Level of service in the shared space area for pedestrians and bicycles

Proposal for a concept of aims

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PREFACE

This report is written as the final thesis for the Degree of Bachelor of Science Civil Engineering at TU Delft. The report counts for 10 EC, which is the equivalent of 280 hours of work.

The topic, the level of service in shared space areas, was definitely new to me. The concept of space sharing took my attention, because the degree of responsibility that comes along with this new approach is quite unusual for the current society. On forehand, I had never expected to investigate these areas regarding to a quantity like the level of service. It was the first time this concept crossed my path, although I must have crossed a million of paths that can be specified by the level of service. To define a new methodology for another type of infrastructure has been very difficult, but very interesting as well. It will be even more interesting to see if the methodology will be applicable on other shared space areas.

I would like to use this preface to thank Yufei Yuan and Maria Salomons for their weekly feedback and suggestions. I am also grateful to the other students writing their final thesis for the department of Transport & Planning. Donn, Chris, Bart, Erik, Thijs and Simone, your comments, feedback and questions contributed to the final result of this research. Thank you!

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Summary

This research aims to propose a definition for a combined level of service for pedestrians and bicycles, within shared space areas. This relatively new concept of traffic integration is based on the removal of all traffic signs, demarcations and segregation. In this way, it is thought to increase both safety and quality of the public area. However, a new traffic approach comes with a lot of unknowns, and more research to safety and perceptions of road users in these new areas is required.

One of the unknown aspects of shared spaces is a definition for the level of service. Level of service (LOS) is a quality measure describing operational conditions within a traffic stream, and is often associated with comfort and convenience. Standards and methodologies for LOS in the common segregated traffic designs exist, but these are not applicable in an integrated design. A valid methodology for shared spaces should include multimodality and the absence of boundaries in directions. Besides, due to a lack of guidelines for shared space design, different shared space areas differ in their characteristics. Therefore, the goal of this research is to come up with a standard definition for the level of service in shared space area for pedestrians and bicycles. Only aspects that are observable during video-analysis are taken into account; the subjective aspects of the LOS were not taken into account. Motorized traffic is left out of the research as well.

The definition was based on standards and methodologies that are currently used for the LOS in other traffic situations. Via literature study, the applicable approaches and criteria could be determined and adapted on a shared space area facilitating both bicycles and pedestrians. One of the main adjustments was inventing an expression for traffic density in mixed traffic. To be able to express bicycles and pedestrians in the same unit, a Pedestrian Equivalent (PE) was invented, expressing bicycles in an equivalent number of pedestrians. The used unit was PE/m^2. As previous methodologies were mostly based on criteria applicable on single mode, two-directional traffic, these criteria had to be adjusted as well. New criteria were defined in a concept of aims, relating specific events like changes in speed and direction to aims like crossing, turning, arriving or waiting. Pedestrians and bicycles both share these same aims, enabling a joint analysis for these two modes. To cope with the differences in characteristics between shared spaces, the last adjustment was to express these new aims and events in a relative way. This is done by usage of indices, relating an absolute number to a corresponding other absolute number. These indices provide a possibility to make this method generally applicable. For every index, a scale was invented. These scale related found indices to levels of comfort. The indices and scale were place together in a framework, ready for quantification. In total, eight different indices were investigated, related to the aims, events and unaffected users.

By quantification via video-analysis, relations between traffic densities and the different indices were found. The used data came from a shared space area at Amsterdam Central Station. The analysis was performed manually, this includes observing, tracking and counting of traffic densities, events and aims. The resulting numbers could be adapted to indices. As the indices were already related to a scale, the traffic densities could be connected to this scale, defining different levels of service. In the end, six different levels (A t/m F) could be defined, for densities varying between 0 and 0,35 PE/m^2. These are presented as standard for level of service for pedestrians and bicycles in the shared space area.

The research has some limitations. Only observable aspects during video-analysis are taken into account. Further research could investigate the subjective side of the level of service, including user perception of comfort and safety. Also research to shared space areas facilitating motorized traffic should be performed, as this research does not include this. The methodology and standard for the level of service are only tested and supported by one small dataset of one particular shared space area. The aim was to make the used concept generally applicable, however this cannot be guaranteed.

CONTENTS

List of figures & tables

1 INTRODUCTION

In traditional distribution of traffic, all different kinds of traffic are separated. Car lanes, bicycle lanes and sidewalks are a common way to regulate streets in urban zones, used to guarantee two main objectives of the design: efficiency and safety for all road users (Beitel, et al., 2016). Although this distribution of traffic has been known for years, urban planners are looking for different approaches nowadays, because integrating a social function to urban transportation is seen as an important pillar to contribute to the quality of life (Pascucci, et al., 2015). In this new interpretation, streets do not only serve as a means of transport of automobiles, but as a part of the social life. Creating a favourable environment for pedestrians and cyclists is essential to increase the quality of these public spaces. To realise these desires, the focus moved from traffic segregation towards traffic integration. An example of this new approach in traffic design is the implementation of shared space areas.

The concept of space sharing is based on the removal of the separation between motorized and non-motorized traffic. Signs, signals and road demarcations are not present in this design, which leads to a regulation of the traffic flow by social interaction. This change in design results in infrastructures with characteristics completely different from those of the traditional designs. Because the characteristics of a certain traffic approach are used to determine guidelines for important aspects like the design and safety requirements, information about this new concept of space sharing is needed to secure safety for users of shared space areas and prevent unnecessary implementation cost for the designers. One of the new unknowns is the level of service (LOS), a quantity that describes the comfort and efficiency of a certain infrastructure.

Standards for LOS were defined for single mode traffic. The Highway Capacity Manual 2000 presents definitions for car traffic, pedestrians and bicycles. Fruin (1971) and Weidmann (1993) both formulated a definition for the LOS for pedestrians on walkways and stairs as well. However, all of these definitions are only applicable in situations with only one specific traffic mode. For multimodal traffic, some methodologies to develop a multimodal level of service exist, but they relate to segregated traffic design. As the concept of space sharing is based on both integrated multimodality and absence of boundaries in direction, these methodologies are not applicable on shared space areas. For this reason, a clear definition for the level of service for shared space areas still lacks. This research aims to propose a definition for a combined level of service for pedestrians and bicycles, within in shared space areas.

By adjusting the known concepts of LOS, a model for the LOS for pedestrians and bicycles in shared space areas is proposed. This proposal is supported by video-data, retrieved from a shared space area at Amsterdam Central Station. To come up with a definition, the following research question was formulated:

"How can the level of service for pedestrians and bicycles in shared space areas be defined?"

The main objective is logically : "Formulate a clear general definition of the level of service for pedestrians and cyclists in shared space areas." To reach this objective, six sub questions have been invented, all relating to specific parts of the research. These questions and the approach to solve them are stated below.

- *What are the main differences between traditional distribution of traffic and shared space areas?*

These two questions are answered via literature study. The answer to this question shows the aspects that current concepts miss, and that should be adjusted for a definition of the level of service in shared space areas.

- *How is LOS expressed objectively, and what kind of methodologies and standards exist?*
- *Which information regarding LOS out of current standards and methodologies is applicable on shared space areas and why?*

These two questions are answered via literature study as well. The objective is to obtain a clear view on the meaning of the level-of-service concept, and on the methodologies and standards that currently exist. With a complete description, the useful information can be filtered from current standards and methodologies, and be adjusted regarding to the missing aspects identified earlier.

