The use of digital maps for the evaluation and improvement of a bicycle-network and infrastructure

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Samenvatting

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Een duurzaam mobiliteitsbeleid gaat gepaard met het stimuleren van fietsgebruik. Potentiële fietsers haken echter vaak af omdat de veiligheid en het rijcomfort van fietspaden langs de Vlaamse wegen te wensen over laat. Een oplossing om de veiligheid van fietspaden te verhogen, is het optimaliseren van de kwaliteit van de fietsinfrastructuur langsheen een fietsroutenetwerk. Rekening houdend met de omvang van zo'n fietsroutenetwerk, is het essentieel om te bepalen op welke locaties de nood aan een verbetering van de infrastructuur van prioritair belang is. In dit artikel wordt een methodologie voorgesteld voor de evaluatie van de fietspadeninfrastructuur en het detecteren van de ernst van knelpunten langsheen het fietsroutenetwerk. De ontwikkelde methodologie berekent de knelpunten in het netwerk aan de hand van een Geografisch Informatie Systeem (GIS). De knelpunten worden bepaald door de afwijking te berekenen van de bestaande fietsinfrastructuur ten opzichte van een vereiste - en dus veiligere - infrastructuur. Als toetsingscriteria werd het Vademecum Fietsvoorziening, een document van de Vlaamse overheid, gebruikt. Dit vademecum beschrijft de vereiste fietsinfrastructuur afhankelijk van karakteristieken van de aanliggende weg. Een eerste stap is het selecteren van alle relevante criteria die bepalend zijn voor de veiligheid van het fietspad. Vervolgens wordt een inventaris opgesteld van alle attributen langsheen het wegennetwerk. Elk attribuut (bijv. de breedte van het fietspad) wordt geëvalueerd een draagt geheel of gedeeltelijke bij tot de ernst van een knelpunt. Aan de hand van een multi-criteria analyse wordt een knelpuntenscore berekend voor elk stuk fietspad in het netwerk. De resultaten worden gevisualiseerd op een kaart. Dit onderzoek kadert binnen het mobiliteitsbeleid van de stad Gent, en is een deel van een prioriteitenkaart die aanduid welke fietspaden als eerste dienen (her)aangelegd te worden.

1. Introduction

Transport and mobility has become a major point of interest in policymaking actions. Therefore, the Flemish municipalities and cities develop action plans on mobility and traffic safety. Extra attention is given to the vulnerable road users such as cyclists: the bicycle is the most preferred sustainable mean of transport. Therefore the bicycle must have a leading part in a sustainable mobility policy.

A precondition to encourage bicycle-use, is the provision of a dense network that connects activity centres (shopping centre, schools ...) and different points of interests. The most important aspect to make cycling attractive and guarantee safety for al cyclist is the quality of the cycling infrastructure. The consistency in the infrastructure is an important factor. It should be conveniently arranged, safe, attractive, comfortable and especially effective.

The aim of this research (De Baets 2007) is to develop a methodology and a geographic information system (GIS) application to evaluate a cycle route network. This implies that the existing infrastructure is compared with the most optimal / desired cycle lane facility, at the same location and under same conditions. The method is implemented in a GIS in order to determine where the most defaults in the cycle route infrastructure are located.

Due to their partnership in the European CIVITAS project, which is a project for a sustainable policy on mobility, the city of Ghent in Belgium proves to be a suitable research area to evaluate the infrastructure along the cycle route network. This network was developed in the light of the mobility action plan of Ghent.

This paper discusses the necessary steps that are taken to evaluate the cycle tracks of a cycle route network. In a first step an overview is given of the requirements that should be used. A second step describes how these requirements can be applied to the existing cycle lanes. A third step describes how the cycle route network should be constructed digitally in order to effectively evaluate the network. In the fourth step a map is composed to give an overview of all the bottlenecks in the cycle route network. Finally some conclusions and recommendations are given.

