BLOS score of 4, which is a relatively high score. Therefore, it is a potential site to make improvement in terms of BLOS for the municipality on contributing to the new bicycle network. The people living in the neighbourhood Stadsveld and southwest Enschede might be attracted to use this route.

6.5.2. Relation between RBLOS and travel distance

The average RBLOS score of each route length category is retrieved after the calculation of BLOS score of all routes cyclists take. It aims to explore the relation between the RBLOS score and the travel distance.

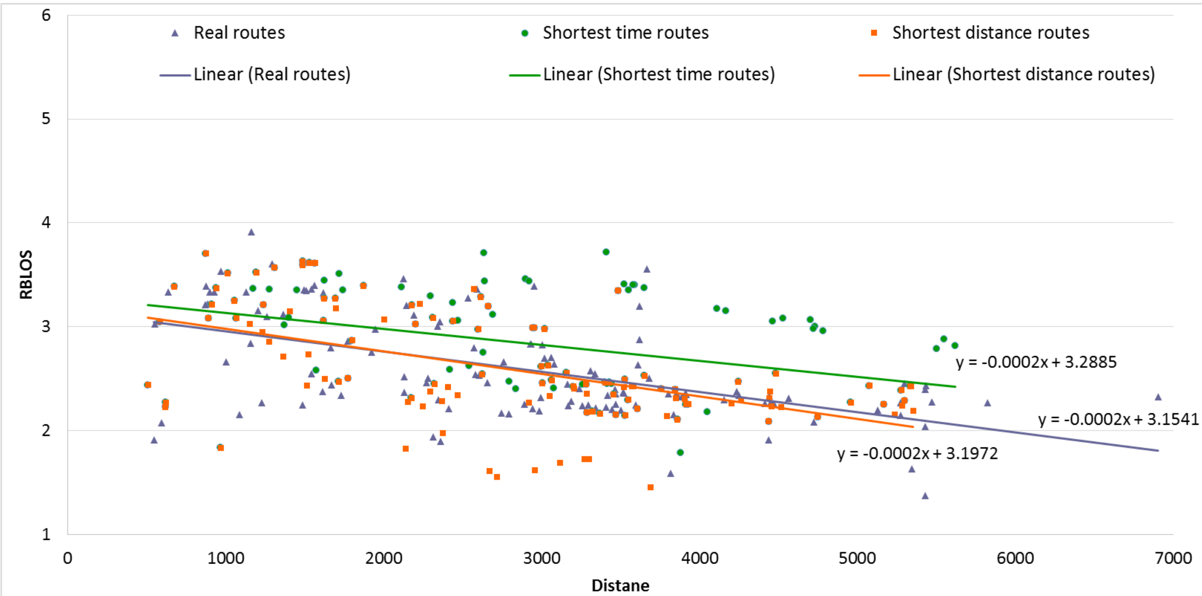


Figure 6-12 RBLOS changes with various distance

The RBLOS score is on a declining tendency with the distance of routes reducing for the three types of routes; real, shortest distance and shortest time routes. To validate it, another six dummy destinations: D1, D2…D6 are created close to the boundary of the study area. They are located as figure 6-13 shown. Shortest distance routes were created using the same set of respondent's home locations as origins and the dummies as destinations. For all derived routes the RBLOS was calculated and the outcomes were set out against the route distances.