- *How can the identified missing aspects and applicable information be combined to a general methodology for level of service in shared space areas?*

The objective of this sub question is to combine the information retrieved via literature study and use this combination to elaborate a methodology for LOS that is generally applicable on shared space areas.

- *How can the defined methodology be quantified?*

This question aims at a solution. To answer this question, a video-analysis is executed on data retrieved from a shared space area at Amsterdam Central Station. This video-analysis will provide the supporting data to determine the unknown parameters for a shared space area for pedestrians and bicycles. The output will be used to fill in the format found during the formulation of a level-of-service concept.

In this research only objective factors are taken into account. This means that the subjective factors like perception of safety are excluded of the research. Furthermore, the research focusses on pedestrians and bicycles. Cars, mopeds and public transport are not taken into account.

Chapter 2 (Literature review) explains the concepts of shared space areas and level of service. It also resumes the literature about level of service for single mode traffic regarding pedestrians and bicycles and the available methodologies for level of service for multimodal traffic. In chapter 3 (Definition of a method to determine LOS in shared space areas), the information retrieved in chapter 2 is combined and elaborated into a methodology that is generally applicable for shared space areas. This includes criteria, scales and a format for the final result. The method used to come up with a standard based on video-analysis is provided as well. In chapter 4 (Interpretation and elaboration results video-analysis) the results of the video-analysis are analyzed. Based on this elaboration, the quantification of a standard for the level of service in shared space areas for pedestrians and bicycles is presented in chapter 5 (Quantification of final standard). In chapter 6 (Conclusions) conclusions regarding the final standards and methodology are drawn. Chapter 7 (Discussion) will argue the results and state inaccuracies.

2 LITERATURE REVIEW

2.1 EXPLANATION OF THE CONCEPTS

In this subchapter, the concepts *shared space areas* and *level of service* are clarified and a defined.

2.1.1 Shared space area

As explained in the introduction, the shared space area is a new approach within traffic design. As it focusses on integration of traffic, all segregation is removed. Traffic measures like signs, traffic lights, kerbs and road humps are removed, or sometimes replaced by infrastructures like coloured floors or changes in surface. Hamilton-Bailie names these kind of measures 'simple design' or 'landscaping measures' (Hamilton-Bailie, 2008). Due to the absence of clear measures, shared space users have to rely on social interaction and awareness. Pascussi et al. (2015) states that in an integrational approach like shared space areas, all traffic modes need to pay attention to the other road users as they share the same part of the road. This increase in awareness is thought to lead to an increased safety (Hamilton-Bailie, 2008) (Anvari, et al., 2016). Important detail is that there are no real guidelines on shared space areas, resulting in many differences regarding area, usage and facilities.

The idea of shared space areas was founded by Hans Monderman, a Dutch traffic engineer. Mondermans original goal was to lower vehicle speed by removing the clear measures. In this way he tried to reduce the dominance of motorised traffic and increase the safety for pedestrians (Hamilton-Bailie, 2008). Currently, integrational approaches like space sharing are chosen over traditional segregated design not only because of safety reasons, but also because of their contribution to the quality of the public area and the social life. The latter holds because space sharing is focussing more on the non-motorized traffic modes. (Hamilton-Bailie, 2008)

The British Department for Transport brought all the aspects above together in a definition. According to them, a shared space area can be defined as:

"A street or place designed to improve pedestrian movement and comfort by reducing dominance of motor vehicles and enabling users to share the space rather than follow the clearly defined rules applied by more conventional designs" (British Department for Transport, 2011).

Based on the concept of shared space areas, two main differences between space sharing and traffic segregation can be identified. These are multimodality and absence of boundaries in both speed and directions.

2.1.2 Level of service

The Highway Capacity Manual (HCM) was the first to introduce the level-of-service-concept in its 1965 edition. Back then it only applied to highways. In the following decades, LOS was specified for other traffic modes, following the same concept as was primarily used for cars. In HCM 2000 the *level of service (*LOS*)* is defined as:

"A quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to manoeuvre, traffic interruptions, and comfort and convenience" (Transportation Research Board, 2000).

In other words, the LOS is used to describe comfort and efficiency of an infrastructural facility in a qualitative way. It has become the standard for determining the adequacy of an infrastructure (Transportation Research Board, 2000). The widely used method to express the LOS is a letter scale, in which each letter represents a comfort level for the user. Standards for the LOS exist for all single traffic modes, and nowadays models for multimodal traffic exist as well. Relevant standards are presented in the next subchapter.

2.2 CURRENT STANDARDS FOR LEVEL OF SERVICE

This subchapter presents some of the existing standards on pedestrian level of service (PLOS), bicycle level of service (BLOS) and multimodal level of service. The methodologies to derive these standards contain some aspects that can be used for the definition for level of service for shared spaces that is searched for. Basic criteria, presentation and shortcomings of the existing standards for each level of service are mentioned.

2.2.1 Level of service for pedestrians

Different experts have defined standards for the pedestrian level of service (PLOS). In this paragraph, three standards are presented, all based on pedestrian density (p/m^2). The scale could also be based on pedestrian flow (p/m/min). John J. Fruin defined his standards in 1971, because he thought pedestrian comfort should be taken into account as well during design (Fruin, 1971). He provided standards for walkways, waiting areas and stairs. Fruin introduced a letter scale for pedestrians, ranging from A to F. These letters represent a comfort level, depending on the pedestrian density. The HCM 2000 presented PLOS based on Fruin's definition, but with different standards. The definition used in the HCM is the standard for design of pedestrian facilities in the USA. (Transportation Research Board, 2000) See appendix A for these standards and the indicators.

In Germany, another traffic expert formulated standards for PLOS. Weidmann (1993) describes eight criteria that should be analysed to come up with a definition for PLOS. These criteria are:

- Free choice of speed
- Frequency of forced changes in speed
- Level of awareness / Need to respect other pedestrians
- Frequency of forced changes in direction
- Crossing conflicts
- Meeting conflicts, due to opposite directions
- Passing conflicts
- Frequency of unintentional physical contact

Weidmann (1993) states that by usage of these eight criteria it is possible to determine the operational quality of a pedestrian facility. By distinguishing different scores within these criteria related to certain pedestrian densities, several quality levels can be defined; this is Weidmann's interpretation of the pedestrian level of service. See appendix B for the tables and indicators. (Weidmann, 1993)

The different standards invented by the different experts are shown in Table 1. Remarkable is that Weidmann defined a larger scale than Fruin and the HCM 2000 did.

Table 1. Pedestrian densities corresponding to each level of service for walkways, defined by different authors [p/m2] (Transportation Research Board, 2000) (Fruin, 1971) (Weidmann, 1993)

LOS	Fruin [1971]	Weidmann [1993]	Highway Capacity Manual [2000]
A	<0.31	<0.10	<0.18
B	0.31 – 0.43	0.10 – 0.30	0.18 – 0.27
C	0.43 – 0.72	0.30 – 0.45	0.27 – 0.45
D	0.72 – 1.08	0.45 – 0.60	0.45 – 0.71
E	1.08 – 2.15	0.60 – 0.75	0.71 – 1.33
F	>2.15	0.75 – 1.00	>1.33
G	..	1.00 – 1.50	..
H	..	1.50 – 2.00	..
I	..	2.00 – 5.00	..