2. Creating a bottleneck map

The aim of the study is to develop a methodology to detect bottlenecks in a (cycle) route network, and to represents the bottlenecks on a map useful for policy purposes in the renewal of cycling infrastructure.
A bottleneck is defined as a part of the cycle lanes where the existing infrastructure are not conform with the guidelines as described in the handbook *"Vademecum Fietsvoorzieningen"* (Vademecum Cycle facilities) (Vlaamse Overheid 2006) for the construction of a cycle path. This is a policy document that describes guidelines that should be used when new bicycle facilities are constructed. The document is used by the City of Ghent for the (re) construction of bicycle lanes, where such guidelines are useful as objective test criteria for the analysis of the current cycle infrastructure.

This analysis will initially be performed along the functional cycle route network. This is a network used to make target-oriented travel for work, school, shopping, etc., as safe and as comfortable as possible. This is a hierarchical network: the highest level in the network contains the main routes which form the backbone of the network. The next level is the upper-local network, a closed network with connections between municipal / urban centres and attraction poles. The lowest level consists of local routes, which are supplementary to the above local network. This study is limited (in a first stage) to the upper-local functional cycle route network. In this stage of the research, the focus will be on line-segments. No special attention will be given to intersections and roundabouts that require a different approach.

Once the analysis has been performed, a 'bottleneck-map' will indicate where the bicycle infrastructure is not in conformity with the guidelines from the Vademecum. This informative map is a resource in determining the priority for renewal on the infrastructure of cycle paths.

3. Method for identifying defaults in the cycle network

As mentioned before, a cycle path is defined as a bottleneck/problem if the existing infrastructure does not meet the guidelines of the handbook. Consequently, the data from the existing infrastructure needs to be linked to the guidelines of the Vademecum. At first it is necessary to determine to which criteria the cycling infrastructure must meet. Next these criteria determine which attributes should be linked to the cycle network and how the network has to be constructed.

3.1. Criteria

The Vademecum describes design-guidelines relating to the whole cycle infrastructure, ranging from measurements and road guards, materials and colours, lights, junctions and roundabouts, bicycle storage, etc. The focus of this research lies within the line elements (no intersections) and their external shape (dimensions and road guards).

The main criteria are the measurements. Measurements are defined as the width and the elevation of the cycle, and the width of the space between the cycle path and road. Between the road and the cycle path a road guard may or may not be installed. The cycle path can be highlighted by a colour, or be marked by white line to get more attention in the traffic environment,

The values of these criteria are determined by the type of cycle path. These types are "categories" to which a cycle path can belong. Each category has specific requirements (see Table 1). Possible types of cycle paths are: *none*, *adjacent* (of the road), *separate* (of the road), *cycle suggestion lane* and *cycle road*. A distinction is made between uni-directional and bi-directional bicycle paths.

"Cycle suggestion lane": Lane on the road, visually indicated by a different colour and / or material. Legally this is not a cycle path, but a sort of mixed traffic where both roadway and suggestion path can be used by all road users. They are usually situated in places where no space is available for a real cycle path, or at the transition from cycle path to mixed traffic.

"Adjacent cycle lane": A cycle path of which the paving (almost) immediately connects with the roadway. There is a visual separation between roadway and bike path through a gutter drain, broken white parallel lines or a different colour or material. These may or may not be elevated.

"Separate cycle path": Cycle path of which the pavement is physically separated from the roadway by a safety zone of at least 1 meter that can not be crossed or be used by moving traffic (increased roadside, green area, parking spaces ...). A cycle path with a the safety zone of at least 70 cm and a clear physical vertical separation (hedge, screen, wall, crash barriers ...) is also defined as a separate cycle path.

"Cycle road": Road where traffic is restricted to cyclists. The physical characteristics of a cycle road do not provide access to other vehicles (narrower than 2.5m)

To each of these cycle paths a ranking is assigned. A higher ranking is associated with a better bike facility. The rank order is (lowest first): *"no bicycle facility" < "cycle suggestion lane" < "adjacent cycle lane" < "separate cycle path" < "cycle road"*.