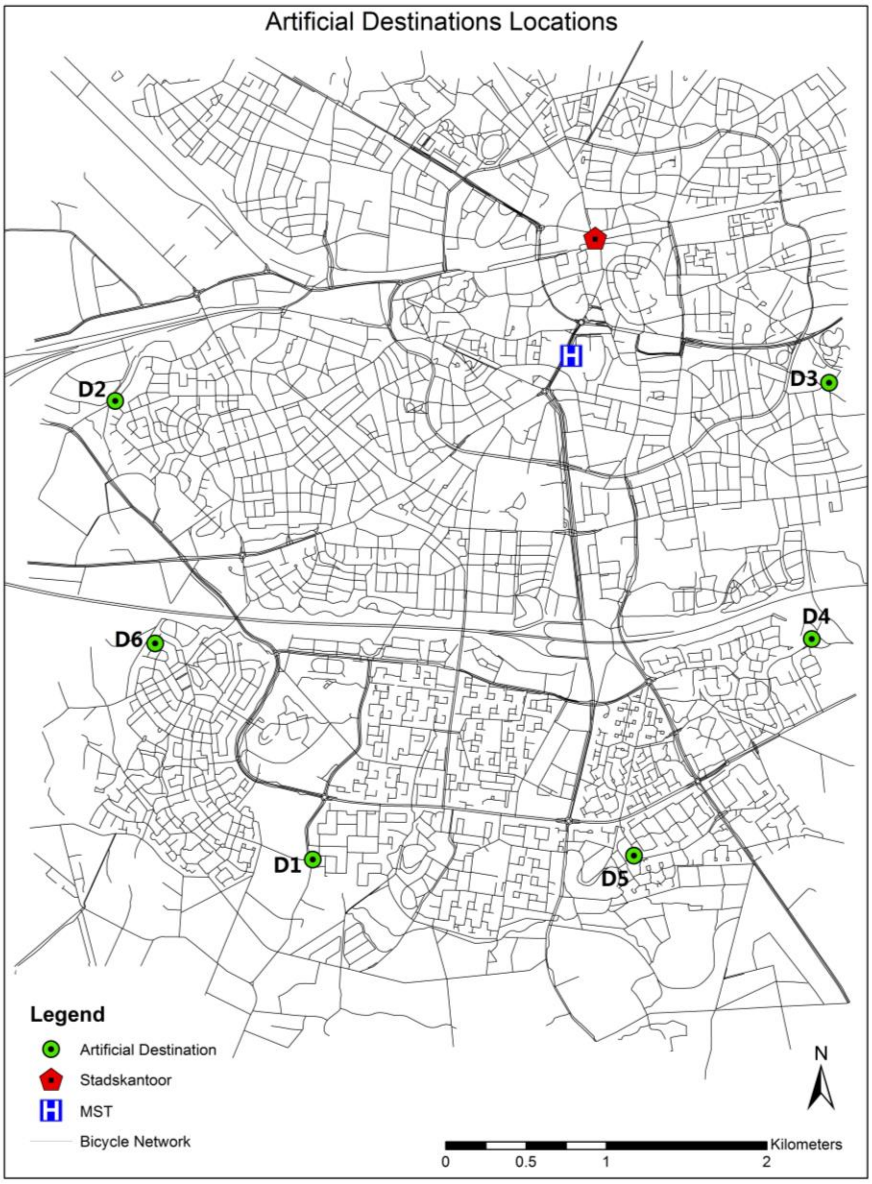


Figure 6-13 Positions of artificial destinations

The RBLOS scores of these shortest distance routes to all the six dummy destinations were calculated. The results are shown in figure 6-14.