Problem with these standards is, that they are only applicable on single mode pedestrian walkways. In shared space areas however, pedestrians share the available space with other vehicles, in this case bicycles. This leads to two main problems. Firstly, density of heterogeneous traffic is difficult to determine, due to differences in speed and dimensions (Thamizh Arasan & Dhivya, 2008) Secondly, the criteria Weidmann defined, originally do not take into account traffic modes other than pedestrian. The third criterion, “Level of awareness / Need to respect other pedestrians”, illustrates this in a clear way, as the word pedestrians is in the criterion itself. These criteria need to be adjusted to make them applicable on a shared space area. Furthermore, walkways facilitate mostly two-directional pedestrian traffic, while in shared space users are not bounded to a direction. Therefore, meeting and passing conflicts are hard to determine, as these events are specifically related to situations with two opposite directions. This should be included in the adjustments of the criteria.

2.2.2 Level of service for bicycles

HCM 2000 presents standards for BLOS for different bicycle facilities. First, these facilities are classified as being interrupted or uninterrupted. HCM 2000 defines an interrupted bicycle facility as: “on-street bicycle lanes that pass through signalized and unsignalized intersections”, and uninterrupted bicycle facilities as: “Bicycle paths that are physically separated from vehicular roadways and do not have points of fixed interruption (except at terminal points) within the paths. “ (Transportation Research Board, 2000).

- Uninterrupted bicycle facilities are:
- Exclusive off-street bicycle paths, accommodating only bicycles.;
- Shared off-street bicycle paths, allowing other non-motorized traffic like pedestrians and skaters to use the area;
- On-street bicycle lanes, in segregated form marked on the street;

Interrupted bicycle facilities are:

- Signalized and unsignalized intersections, using traffic lights or stop signs to regulate the traffic stream;
- Urban streets, focusing on the total of interrupted and uninterrupted bicycle flow segments.

Interrupted bicycle facilities are not comparable to shared space areas, as these are regulated by traffic lights or signs. It is hard to adapt these standards to a situation lacking these kind of measures. Since exclusive off-street bicycle paths are uninterrupted and facilitate just one single mode of traffic, the capacity and related level of service are the highest of these five standards for BLOS presented in HCM 2000. However, this research aims at a level of service in a shared space environment, so the most relevant standard is the standard for shared off-street bicycle paths. Compared to single mode bicycle paths, capacity is limited in a shared facility, due to the differences in speed between different modes. These differences in speed affect the LOS for bicycles in shared facilities as well. (Transportation Research Board, 2000)

Defining the BLOS is difficult, as density of bicycles is hard to determine, especially in a shared environment. For this reason, HCM 2000 uses the concept of hindrance to determine BLOS. This concept is based on the amount of passing and meeting events cyclists experience, and is therefore more related to the comfort for bicyclists rather than to the capacity of a bicycle path. Hindrance was originally defined by the HCM as “the fraction of users over 1.0 km of a path experiencing hindrance from passing and meeting manoeuvres” (Transportation Research Board, 2000).

In general, for uninterrupted bicycle facilities, the standard shown in table 2 is applicable. Here, the concept of hindrance is used to express the level of service. Note that at LOS E, 100 % is already reached. The difference between LOS E and LOS F is the amount of events that a single user experiences, as this still increases. This shows the difficulty of this model, as it does not show the numerical values for certain calculations. For shared off-street paths, a more specific model was established. Some predictive formulas have been invented, taking into account both pedestrian and bicycle flow rates in two directions. These equations provide the standards shown in Table

3. The standards are based on a directional split of 50:50 for pedestrians. As can be seen, this model uses events per hour to express the BLOS. In that way it differs from the general standards for bicycle facilities.

Table 2. BLOS criteria for uninterrupted bicycle facilities (Transportation Research Board, 2000)

LOS	Hindrance (%)
A	≤ 10
B	> 10 – 20
C	> 20 – 40
D	> 40 – 70
E	> 70 – 100
F	100

Table 3. BLOS criteria for shared off-street paths (Transportation Research Board, 2000)

LOS	Frequency of Events, 2-way, 2-lane paths (events/h)	Frequency of Events, 2-way, 3-lane paths (events/h)
A	≤ 40	≤ 90
B	> 40 – 60	> 90 – 140
C	> 60 – 100	> 140 – 210
D	> 100 – 150	> 210 – 300
E	> 150 – 195	> 300 – 375
F	> 195	> 375

Shortcoming of the current standards for bicycle level of service for this research is that there is no definition facilitating more than two directions, while the shared space area does not restrict its users to only two directions. Meeting and passing conflicts are typical for two-directional traffic facilities. Besides, the directional split of pedestrians in a shared space area will not be equal to 50:50. This should be adjusted for a solid definition. Nevertheless, the concept of hindrance and its indicator, namely the events, might be applicable on shared space areas. The interactions between pedestrians and cyclists also occur in shared space areas, so counting the events can provide a basis for a level-of-service-definition. In that case, the number of events experienced by pedestrians should be evaluated as well, as this is not been done at the moment.

2.2.3 Multimodal level of service

The standards presented in the previous subchapters are limited in usage, as they only define single mode traffic. In these standards, interaction between two different modes is not taken into account. The definition for shared off-street paths already introduces this interaction by including pedestrian influences on BLOS. Researches about defining multimodal level of service have been executed, and some theories already exist.

HCM 2010 adopted report 616 of the National Cooperative Highway Research Program (NCHRP), introducing an analysis on multimodal level of service for urban streets. (Ryus, et al., 2011) This report focusses on the development of a framework to determine levels of service for different traffic modes within urban streets, specifically by taking into account the interaction between different modes. In the end, an integrated multimodal framework for level of service is elaborated, combining definitions found for all different modes. Focusing on the pedestrian – cyclist relation, the only interaction between these two modes that is taken into account are bicycle – pedestrian conflicts, but only if they share the same facility. Other criteria are all related to larger vehicles, or are based on single mode level of service definitions. (Dowling, et al., 2008)

Two of the experts working on NCHRP 616 contributed to another paper defining a multimodal level of service methodology. Commissioned by the Florida Department of Transportation (Florida DOT), this research focusses on developing an bicycle LOS methodology for intersections, including different traffic modes. One of the outcomes of the research is that (amongst others) roadway traffic volume influences the Intersection LOS for bicycles. (Landis, et al., 2003)

As the concept of space sharing differs from an urban street or an intersection, these researches do not provide a definition for multimodal level of service that would be applicable on shared spaces areas. Pascucci (2015) even states that level of service is currently not taken into account in particular shared space design. However, some basic principles named in this subchapter can be adapted in describing shared space areas as well. The interaction between pedestrians and cyclists, expressed in conflicts, is applicable in a shared environment, as these events will take place over there as well. The influence of the total roadway traffic volume on the Intersection LOS for bicycles raises the idea that the total volume of road users in a shared space area influences the LOS for bicycles as well. However, expressing a multimodal traffic volume raises a new challenge.