Type	**Recommended width(cm)**	**Minimal width (cm)**	**Elevated**	**Safety zone (cm)**	**Speed limit**
Mixed traffic	Not applicable				≤ 30kph
Adjacent Unidirectional	> 175	150	X	> 25 recommended:50	< 50kph
Separate Unidirectional	> 175	150	/	> 100	> 50kph
Adjacent Bidirectional	Not applicable (= NOT PERMITTED)				
Separate Bidirectional	> 250	200	/	> 100	> 50kph
Cycle suggestion lane	125 - 150	120	/	/	< 50kph
Cycle Road	250 - 350	250	/	/	/

Table 1. Source: Flemish Government

The faster the traffic along a road is, the more dangerous the situation becomes for the cyclists, and the more important the separation between road and cycle path becomes. Therefore it is the road next to the cycle path that determines what type of cycle path should be provided, and consequently, what measurements should be used (*cycle path type = f (road type)*). Table 1 gives an overview of the parameters that are influenced by the adjacent road.

From Table 1 we can identify the key parameters. These parameters are *Width (recommend and minimal), Elevation* and *Safety zone (between cycle path and road).* The additional parameters such as *Highlighting* and *Marking* are not directly linked to a certain type of bicycle facility. Nevertheless they are important next to adjacent cycle paths and cycle suggestion lanes. Another crucial aspect for the safety of the cyclist is the presence of *road guards*. This is particularly true for adjacent cycle paths.

3.2. Internal versus External approach

Once the criteria are identified, a first step is to determine how the existing infrastructure can be evaluated based on these criteria. Therefore it is a necessity to evaluate the actual parameter values of each cycle path. At first the situation (adjacent road) will be considered. This will determine the desired type of cycle path. E.g. along a road with a speed limit of 50 kph a separate cycle path is desired. We call this the *desired type*. Once the desired type is stated, the requirements can be determined by which the actual existing infrastructure must comply, since each type of cycle path is associated with specific requirements.
However, an important aspect of the analyses is how to approach the situation. There are two different ways to determine whether a cycle lane is a bottleneck or not. The distinction is made depending on how the actual parameters and the actual existing type of cycle path (hereinafter called the true type) are compared with the corresponding desired type and accompanying requirements. The two possibilities are the internal and the external approach.

One possibility is the *internal* approach. The cycle path is analyzed in its current state, regardless of the road located next to the cycle path. This means that the bottleneck-score is calculated based on the requirements of the true type instead of the requirements prescribe by the desired type (determined by the corresponding motorway). As such an analysis of the cycle path must determine if the present cycle path meets the requirements in its current state, based on its true type. At this stage, the desired type is not taken into consideration. The comparison of the true type and desired type is processed separately.

A second option is the *external* approach. It examines the road, which determines the desired type of cycle path. Once the desired type (and its accompanying requirements) is determined, the bottleneck-score will be calculated by comparing the existing cycling infrastructure with the desired infrastructure, based on the requirements of the desired type.
By applying the external approach it is noted that, if the desired type is of lower rank than the true type, the calculation of the bottleneck-score will be based on the requirements for the lower type. This is a wrong approach, especially in the situation where no bicycle infrastructure is required (hence no criteria). This result indicates that a cycle path with poor conditions can still be accepted. Another problem arises if the current adjacent cycle path is in perfect condition, but the true type is not the desired type. At this point, the deviation of each parameter value will be large, merely by the fact that the true type did not meet the desired type.

If the internal approach is applied, the possibility arises that the present cycle path receives a bad scores despite the fact that the true type is of a higher rank than the desired type. In itself this is not a problem, since this case can be indicated by the statement "higher type" to point out that the type of the cycle track is of a higher ranking. In this research the internal approach is applied, since this approach proves to have no unsolvable flaws. Consequently each cycle path is first evaluated based on the true type. Next to this, it is determined if the true type is equal to the desired type.