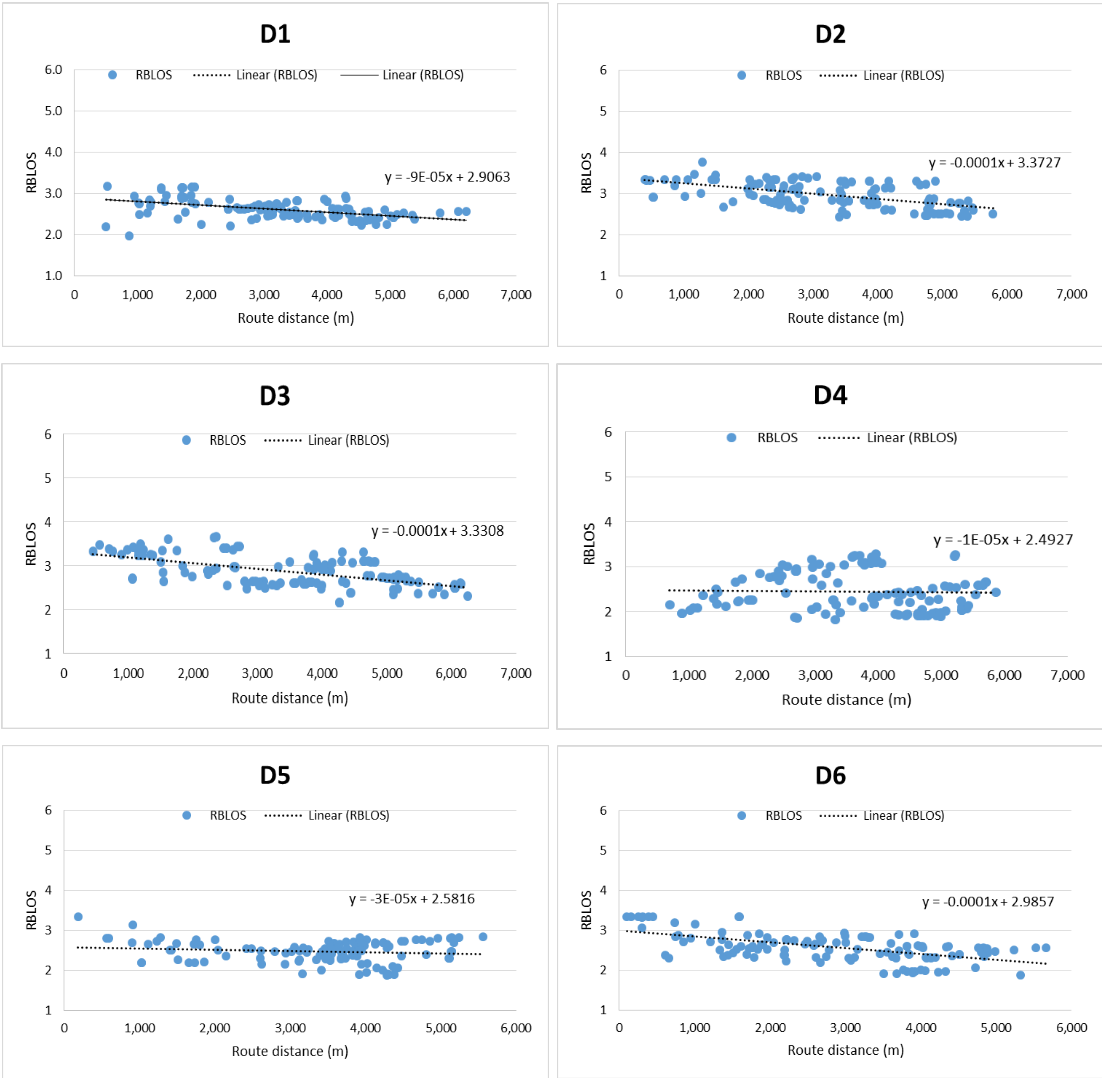


Figure 6-14 RBLOS of different route distance

From the figure 6-14, it is demonstrated the tendency that the RBLOS value decreases with the route distance increases. Due to the limited numbers of passages across the highway and the radial structure of the network, the routes coming from the outskirt are largely concentrated in several routes after crossing the highway from south to the city centre. That is to say the cyclists living further away frequently use partially the same routes. Combined with the segment BLOS distribution map (figure 6-5), it can be observed that the BLOS in southern outskirts are better than the centre area.

The Stadskantoor and the hospital are both located in the centre where the BLOS scores are relatively high. That is why for all the real routes and the shortest routes the longer the distance, the lower the RBLOS score is, as we can see from the scatter plot 6-14.

This is verified by the dummy examples results: if the destination is located in a higher score area, such as D2, D3 and D6, the tendency is that the RBLOS reduces with the distance increase. Otherwise this relation is not obvious, such as D1, D4 and D5 because of their low-score surroundings (see figure 6-5). We can see the absolute values of their slopes are one order smaller than the other three destinations (D2, D3 and D6).

7. CONCLUSIONS AND RECOMMENDATIONS

This chapter is focusing on the conclusions of the whole research and the limitation of the current work as well as the recommendations for the future study.

7.1.1. Conclusions

In this research, a BLOS model has been developed for the southern part of the city of Enschede. The BLOS model operates at the level of individual sections, segments and routes. This allows for an evaluation of bicycle infrastructure quality at route level. This is achieved by a GIS based dynamic segmentation model and network analysis model in GIS. Looking back at the initial sub-objectives of this research, it could be concluded:

1. The segment BLOS score is obtained by measuring the "line events" along the roads and combining these with the actual network segments. The intersection BLOS score is modelled in forms of "point events" in the dynamic segmentation model and "turns" in the network analysis model.
2. The Route BLOS (RBLOS) scores of real routes are calculated based on the overlay result of individual BLOS indicator values. The RBLOS scores for shortest routes are processed in the network analysis model and based on the extrapolated segment LineBLOS scores. The calculation method for any route set (real or shortest) is consistent.
3. The segment LineBLOS scores are stored in forms of table GIS. The undefined segments are assigned scores according to the measured segments of real routes which are typologically similar. The PointBLOS scores are stored in a turn table in GIS.