In a multimodal traffic flow, different types of vehicles occur. As these different modes have different characteristics, it is hard to determine for example traffic flow or density. These quantities are important for defining the level of service of an infrastructure. Therefore it is necessary to convert heterogeneous traffic into a representative homogenous traffic stream. For this purpose the passenger car equivalent (PCE) was introduced (Saha, et al., 2009). Passenger car equivalents are used to express the impact of a particular mode of traffic on traffic variables in single standard passenger cars (Shalini & Kumar, 2014).

The HCM 1965 was the first to introduce the term to describe the effect of trucks and buses in a traffic stream. Since then, multiple formulas for PCE have been invented to describe different traffic situations on different roadway types. Methods for determining the PCE are based on different factors, for example flow rates and density, speed, or headways (Shalini & Kumar, 2014).

In HCM 2000, the Passenger Car Equivalent is defined as:

"*The number of passenger cars displaced by a single heavy vehicle of a particular type under specified roadway, traffic and control conditions.*" (Transportation Research Board, 2000)

As this definition suggests, PCE is mostly used to transform mixed motorized traffic streams into single passenger cars. For this research, there is no relevance for expressing pedestrians or bicycles in passenger cars, as cars are neglected. However, the PCE-concept can be adapted to the relevant situation. In this way it is possible to come up with a Pedestrian Equivalent (PE), enabling specification of a homogenous traffic situation in shared space. It is important that the used equation therefore simply compares two different modes, rather than using constants for passenger cars in the equation. A suitable formula is used by Van Lint, Hoogendoorn & Schreuder (2008):

$$STE_{n,m} = \frac{L_m + v_m * \Delta t_m}{L_n + v_n * \Delta t_n}$$

In which:

- STE = specific traffic equivalent for mode *m* related to mode *n* (-)
- L_m = length mode *m* (m)
- V_m = velocity of traffic mode *m* (m/s)
- Δt_m = reaction time mode *m* (s)
- L_n = length mode *n* (m)
- V_n = velocity of traffic mode *n* (m/s)
- Δt_n = reaction time mode *n* (s)

This formula could be applied on pedestrians and bicycles, by filling in the right parameters. These parameters can be determined either dynamically, or on average values. The accuracy of the equivalent depends on the choice for approach. In this research, this equation can be used to express the total traffic density of the shared space area. In this equation, both length (physical characteristic) as well as reaction time (behavioural characteristic) are included. The equation is further elaborated in chapter 3 (Methodology for video-analysis and elaboration).

2.2.4 Summary

To give an overview of the information provided in subchapter 2.2, a summary is provided in Table 4.

Table 4. Overview of usable aspects and shortcomings of current definitions for level of service

	Pedestrian LOS	Bicycle LOS	Multimodal LOS
Usable aspects	• LOS based on traffic density • 8 clear criteria, that can be used as a basis for new, specific ones applicable on shared space areas	• Taking into account interactions between bicycles and pedestrians by the concept of hindrance	• Use of total traffic volume • Use of an equivalent for heterogeneous traffic • Conflict-approach to express the bicycle-pedestrian interactions
Shortcomings	• Density for mixed traffic not known • Criteria cannot be applied on mixed traffic • Mainly two-directional	• Two-directional, so boundaries exist • Assumption of a pedestrian directional split of 50:50 • Pedestrian experience is not included	• Mainly separated traffic, so boundaries exist • Focus lays on motorized vehicles

The main conclusion of the literature study is that both parameters and criteria need to be adjusted to be applicable on shared space areas. Adjustments should satisfy heterogeneous traffic and absence of boundaries in direction, and should be focussed on pedestrians and bicycles.

3 DEFINITION OF A METHOD TO DETERMINE LOS IN SHARED SPACE AREAS

In chapter 2 (Literature review), some methodologies and criteria for defining the level of service are presented. Based on that study, the approach and the format for the final result of this research will be chosen, containing usable aspects of the existing methodologies and criteria. These usable aspects are adjusted to satisfy the requirements for shared space areas.

In steps, the approach comes down to:

1. Make adjustments, applicable to shared space areas, to the parameters to which the LOS will be related.
2. Make adjustments, applicable to shared space areas, to the concept of hindrance.
3. Make adjustments, applicable to shared space areas, to Weidmann's criteria.
4. Combine the information obtained during steps 1,2 and 3 to formulate a usable methodology applicable on shared space areas.
5. Define the relations between parameters and criteria for the final level of service.
6. Define a format of criteria for a standard LOS for pedestrians and bicycles in shared space areas.
7. Quantify the relations formulated in step 5 by usage of video-analysis.
8. Formulate a quantified standard for LOS for pedestrians and bicycles in shared space areas.

The steps will be explained further in this chapter.

3.1 ADJUSTMENT AND COMBINATION OF EXISTING METHODOLOGIES

As can be read in subchapter 2.2.4, existing parameters and criteria need adjustments to be generally applicable on shared space areas. Therefore, the useful aspects of each standard will be adjusted so they include:

- Multimodality
- Absence of boundaries in direction
- Focus on pedestrians and bicycles
- Relative indicators, because of the diversity among shared space areas.

Similarities in the useful aspects of existing standards are investigated as well. Where possible, the aspects will be combined and elaborated. The focus lays on the video-analysis that is executed. Therefore, some aspects that cannot be observed will be excluded. As mentioned before, the subjective side of the LOS is left out entirely. This does not mean that the methodology is not applicable on other shared space areas. The method described in this subchapter is written down in a generic way, and can easily be applied to other shared spaces, facilitating other traffic modes.

3.1.1 Adjustments to traffic density and traffic flow

To come up with representative values for the traffic density in this heterogeneous situation, a Pedestrian Equivalent, to compare bicycles to pedestrians is determined according to the equation described in chapter 2 (Literature review). This equation takes into account differences in both speed and dimensions. For this purpose the lengths, velocities and reaction times of both pedestrians and cyclists should be determined.

Length is determined based on known averages. With *length* the relevant size in the direction of movement is meant. For a pedestrian, this comes down to body depth. The HCM 2000 uses Fruin's definition for the *pedestrian body ellipse* (Transportation Research Board, 2000). For a cyclist, it is the length of the bike. For the velocities, the mean values for shared off-street paths are used as described in the HCM. These values for velocity are chosen as these are determined in an environment facilitating both pedestrians and cyclists. The value for the reaction time of cyclists comes from a study to hazard perception among cyclists, and is determined empirically. The value for reaction time of pedestrians was found in a study to the reaction of pedestrians to warning sounds of electric vehicles.

The formula for this research is adapted to:

$$PBE = \frac{L_b + v_b * \Delta t_b}{L_p + v_p * \Delta t_p}$$

In which:

- PE = Pedestrian Equivalent (-)
- L_n = length bicycle (m)
- V_n = average velocity bicycle (m/s)
- Δt_n = reaction time cyclist (s)
- L_p = body depth pedestrian (m)
- V_p = average velocity pedestrian (m/s)
- Δt_p = reaction time pedestrian (s)

Table 5. Parameters for PE

Mode	Average length (L)	Velocity (s)	Reaction time (Δt)
Pedestrians (index n)	0.5 m (body depth) (Transportation Research Board, 2000)	4.5 km/h (Transportation Research Board, 2000)	1.72 s (Poveda-Martinez, et al., 2017)
Bicycles (index m)	1.68 m (Minnesota Office of Transit, Bicycle and Pedestrian Section, 2007)	18 km/h (Transportation Research Board, 2000)	1.93 s (Zeuwts, et al., 2017)

Filling in the parameters provided in Table 5 results in a PE of 4.42 . This factor is used as a multiplier in densities. Bicycles taken into account are multiplied with the PE. Pedestrians will be multiplied with a PE is equal to 1.0 . This results in a number of pedestrians, a number of bicycles and a number of equivalent pedestrians taking into account the present bicycles.