Calculating the bottleneck-score: Multi Criteria Analysis

The criteria are identified, and it is determined how to approach every situation. Now the question remains how the criteria can be linked to a bottleneck-score for each cycle path. As several parameters have an effect on the bottleneck-score, a multi-criteria evaluation is used. For each individual parameter a score is formulated that indicates to what extent the cycle path differs from the desired value at this criterion. Each of these parameter scores will be linked to weight (Voogd 1983). From then on a total score can be calculated.

Parameter score

The score of each parameter, e.g. width, is obtained by comparing the true value with the desired value. To apply an equal minimum and maximum score for each parameter a rescaling is needed. Moreover, the calculated score is inversely proportional. This means that small parameter values (e.g. narrow bike path, low elevation) should receive a higher bottleneck-score than major parameter values. Therefore, bottlenecks will get a high score, and cycle paths that meet the requirements receive a low score. This following formula can be used:

$$x_i = (R_{max} - R_i)/(R_{max} - R_{min}) \times range \qquad \text{with } R = \text{parameter value}$$

For a parameter *i*, a parameter score x_i is calculated, which indicative value of how much a bike path deviates from the desire value on the criterion x. The score is a value between 0 and 1 which can be multiplied by the *range* (in this study the value 100, to obtain scores between 0 and 100).

The values R_{max} and R_{min} are the scale points (Wens 2001). Values between R_{max} Rmax and R_{min} are linearly rescaled and given a score between 0 and 100, depending on the degree of deviation. Values higher than R_{max} get a score equal to 0, and do not constitute a bottleneck (on this criterion). Values less than R_{min} get a score of 100, which is the highest (and worst) score possible.

Assigning weights

All parameters are not necessarily of equal importance in calculating the bottleneck-score. Depending on the cycle path type, certain parameters play a more important role than others. Thus, e.g. the width of an adjacent cycle lane will get a different valuation than the width of a separate cycle path.

Ten sets of weights are formulated, one for each type of cycle path, depending on the roadway next to it. Although the dimensions of the requirements are fixed, the variation in the use of the weights can anticipate the situation. Thus a distinction is made in weights for a separate cycle path along a main road (the highest road category) and weights along a secondary road. The reason is that the width between cycle path and road, and the presence of road guards are much more important along the main road than along a secondary road.

Since the weights should be determined for multiple parameters, the matrix of Saaty (Eastman 2001) is used. In a process for making a decision, the parameters are compared by pairs. Each parameter is compared to each other and their relative importance is listed in the matrix.

Total score

For each individual parameter a score was calculated and an accompanying weight. Each of these scores should be within the interval [0, 100]. This is not necessarily the case. Values higher than the desired value and values lower than the minimum acceptable value will always be outside the interval. Consequently, these extreme values should be truncated. Therefore, negative values are zero, and values higher than one hundred become one hundred. The total bottleneck-score S for each cycle path segment is formulated as follows:

$$S = \sum w_i x_i \times \prod c_j$$

The individual parameter x_i scores are multiplied with the accompanying weight w_i, and summed. These parameters are continuous variables that can be measured. E.g. the broader the cycle path, the safer it will be. The value of c_j is a constraint that can limit the bottleneck-score, as a prerequisite. In this study, the type of cycle path is considered as a constraint. This means that, if the true type is of a lower rank than the desired type, the other parameters will not have any influence on the total score. The bottleneck-score will be 100 anyhow due to a wrong cycle path type.

3.3. Constructing a digital cycle path network

To determine whether the existing cycle infrastructure meets the desired criteria, it is necessary to have a digital map of the cycle path network. At first an inventory of all desired routes is necessary. Along each of these routes, the attributes (based on the criteria) of the cycle infrastructure are identified. It is also important to know to what type of road and speed limit the cycle path is linked.

Due to the funding scheme of these roads, the priority of inventarisation is set along the cycle route network, which are determined at provincial level (DRuM 2005). Nevertheless, the city has also drawn routes independently of the provincial networks, yet partly overlapping. These eight routes at municipal level are of equal importance and will also be included in the inventarisation.