7.1.2. Limitations and recommendations

Primarily due to the limitation of time and data, there are a number of areas in need of improvement.

1. Survey of route choice

- **Sampling**

In the statistical analysis of the association between the gender and the ranking preference of the route choice reasons, the sample size hindered the analysis. This analysis for categorical data should have been done by Chi-square test. However, the expected counts for each item should be greater than 5, which is not in this case due to the answers of "most safe" as the No.1 reason are few. Therefore, we could only observe the practical situation instead of discover this association of the population. Thus, it would be much better to expand the sample size in the future work. That is also for the duration of the survey because this questionnaire are only for one morning at only one organization. In addition, there is few age variation. More teenager respondents may bring different outcome.

- **Travel purpose**

This research just focused on the routes people going to work for the questionnaire part. So it is not very surprised that the respondents take routes of shortest distance or travel time. It can be imaged that if the questionnaire is asking people about their route way home or go shopping on weekend, the result could show more variation.

- **Multiple answers of reasons ranking**

In the ranking result of the route choice reasons, some respondents rated more than 1 options at the same rank. For example, "shortest distance" and "shortest travel time" are both selected as the 1st reason. There are even cases that all reasons are all selected as the 1st choice. That brings potential overestimation of the occurrences for each reason so that they could not be compared precisely. In the future, the method to deal with this multiple answers of ranking should be come up with.

2. BLOS indicators

In this study, each indicator of the BLOS index is treated the same using the equal-weighing method to come up with the RBLOS score. The components of segment and the signalized intersection are considered as the same priority along the route.

However, the RBLOS is highly relevant to what indicators are used and how they are weighted. In fact, the selection of the indicators and the weighing method also affect the result of the segment LineBLOS extrapolation. So this extrapolation process needs to be updated when either the indicators or their weights change. The sensitivity of the RBLOS scores over the indicators or the weights changes is unknown.

Therefore in the future study, the set of road indicators could be updated to add more indictors (e.g. volume of bicycles, accident rate, noise level, etc.) and the weighing system could be structured to the evaluation system to flexibly approach to the reality.

3. Data collection of BLOS indicators

With regard to the attributes of facility type, width, pavement, parking condition and traffic lights are measured and from the aerophoto combined with the Roads and highways measuring tool and street views of the Google maps. These attributes of few routes were measured from the field， using a running and walking cell phone app to measure the positions and laser distance meter to measure the width of the bicycle lane. Comparing these two capturing methods, their advantages are found out. It should be improved in future data capturing process.

For the facility type and width, the aerophoto is easy to see and helpful to measure. But there are still resolution limitation or tree obstructions. In fact, the pavement condition can hardly be specified from it even the photo is zoomed in to the largest. In addition, the parking condition cannot be identified because some of the road side space are shaded by trees, or illegal parking. Therefore, it is recommended that these two attributes are befitted to field measuring.

4. Dynamic segmentation model in GIS

The model of route dynamic segmentation in this research allows the time-wise process. For example, the route layout and the events of the network could be easily created dynamic at any time. What's more, it can not only be applied for the study area or bicycle infrastructure, but also for anywhere else within the network or other transport infrastructure flexibly. Thus in the future, this method could be applied to the whole network of Enschede city.

5. Network analysis model in GIS

- **Extrapolation of the segment scores**

In the process of segment BLOS populating to the undefined road segments, the method is to compare the road pattern to the known segment. The scores are assigned to the undefined segment just according to the similar known segment's scores. It could be more accurate if these segment are measured in practice, or if there are categorized segment data which can be utilized.

- **Complexity of optimal BLOS routes analysis**

Theoretically with the segments BLOS dataset acquired, the optimal BLOS routes of certain O-D pair could be sought by setting the segment BLOS as the impedance. Nonetheless, the BLOS score is non-numeric, which means among there is no numerical or multiple relation among these various level values. But there is relative magnitude relation. For example, the BLOS of the segment scored 1 point is not twice as better than the one scored 2 points. That causes the segment BLOS score could not be simply utilized as the travel impedance.

Besides, to avoid that the longer the routes is, the higher the RBLOS score is, the RBLOS score is compensated by travel time instead of adding up directly all the segment LineBLOS scores along one route. Thus, it is needed to know the whole travel time beforehand during the seeking process of the "shortest" (optimal in BLOS) routes. The shortest route analysis adopts the Dijkstra algorithm which accumulatively summarize the impedance of all segments and intersections. It is not completely fit this case because it lacks of travel time-compensation step. Hence an improved method might be needed to search for the optimal BLOS routes in the future study.