A problem that comes along with relating the LOS to traffic density, is that this density changes over time. A way to take into account the change in users over time, is an expression in traffic flow. Flow normally is described per unit of width (P/m/min). Because a shared space area does not have a specific direction, flow through a specific width will be hard to determine. A way to come up with a quantity including change over time is to use the *area usage* in the time. This is expressed in the amount of users per square meter per minute (U/m^2/min). In this case, the amount of users will be expressed in PE.

3.1.2 Adjustments to the concept of hindrance

To make the concept of hindrance applicable on shared space areas, freedom in boundaries and heterogeneous traffic should be included. Furthermore, the experience of pedestrians should be included as well.

The concept of hindrance is based on the amount of hindrance a user experiences. The only adjustment that has to be made to this definition is the meaning of the word *users.* In this research, a user can be either a pedestrian or a cyclist. Furthermore, the conflict types that are taken into account by the original concept of hindrance are meeting and passing conflicts. These type of conflicts are specifically applicable on two-directional traffic facilities. In a shared environment, it is hard to define meeting and passing because directions are not restricted. Therefore, the conflict types should be adjusted, according to a shared environment. In a shared space area, users can either cross, take a turn left or right or go to a place located at the shared space area. Besides, one of the purposes of shared space is to stimulate social interaction. This might result in users that use the area for a different purpose than transportation. Therefore, the types of conflicts taken into account are adjusted to:

- Crossing conflict: a conflict, that leads to an event, when the analysed user is aiming to *cross* the shared space area, e.g. aims for the opposite side of the shared space area.
- Turning conflict: a conflict, that leads to an event, when the analysed user is aiming to take a *turn* either right or left .
- Arriving conflict: a conflict, that leads to an event, when the analysed user is aiming to *arrive* at his destination in the shared space area.
- Waiting conflict: a conflict, that leads to an event, when the analysed user is affected by another user that has no intention to move, e.g. during conversation or waiting. This is the only conflict related to the action of the other user instead of the analysed user.

Note that the definition of the *waiting conflict* does not exclude the other two conflicts; it is an extra type, included because the shared space area has a purpose for social interaction as well. Furthermore, note that arriving conflicts are only applicable if the analysed shared space area accommodates destinations, for example shops or houses.

The defined types of conflicts do not rely on the direction of the involved other user anymore, but only on the direction of the analysed user. The only case in which the action of the other user is important is in a waiting conflict, however the other user does not have a direction at that moment; as described above, he has no intention to move. These conflicts can apply to pedestrians as well, as they aim to cross, turn, arrive or wait as well, just like cyclists.

Another interpretation of the concept of hindrance depends on the fraction of users experiencing a conflict. At higher levels of service (e.g. level E or F), almost all users are affected by a conflict. At lower levels, more users complete their route without getting into a conflict. This indicates that the amount of unaffected users can be seen as an indicator for level of service as well.

3.1.3 Adjustments to Weidmann's criteria

Main shortcoming of Weidmann's (1993) eight criteria is the homogenous character, only taking into account pedestrians. Adjustments should include heterogeneous traffic and absence of boundaries in direction.

Firstly, the criteria are evaluated for subjectivity. The criterion "level of awareness / need to respect other pedestrians" implicates a subjective aspect, as this is user specific. Therefore this criterion will not be further investigated.

The criteria involving change in speed or direction ("frequency of forced changes in speed" and "frequency of forced changes in direction") are directly applicable on heterogeneous traffic. Cyclists also change their speed or direction. These criteria do not need any adjustment, but should only be applied on a shared environment facilitating both pedestrians and cyclists.

The three criteria involving crossing, passing and meeting conflicts can be adjusted in the same way as the concept of hindrance. That means, the adjusted conflicts will be crossing, turning, arriving and waiting conflicts. In this way, the criteria only depend on the direction of the analysed user, instead of including the direction of the other user involved in the conflict. Nevertheless, the criteria do provide an indication of the conditions for respectively crossing, turning, arriving or waiting.

Unintentional physical contact is specifically applicable on pedestrians. Unintentional physical contact with a bike namely results in a collision. This situation is highly undesirable, but should be taken into account in a shared environment. Collisions that are applicable in this situation are collisions between two bicycles, between a bicycle and a pedestrian or between two pedestrians. The latter relates to the criterion as defined by Weidmann, 'frequency of unintentional contact'. Collisions will be rare, because this event is highly undesirable for every user. Everybody therefore will take action to prevent a collision.

Evaluating observability of the criteria, free choice in speed and frequency of unintentional contact are both excluded from the research. Free choice of speed is hard to measure during a video-analysis, and the frequency of unintentional contact is difficult to observe.

There is another criterion that is not introduced by Weidmann (1993), but that provides information for the operational conditions of a shared space area for bicycles and pedestrians. This is related to the amount of cyclists that needs to walk their bike in the shared space area, as this can indicate a decrease in comfort. This criterion will be added to the remaining list of criteria based on Weidmann's (1993) pedestrian criteria.

The remaining criteria is a list of eight as well:

- Frequency of forced changes in speed
- Frequency of forced changes in direction
- Number of collisions
- Crossing conflicts
- Turning conflicts
- Arriving conflicts
- Waiting conflicts
- Number of cyclist walking their bike

The only remaining factor of difficulty is the word *forced* in the first two criteria. It implies that there is a difference between a regular change and a change that is unintentional and due to an external factor. This factor will be another user. By just simply leaving out the word *forced,* this difference is neglected. This is undesirable, as the reliability of the model will decrease. The solution for this problem lays in the combination of the adjusted concept of hindrance with the adjusted criteria.

3.1.4 Combination of adjusted aspects

The possibility for combining the aspects above lays in the differences in concepts. Weidmann (1993) defined his 8 criteria to relate them to differences in traffic density. These criteria serve as a kind of indicator for all different level of service. The concept of hindrance uses the number of conflicts, expressed in events, as a direct link to a level of service. However, an indication of an event is needed as well. This opens up room to put together the criteria and the concept of hindrance.

Different events that might occur in a shared space area facilitating pedestrians and bicycles are:

- A cyclist brakes to avoid conflict
- A cyclist stops to avoid conflict
- A cyclist changes direction to avoid conflict
- A pedestrian reduces its speed to avoid conflict
- A pedestrian stops to avoid conflict
- A pedestrian changes direction to avoid conflict
- A crash between a pedestrian and cyclist
- A crash between two cyclists
- Unintentional physical contact between two pedestrians, as pedestrians will not 'crash'

Some similarities between these events and the first three criteria described in the previous subchapter can be noticed, as these events all come down to either changing speed, changing direction or colliding. Based on these similarities, it can be concluded that these criteria (a change in speed, a change in direction or a collision) are an indicator for conflicts. At the same time, relating a change in speed or direction to a type of conflict can provide a definition for the word *forced* in the criteria mentioned earlier. When a change in speed or direction is related to a conflict (crossing/turning/arriving/waiting), this can be seen as a forced change. When this is not the case, the change can be interpreted as a *general* change. This applies to collisions as well. The users walking their bike into the shared space area also have the goal to either cross, turn, wait or arrive, so this criterion can be related to the four types as well. Every other reason can again be interpreted as being *general*.