In building the cycle path network a high degree of detail is aimed for, corresponding to the actual infrastructure. This is because the infrastructure can change quickly over a short distance. The existing data do not satisfy the necessary requirements, both in terms of quantity (missing cycle paths and attributes) and quality (level of detail). On the basis of field work, the necessary data will be collected. Once the inventory of the cycle paths has been completed, the digitization will follow.

In each digitization the cycle path/road is split into segments, where the terminus of each segment is accompanied by a change in one of the parameters/criteria. It is opted to use two tracks along each road so that every cycle facility can be unambiguously described by one line object, located at the site of the bicycle facility and, unlike many other road networks, not on the axis of the road.

The digitization is based on the digital provincial network. However, this digital network shows little detail. This information is supplemented by the Road-Information-System, which is a digital file that consists of polygons with an accurate rendering of (a limited number of types of) cycle paths. A final information source is the road network of Ghent, which contains al the roads and speed limits.

3.4. Interpreting the bottleneck score

The bottleneck-score is a number within the interval [0, 100]. The score for each cycle segment will vary within this range. A low score indicates little deviation from the true type versus the desired type. A score 100 indicates a maximum bottleneck-score, and needs maximum attention.

The cycle path type is considered as a constraint. If the true type is of a lower rank than the desired type, the bottleneck-score will always be 100, independent of other parameters. However if the true type is of a higher rank, this constrain does not apply. In that case, the score based on the requirements will vary between [-101, -1]. The negative score indicates that we are dealing with a higher true type. However, this cycle path may deviate strongly from the requirements. Therefore, a good cycle path of a higher type will get a score of -101, and a poorly constructed cycle path of a higher type will have a score equal to -1.

The scoring table takes into account two exceptional cases; the cycle suggestion lane and the bi-directional cycle path. If the true type is a cycle suggestion lane and the desired is an adjacent cycle path, this will be mentioned in the scoring table. Although a cycle suggestion lane is never a desired type, its presence can still give a surplus value to the cycle infrastructure, as a cycle suggestion lane bears resemblance to an adjacent cycle path. In other words: a (good) suggestion cycle lane is better than nothing. However, this is still a deviation of the desired type. Another special case is the bi-directional cycle path. If this cycle path is situated on one side of the road, there is no need a cycle path on the other side of the road. The score table will mention that the cycle path on the other side of the road (bi-directional) should be consulted.