- **Restriction settings of network**

For the restriction setting of the network, the bicycle facilities along the main road are normally separated to each side of the road. Yet the sharing roads in residential area are not that case. Therefore, the one-way setting was processed as one type of the restrictions. What's more, restriction like the non-bicycle facility was also defined by assigning the negative travel impedance value.

The other restriction is turns. According to the aerophoto from the geo-information system of the municipality, the impedance of turns are set based on the turn direction. For example, most of the right-turns has no waiting time. But the rest of them does not. Some of the turns are time-wise changing. In addition, the straight one may change to double right-turn in the case of avoid waiting long at traffic lights. So this turns data could be more accurate when digitizing the turns in GIS.

In addition, there is a short coming which was not foreseen. For the whole data processing duration, the origins and destinations of routes are the exact start or end points of the centerline elements when the routes are created in Road and Highway system. Whereas, the origins and destinations in the shortest route analysis are the foot of perpendicular from the actual origins/destinations to the adjacent network centerline. Therefore, for the cases that the O/D are in the middle of one segment, the shortest route sought by the system will be slightly shorter than the digitized routes automatically. But this is not the case in this research. But to be more accurate, the centerline can be split up before the routes network created in the GIS for the future study.

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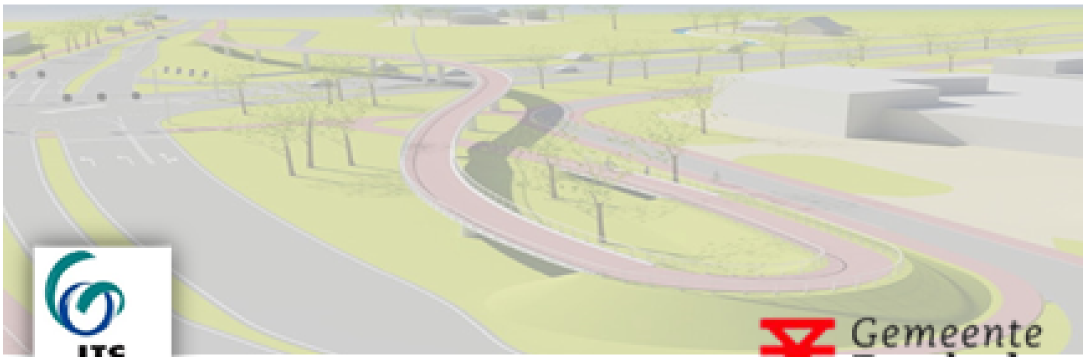
APPENDIX A: QUESTIONNAIRE FORM FOR MST

Date: 16/12/2014



ITC UNIVERSITY OF TWENTE

Gemeente Enschede

Enquête Fietsroutekeuze

Medisch Spectrum Twente, Enschede

Locatie Haaksbergerstraat

Beste MST medewerker,

We willen hierbij graag uw medewerking vragen bij een onderzoek naar fietsroutekeuze dat momenteel wordt uitgevoerd bij de Universiteit Twente, faculteit ITC.

De resultaten van dit onderzoek zullen o.a. worden gebruikt bij de totstandkoming van door de gemeente Enschede geplande uitbreidingen van het fietsnetwerk in het zuidelijk deel van Enschede.

Zou u, als u in een van onderstaande postcodegebieden woont, de vragenlijst op de volgende pagina willen invullen, dit neemt minder dan 5 minuten in beslag. De lijst is anoniem en de resultaten zullen alleen worden gebruikt in de verslaglegging van het onderzoek en voor de verbetering van de fietsinfrastructuur in Enschede.

- ☺ **7511, 7512, 7513**
- ☺ **7541, 7542, 7543, 7544, 7545, 7546**

Na invulling kunt u uw formulier in de envelop stoppen en meegeven met de interne post

Hartelijk dank!

Bij vragen over het onderzoek kunt u contact opnemen met:

y.zhang-14@student.utwente.nl of m.j.g.brussel@utwente.nl

VRAGENLIJST MST FIETS ROUTEKEUZE

1. Geslacht: □ Man □ Vrouw

2. Leeftijd: □ <35 □ 36-50 □ 51-65 □>65

3. Hoeveel dagen per week fietst u naar het ziekenhuis?

   __ dagen

4. Teken alstublieft de fietsroute (zo gedetailleerd mogelijk) die u normaal gesproken fietst van uw huis naar het ziekenhuis (stalling), met een doorgetrokken lijn **op de kaart (achterzijde van dit papier)**.