Another observation is the differences in changes in speed mentioned in the possible events. Two possibilities are distinguished: a speed reduction and a full stop. This scaling holds more information than a regular number of changes in speed. It therefore is implemented in the change in direction as well. A possibility to distinguish two situations can be found in the angle of change. It is chosen to distinguish small and large changes in direction. A small change holds a change between 0 and 45 degrees. A large change in direction holds a change larger than 45 degrees. These *heavy measures* (full stop, larger than 45 degrees) create a possibility for an extra indicator, namely the frequency of heavy measures. This is a specific indicator within the frequency of indicators. As mentioned before, collisions are always highly undesirable. Therefore, no separation is made within collisions.

In subchapter 3.1.2, the importance of the amount of users that does not experience an event is stated. This of course cannot be seen as an indicator for an event, but provides extra information on the relative amount of events. Users not experiencing an event can also be related to either crossing, turning, waiting or arriving.

To conclude, the combination relies on interpreting crossing, turning, waiting and arriving as an aim, instead of only interpreting them as types of conflicts. When one of the remaining identified events can be related to one of these aims, it can be interpreted as a conflict. The unaffected users can also be related to one of these aims, providing a possibility to compare two situations both quantitatively and relatively. As a result, the level of service can be expressed by usage of three different aspects:

- Change in ease to complete a particular **aim**
    - Crossing
    - Turning
    - Waiting
    - Arriving
- Frequency of **events**
    - Changes in speed or direction
    - Heavy measures
    - Collisions
    - Users walking their bike
- Relative amount of unaffected users

In Table 6, the relations that are described above are presented in an evaluation scheme. This table provides a possibility for quantification during analysis. The approach for the analysis is explained in subchapter 3.2.

Table 6. Evaluation scheme, enabling relating aims to indicators of conflicts or unaffected users

		Events					Not affected
		Change in speed	Change in direction	Heavy measures	Collision	Walking bike	
Aim	Crossing						
	Turning						
	Waiting						
	Arriving						
	General						

In addition, the above described expression aspects can also be related to the parameters traffic density (PE/m^2) and area usage ($PE/m^2/min$). This will indicate the relation between the number of users on one side and the different aims and events on the other, providing a basis to define different levels of service.

3.1.5 Relations within the methodology

The relation between the parameters (traffic density and area usage), the different aims (crossing, turning, waiting and arriving), events (change in speed or direction, collisions and users walking bikes) and the relative amount of unaffected users is used to determine different levels of service. Hypothesis is that the relations work positively or negatively as described in Table 7. The table is based on the effects of a rise in traffic density.

Table 7. Relation between traffic density and the aims/indicators/parameters.

Aim/event/parameter	Effect
Area usage per minute	+
Ease to cross	-
Ease to turn	-
Ease to wait	-
Ease to arrive	-
Frequency of change in direction	+
Frequency of change in speed	+
Frequency of heavy measures	+
Frequency of collision	+
Frequency of users walking their bike	+
Relative amount of unaffected users	-

Relations can eventually be described either qualitatively ("Crossing becomes more difficult as traffic density increases"), quantitatively ("For a traffic density of 5 PE/m^2, between 50 and 70 crossing events occur") or relatively ("20 percent of the users with the aim to cross do not experience any problem until a density of 2 PE/m^2"). To be able to observe a qualitative description, it is useful to quantify the different events, aims and parameters first. In this research, quantification is done by video-analysis. Relative relational descriptions are preferable. This is explained in the next subchapter.

Note that not all aims, events and parameters have to be applicable on the analysed shared space area. In that case you can simply leave them out of the analysis.

3.1.6 Relative index

As mentioned before, every shared space areas is different from another. Differences occur in dimensions, type of traffic modes and adjacent facilities. Therefore, using absolute numbers as a basis for level of service leads to difficulties in comparing different shared spaces. This can be prevented by using relative indicators. These indicators are based on absolute numbers, but provide a ratio between two related quantities, for instance the total number of users and the total number of events. For a shared space with a smaller area, less users are needed to reach a certain density. This automatically leads to a decrease in the absolute value for events. If the levels of service are based on this absolute value for events, this would mean that the smaller shared space would be interpreted as functioning at better operational conditions than a shared space with a larger surface area, while this is actually not the case. Relative indices might prevent this situation. The specified relative indices, based on the aims and events presented in table 7, are presented in Appendix C. The used abbreviations can also be found in the appendix. The number of collisions is not determined relatively, as the characteristics of a shared space do not have an influence on the impact of a collision; every observable collision can be seen as one to many. Therefore, this quantity can be approached absolutely.

3.2 METHODOLOGY FOR FORMULATING STANDARD LOS BY QUANTIFICATION BY VIDEO-ANALYSIS

This subchapter presents the approach during video-analysis, to come up with a standard for pedestrian and bicycle LOS in shared space areas. It includes the specification of a format of criteria and the quantification of this format by usage of video-analysis. This video-analysis is performed on a shared space area at Amsterdam Central Station. Because this area has specific characteristics, the general approach presented in the previous subchapter is adjusted to a format applicable on this particular shared space.

3.2.1 Inventing scales for quantification

First, a format of criteria is formulated. These criteria will define a scale in each of the events and aims mentioned before. This scale is based on the indices from Appendix C, and can later be related to the parameters by usage of video-analysis. Therefore, it is useful to come up with such a format before video-analysis is started, as it will guarantee the objectivity of the model. However, the scale might need some adjustments, based on the numbers found after quantification. Note that this is a scale used to divide the observations during analysis, not the final scale of the level of service.

Requirements for an invented scale are:

- Quantified
- Observable during video-analysis
- Based on relative information

The last requirement holds because a single number does not take into account variables like the surface of the surveyed area or the total number of users. To use relative numbers or percentages, a framework of reference is included in the scale.

Assumptions for an invented scale are:

- The scale is divided in three different levels (+, ±, -)

Because the surveyed shared space does not accommodate any destination, the aim *arriving* is left out of this analysis and is not scaled. The other aims and events are all taken into account by usage of the indices as described before.

The quantified scaling is shown in Table 8. The equations presented in appendix C can be solved by inserting values obtained during video-analysis. The resulting values can be related to this scale, linking them to either a +, a ± or a – for each different aspect. These signs are also linked to a letter format. By combining the two relations, the densities can be related to the letter format, leading to a definition of different levels of services with different indicators due to different densities. This approach is based on the approach Weidmann used for his standards for pedestrians, see appendix B. The scaling is based on comfort. For crossing, turning and waiting, the scale varies between 1.5 and 0.5, respectively corresponding to a ratio of 3/2 and 1/2. An uncomfortable situation is defined as “the number of users that do not experience a problem while crossing/turning/waiting is lower than half of the number of users that doe experience a problem for the particular aim”. For heavy measures, uncomfortable is defined as “Of every four events, one or more is a heavy measure”. For people walking their bike, this value is set at one in three. For the unaffected user index, the situation is considered uncomfortable if at least four out of five users experience a conflict. The criterion 4 out of 5 is used for the total number of events as well. With regard to the events, the uncomfortable situation is defined as “for every five users, four events take place”. Note that the scaling for collisions only distinguishes two situations, respectively the absence and the presence of a collision. This because a very uncomfortable situation already occurs when just one collision happens.