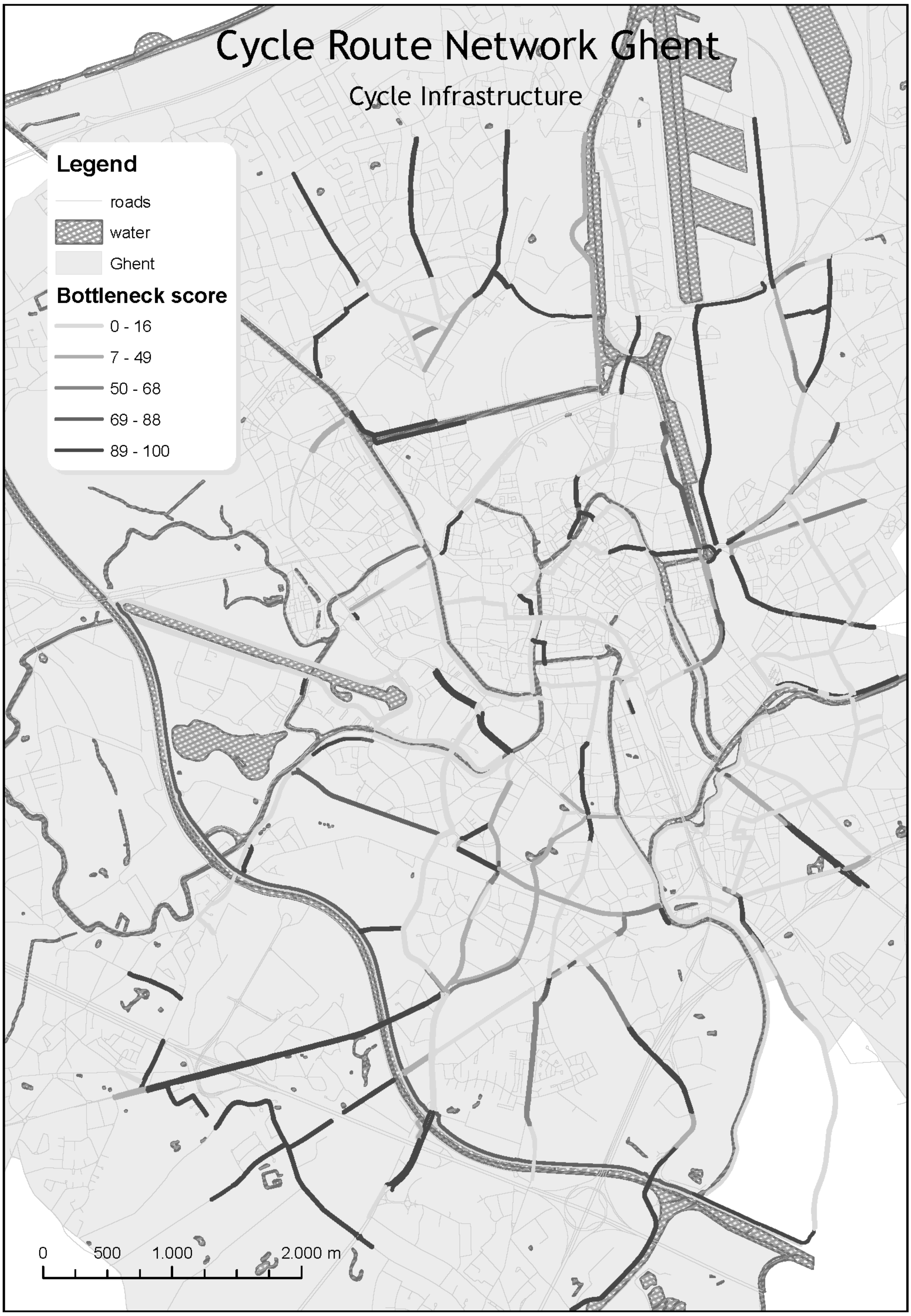

Fig 1: Bottle-neck map

The scores are stored in a database. For a proper interpretation, the scores are displayed visually using a GIS. The bottleneck-scores linked to the road network will result in a bottleneck-map.

4. Results

From the results (fig 1) we can infer that only 27% (265/964) of the investigated roads segments in Ghent fully meets the conditions set by the "Vademecum Cycle facilities". On closer inspection these turn out to be predominantly those roads where cycling infrastructure is not required, i.e. where a permanent 30kph-zone is adopted. Along roads where cycle infrastructure is required, one can make a distinction between cycle paths with low bottleneck-score and cycle paths with a high bottleneck-score.

Nearly half of the cycle paths gets a low score, usually the result of small deviations, like the width of a cycle path that was a few centimeter too small. A high score (45% of the existing cycling infrastructure) is due to either large deviations, or a wrong type of cycle infrastructure, such an adjacent cycle path instead of separate cycle lane. Most bottlenecks with a high score can be found on roads without cycle paths, although an adjacent cycle path should be implemented.

Although cycle suggestion lanes can be a good addition to the infrastructure, they are never really required (in the Vademecum). If in a particular traffic situation an adjacent cycle path is desired, it usually requires little effort to upgrade the cycle suggestion lane to an adjacent cycle path, and thus lower the bottleneck-score. Often, the presence or absence of a traffic sign D7 (compulsory cycle path) can make the difference. The placement of such a sign may well have upgraded the cycle suggestion path to a adjacent cycle path legally, nevertheless this cycle path should also meet the requirements, e.g. an elevation of the cycle path.