5. Waarom kiest u deze route?

— Geef aan onderstaande redenen een score van 1 tot 5, waarbij 1 de meest belangrijke reden is en 5 de minst belangrijke. Elke score mag 1 keer gebruikt worden.

— Als u geen “Andere reden” heeft, gebruik dan scores van 1 tot 4!

. . . . . Kortste afstand

. . . . . Kortste reistijd

. . . . . Meest verkeersveilig

. . . . . Meest comfortabele rit

. . . . . Andere reden:

Hartelijke dank voor uw medewerking!

Na invulling kunt u uw formulier in de envelop stoppen en meegeven met de interne post.


Twekkelerveld
Enschede
Roombeek
Laares
Rigtersbleek
Zeggelt
De Bothoven
Bruggert
Pathmos
Veldkamp
Perik
't Zwering
Stadsveld
Hogeland
Boswinkel
Brinkstraat
Ruwenbos
Stroinkslanden
Helmerhoek
Wesselerbrink
Horsterveld
Knalhutteweg
Geesinkweg
Haverkateweg
Kwekkeboomweg
Buurserstraat
Groene Laan
Usseler Markeweg
Loeksweg
Groot Bruninkshoek
0
0.25
0.5
1 Km
NORTH

APPENDIX B: QUESTIONNAIRE FORM FOR STADSKANTOOR

Date: 6/1/2015

ITC UNIVERSITY OF TWENTE

Gemeente Enschede

Enquête Fietsroutekeuze

Gemeente Enschede

Locatie Stadskantoor

Beste medewerker,

We willen hierbij graag uw medewerking vragen bij een onderzoek naar fietsroutekeuze dat momenteel wordt uitgevoerd bij de Universiteit Twente, faculteit ITC in samenwerking met de gemeente Enschede.
De resultaten van dit onderzoek zullen o.a. worden gebruikt bij de totstandkoming van door de gemeente Enschede geplande uitbreidingen van het fietsnetwerk in het zuidelijk deel van Enschede.

Zou u, als u in een van onderstaande postcodegebieden woont, de vragenlijst op de volgende pagina willen invullen, dit neemt minder dan 5 minuten in beslag. De lijst is anoniem en de resultaten zullen alleen worden gebruikt in de verslaglegging van het onderzoek en voor de verbetering van de fietsinfrastructuur in Enschede.

- **7511, 7512, 7513**
- **7541, 7542, 7543, 7544, 7545, 7546**

Na invulling kunt u uw formulier in de envelop stoppen en meegeven met de interne post

Hartelijk dank!
Bij vragen over het onderzoek kunt u contact opnemen met:
y.zhang-14@student.utwente.nl of m.j.g.brussel@utwente.nl of g.spaan@enschede.nl
(053-4815535)

VRAGENLIJST GEMEENTE ENSCHEDE FIETS ROUTEKEUZE

6. Geslacht: ☐ Man ☐ Vrouw

7. Leeftijd: ☐ <35 ☐ 36-50 ☐ 51-65 ☐>65

8. Hoeveel dagen per week fietst u naar het stadskantoor?

   _ dagen

9. Teken alstublieft de fietsroute (zo gedetailleerd mogelijk) die u normaal gesproken fietst van uw huis naar het stadskantoor (stalling), met een doorgetrokken lijn **op de kaart (achterzijde van dit papier)**.

10. Waarom kiest u deze route?

    — Geef aan onderstaande redenen een score van 1 tot 5, waarbij 1 de meest belangrijke reden is en 5 de minst belangrijke. Elke score mag 1 keer gebruikt worden.

    — Als u geen “Andere reden” heeft, gebruik dan scores van 1 tot 4!