Table 8. Scales for criteria for quantification by video-analysis

Ranking	Turning index (TI)	Crossing index (CI)	Waiting index (WI)	Events index (EI)	Unaffected users index (UUI)	Heavy measures index (HMI)	Walking bike index (WBI)	Collisions (C)
+	>1,5	>1,5	>1,5	<0,2	>0,6	<0,1	<0,1	0
±	1,5 – 0,5	1,5 – 0,5	1,5 – 0,5	0,2 – 0,8	0,2-0,6	0,1-0,25	0,1-0,33	-
-	<0,5	<0,5	<0,5	>0,8	<0,2	>0,25	>0,33	≠0

As said, the rankings can be related to a letter format. This letter format is a hypothesis; after analysis, it might turn out that the sequence of change or the number of levels is chosen incorrectly. In that case, both scale and letter format can still be changed. The hypothesis consists of six levels of service. Basis of the hypothesis is that level A scores a '+' for every aspect, and F scores a '–' for every aspect. Between these two extreme levels, a plausible trend is assumed. This trend assumes that an increase in traffic density will firstly lead to a small increase in events. Afterwards, for increasing density it will be noticeable that crossing becomes harder and more people start experiencing problems. Later, turning and waiting become more difficult, people will have to walk their bikes and more heavy measures are necessary to avoid serious conflicts. Eventually, at a certain density the whole area is full, leading to collisions as well. The letter format is presented in Table 9. In this format, the relation to the parameters traffic density and area usage is already included. However, this relation should still be specified. This is the main goal of the video-analysis: finding the quantitative relation between the indices and the parameters traffic density and area usage. The next subchapters provide an insight on the surveyed area and the execution of the analysis.

Table 9. Letter format for level of service

LOS	P1	P2	CI	TI	WI	EI	UUI	HMI	WBI	C
A	?	?	+	+	+	+	+	+	+	+
B	?	?	+	+	+	±	+	+	+	+
C	?	?	±	+	+	±	±	+	+	+
D	?	?	±	±	±	-	±	±	±	+
E	?	?	-	±	±	-	-	±	±	+
F	?	?	-	-	-	-	-	-	-	-

3.2.2 Surveyed shared space area and video-data

The analyzed shared space is located at Amsterdam Central Station, at the side of the river IJ. The location is clarified in figure **Error! Reference source not found.**. As can be seen, bicycles lanes from three external directions connect to the shared space area. The embarking location for the ferries is connected to the shared space area as well, providing a fourth external direction for bicycles. Pedestrians can attend the same four external directions, but it is expected they will mostly use the shared space area to cross between ferry and train station.

The timetable of the GVB, the provider of public transport in Amsterdam, shows that the ferries leaving from this location are:

- Ferries 901 and 907 from the eastern embarking point.
- Ferries 905 and 906 from the western embarking point. (GVB, 2016)

The video footages are taken from a camera positioned at the north side of the surveyed area, above the embarking location of the ferries. In **Error! Reference source not found.**, an image out of the video-data is presented to show the positioning of the camera, as well as an image containing the surveyed area. The red lines define the borders to make clear when a user is taken into account for determination of the traffic density. Sizes of this area are about 12 m (horizontal) x 15 m (vertical).

The available video-data cover a week (13-02-2016 to 19-02-2016), divided into clips of fifteen minutes each. The investigated videos are selected on diversity. Therefore, videos from multiple days and hours are analyzed, containing morning and evening peaks and afternoons. Specific days and times are: Monday, 15-02, 07:30 / 07:45 / 15:00, Tuesday, 16-02, 08:15 / 08:45 / 09:00 and Friday, 19-02, 07:45 / 15:00 / 17:30. Monday morning and Friday evening are expected to require the highest traffic densities.

3.2.3 Approach video-analysis

The goal of the video-analysis is to identify different values for both traffic density and area usage, and the corresponding quantities needed to determine the indices. The analysis will be executed manually, so no software is used. This means that users and aspects are observed, tracked, counted and interpreted all by hand. Every user is tracked separately to make sure no event is missed.

First, the moment of survey should be specified. The busiest moments, corresponding to less comfort, are expected just after arrival of a ferry. This therefore is an important moment of survey. The timetables for the earlier mentioned ferries are used to determine the exact moment of measurement. The period of survey is one minute, starting at the moment the first people leave the ferry and enter the shared space area, and ending exactly one minute later. These measurements provide the data for high densities. To obtain information about lower densities, the minute after the first surveyed minute is observed as well. This results in lower traffic densities, which are useful to observe as well for defining different levels of service.

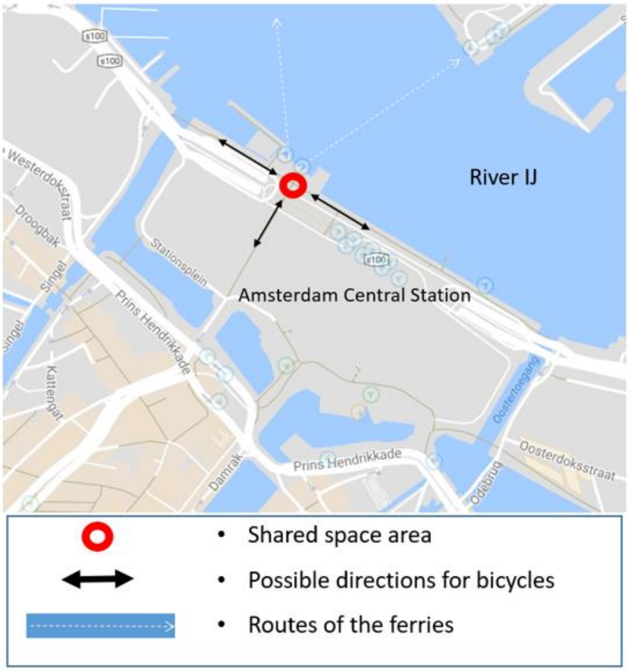


Figure 2. Localization of the shared space area at Amsterdam Central Station.