Adjacent bi-directional cycle paths without road guards are a serious bottleneck with score equal to 100. Often the solution lies in placing an appropriate road guard or the provision of a one-way cycle path.

In the center of the city, less bottlenecks are found. This is logical because there is usually no need for cycle paths in the 30 kph-zones. However, the speed limit along parking routes is 50 kph. Such speed requires a adjacent cycle path along this roads, making some sections along these routes result in a major bottleneck.

5. Conclusion and discussion

5.1. Results

In this study, a methodology is developed to draw up a bottleneck map that shows where cycling infrastructure is not in conformity with the guidelines from the Vademecum. The analysis of the bottlenecks shows that three out of four of the cycle paths deviate from the desired values. Of these, half showed negligible minor deviations. The other half, however, shows large deviations and should receive the necessary attention to ensure the safety of cyclists.

It should be noted that 233 out of 265 cycle path segments that are not defined as bottleneck, seem to be the result of a 30 kph-zone regulation. According to the Vademecum, areas with a speed limit of 30 kph do not require cycle paths. This raises the question whether these areas are really cycle-friendly, and whether the actual driving speed of traffic is no more than 30 kph. The analysis of cycle paths along parking routes illustrates this problem. Along parking routes with a speed regulation of speed 50 kph, cycle tracks should be provided based on the Vademecum. Often these cycle paths are absent since these routes cross a 30kph-zone. These routes will be described as major bottlenecks, though in practice they will not remarkably differ from other 30-zone roads. It is also noted that classifying an area as 30 kph-zone can be considered as a cheap solution, since it requires no infrastructure. The question is whether this benefits the safety of the cyclists or not.

5.2. Funding and priorities for the reconstruction

However, it should be noted that only the functional cycle route network is covered in the analysis. The reason is that only for those routes a funding is provided. The increasing focus on sustainable mobility policy that takes account of vulnerable road users, has ensured the availability of government funding that allow to build and/or optimize good cycling infrastructure. They can encourage municipalities to pay attention to the growing importance of the cyclist in the street.

However, these funding channels are arranged in a complex manner, as different authorities are responsible for their own roads. It would be better to arrange funding based on the actual condition of the bicycle infrastructure. Moreover, due to the funding, the reconstruction of cycle paths happens primarily along these subsidized routes. This puts other routes, which are often used for short trips, less eligible for improvement.

In the city of Ghent, the funding issue is tackled by means of a funding-map. The map indicates the funding channels that are accountable for a particular location of the road. This funding map will be linked to a priority-map, which indicates where the safety and comfort of the cyclist should be tackled first. By joining these two maps, an overview is given to explore which resources should be exploited for the reconstruction of cycle paths.

The creation of the bottleneck-map in this research was the first step for establishing the priority-map. In a next step, not only the infrastructure bottlenecks will be taken into account. Accident rates, cycling potential and other route networks will also be handled.

5.3. Future use of methodology

The City Gent uses the methodology proposed in this paper to measure bottlenecks in a cycle route network objectively and to create a bottleneck-map of the cycle infrastructure. The aim is to increase the safety for cyclists, and to make optimal use of government funding. The methodology is not exhaustive, and can be extended to other road infrastructure. While the current research was focused on single-line infrastructure, it is possible to carry out similar studies for intersections and roundabouts, to evaluate the complete cycle infrastructure. The methodology can also be used for pedestrian sidewalks, when aiming to maximize safety for pedestrians.

As the methodology is primarily used for the analysis of bicycle infrastructure, the question arises whether the inclusion of the bicycle network in the national road database would be beneficial. Partly for use in traffic safety management, and partly for the navigation of vulnerable road users. A growing number of cities already offers public services like bicycle travel planning (e.g. In Sweden: Stockholm, Göteborg and Malmö) and even navigation services for pedestrians, disabled and elderly users.

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