    ..... Kortste afstand

    ..... Kortste reistijd

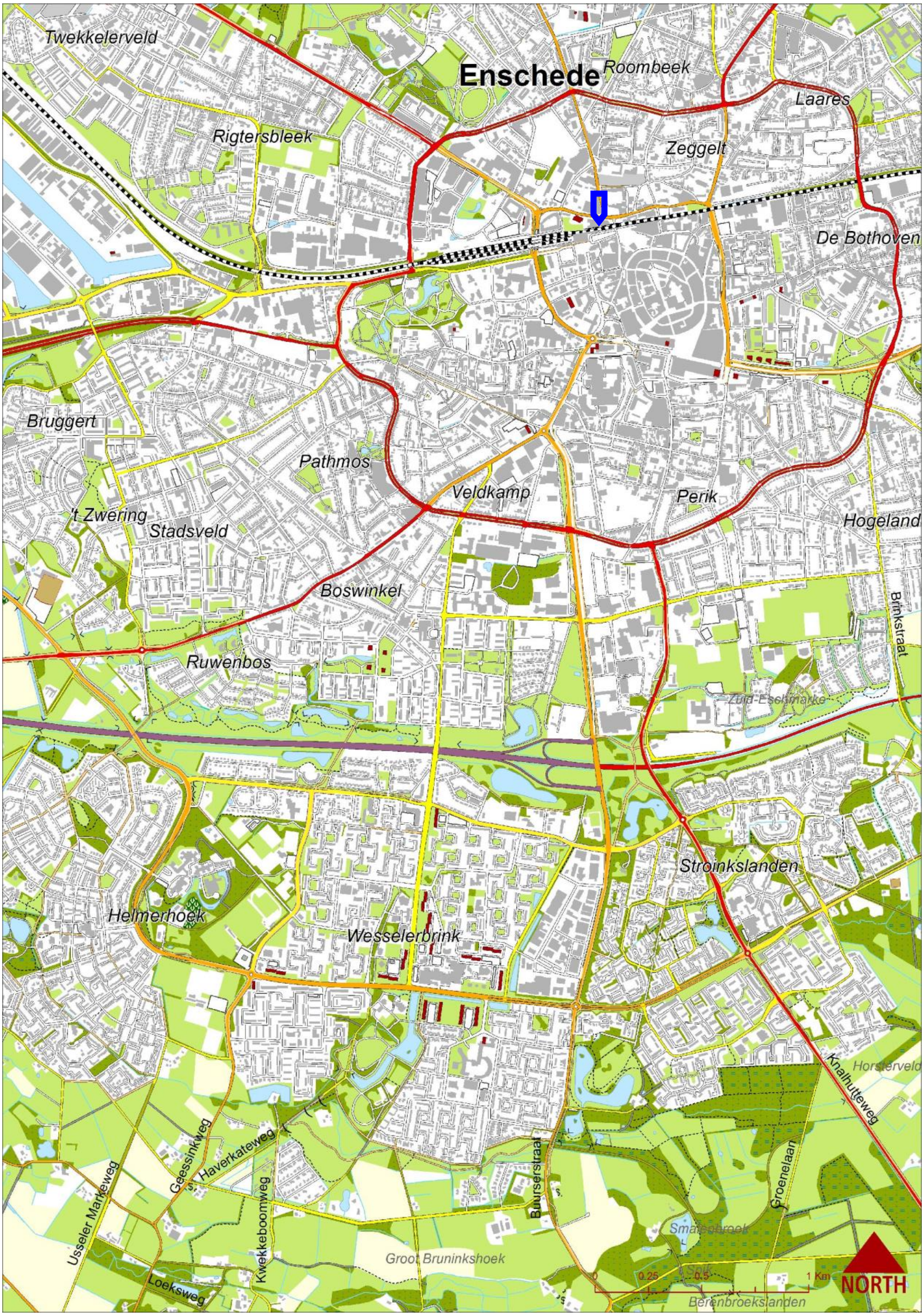
    ..... Meest verkeersveilig

    ..... Meest comfortabele rit

    ..... Andere reden:

Hartelijke dank voor uw medewerking!

Na invulling kunt u uw formulier in de envelop stoppen en per interne post zenden aan G. Spaan SO-beleid erve 4.4.


Twekkelerveld
Enschede
Roombeek
Laares
Rigtersbleek
Zeggelt
De Bothoven
Bruggert
Pathmos
Veldkamp
Perik
't Zwering
Stadsveld
Hogeland
Boswinkel
Brinkstraat
Ruwenbos
Zuid-Esmarke
Stroinkslanden
Helmerhoek
Wesselerbrink
Horsterveld
Knalhutteweg
Geessinkweg
Haverkateweg
Usseler Markeweg
Kwekkeboomweg
Buurserstraat
Groenelaan
Smalenbroek
Groot Bruninkshoek
Loeksweg
Berenbroekslanden
0
0.25
0.5
1 Km
NORTH