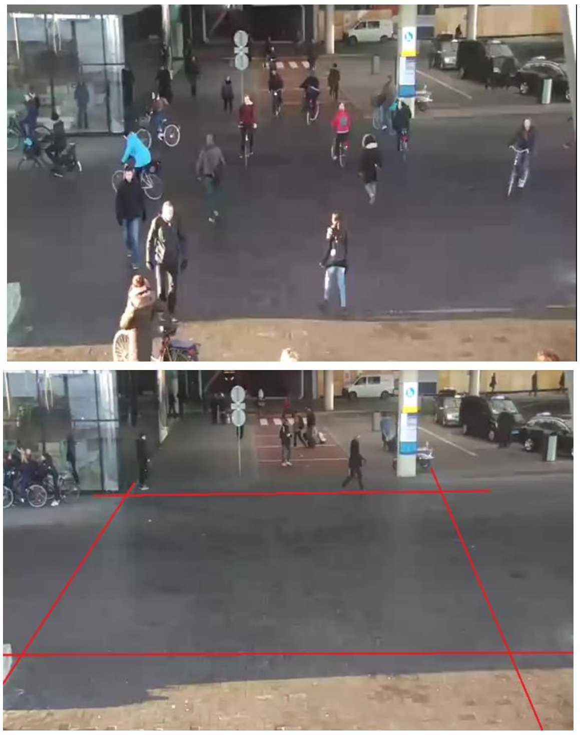


Figure 1. Top: Positioning of the camera used for the video survey and an impression of the usage of the area. Bottom: Demarcations of surveyed area in red

Now, the approach for the analysis will be presented. All aspects aimed to observe are separately analyzed for bicycles and pedestrians. All aspects described below (except for traffic density and total number of users) are analyzed with regard to the specified aims: crossing, turning and waiting. Other events will be placed under the name of a general event. The investigated aspects include:

- Traffic density. The traffic density will be expressed in PE/m^2. During a surveyed minute, the traffic density is determined every fifteen seconds. This results in five (mostly different) densities. Traffic density will be presented both in range and in average. To come up with a range, the highest and lowest observed density are neglected, lowering the error. The average density is determined based on all five measurements.
- Total number of users. The total number of users in one minute is counted and separated in pedestrians and bicycles. Based on the total number of users, the area usage in time can be determined, by expressing the number in PE and divide it over the area. The area usage in time is expressed in PE/m^2/min. Area usage in the time. The area usage is expressed in PE/m^2/min. To determine the area usage in time, all users (pedestrians and cyclists) for the surveyed minute are counted, expressed in PE and divided by the area.
- Number of speed reductions. A speed reduction is defined as an observable lowering in velocity given that the analyzed user is still moving, for instance a cyclist who brakes or stops pedaling.
- Number of full stops. A full stop for pedestrians is defined as an observable stop of movement, for bicycles a full stop is defined as a reduction in velocity, during which the cyclist needs to put one or more foot to the ground. The number of full stops and the number of large changes in direction together give the number of total heavy measures.
- Number of small changes in direction. A small change in direction is a change smaller than 45 degrees, for both pedestrians and bicycles. A change in direction is also applicable when an observable curve is needed to arrive at the leaving location of the surveyed area.
- Number of large changes in direction. A large change in direction is a change larger than 45 degrees, for both pedestrians and bicycles. This holds a correction in direction that influences the user's speed as well. Again, the number of large changes in direction and the number of full stops together give the number of heavy measures.
- Number of users that walks their bike. This includes all users that walk their bike before they start cycling. These users are interpreted as a pedestrian while walking. From the moment a user observably sits at its saddle, it is interpreted as a cyclist. When someone sat on his saddle and has to get of his bike again, this is counted as a bicycle full stop. Note that a full stop does not indicate a user walking his or her bike. This is only applicable when the user has to get off his saddle and walk his or her way through shared space.
- Number of collisions. This is defined as an observable crash of either two pedestrians, two bicycles or a pedestrian and a bicycle.
- Number of unaffected users. This includes all pedestrians and bicycles that do not experience any change in speed, direction or collision and do not have to walk their bike.

Other desired quantities can be determined out of these observations. The total amount of events can be obtained by adding the number of speed reductions, full stops, small changes in direction and large changes in direction. The number of conflicts related to each aim is analyzed by specifying the aim of the affected user. This is executed via an analysis schedule, containing the aspects mentioned above, the aims and the parameters. The two parts of the schedule (namely traffic density, area usage and total amount of users on one side, and the events and aims on the other side) are shown in Appendix D.

Results will be interpreted and related to the format described above. It might occur that some indicators or aims eventually turn out to be irrelevant or unobservable. In that case, these can left out of the results.

4 INTERPRETATION AND ELABORATION OF RESULTS VIDEO-ANALYSIS

In this chapter, the results of the video-analysis are discussed. The information obtained from the analysis schedules, is put together in an organized table, presented in Appendix E.

The table contains quantities needed for the calculation of the indicator indices according to Appendix C, and the corresponding densities and area usages. Using these results into the equations specified in appendix C, all indices can be quantified for each timeframe. These indices can be placed next to the scales, defined in the methodology. Based on the scale, each index corresponds to a ranking. Based on the results, the indices correspond to a density as well. The relation between density, indices and ranking is described in table 11. When an index cannot be determined due to a division by zero, the zero is replaced by the a one, as events cannot be expressed in decimals. After the video-analysis, it turned out that waiting conflicts hardly take place. This aim and index (WI) are therefore left out of the results. Based on this observation, it is concluded that this shared space generally services for the use of transportation. Also no collisions were observed, but this corresponds to lower levels of service and is therefore not a strange observation. The table is shown in order of average traffic density.

Table 10. Relation between density and aspects

Density		CI		TI		EI		UUI		HMI		WBI		C	
Range	Av	Index	Rank	Index	Rank	Index	Rank	Index	Rank	Index	Rank	Index	Rank	No.	Rank
0,03-0,07	0,06	2,80	+	1,33	±	0,30	±	0,74	+	0,15	±	0	+	0	+
0,05-0,09	0,06	2,56	+	0,75	±	0,33	±	0,67	+	0,31	-	0,04	+	0	+
0,07-0,10	0,07	1,68	+	1,29	±	0,46	±	0,65	+	0	+	0,02	+	0	+
0,06-0,07	0,08	1,63	+	6,00	+	0,35	±	0,67	+	0,12	±	0	+	0	+
0,08-0,10	0,09	5,67	+	1,4	±	0,20	±	0,75	+	0,09	+	0	+	0	+
0,08-0,12	0,11	2,00	+	2,19	+	0,32	±	0,66	+	0,05	+	0,02	+	0	+
0,12-0,20	0,14	0,75	±	0,80	±	0,60	±	0,44	±	0,14	±	0,08	+	0	+
0,11-0,23	0,15	0,91	±	0,44	-	0,61	±	0,44	±	0,15	±	0,04	+	0	+
0,11-0,19	0,16	0,56	±	0,58	±	0,69	±	0,40	±	0,16	±	0,06	+	0	+
0,14-0,20	0,18	0,48	-	0,30	-	0,77	±	0,32	±	0,11	±	0,05	+	0	+
0,17-0,27	0,19	0,43	-	0,59	±	0,77	±	0,35	±	0,16	±	0,08	+	0	+
0,19-0,23	0,2	0,40	-	0,48	-	0,82	-	0,34	±	0,26	-	0,20	±	0	+
0,25-0,27	0,26	0,07	-	0,20	-	1,04	-	0,10	-	0,36	-	0,21	±	0	+
0,25-0,33	0,3	0,13	-	0,16	-	1,21	-	0,12	-	0,33	-	0,22	±	0	+

4.1 GENERAL INTERPRETATION

Looking at table 11, the effects of an increase in traffic density mostly correspond to a predictable trend in rankings, namely from '+' through '±' to '-'. The indices that do not stick to that relation (based on the scale used) are TI (turning index) and HMI (heavy measures index).

The obtained values for the indices can vary a lot. To show this variance, some of the indices have been plotted against the density in the graphs below. The values are approximated with a trend line. Values above a 5,0 are left out of the graphs, as these have a lot of influence due to the little amount of data points.

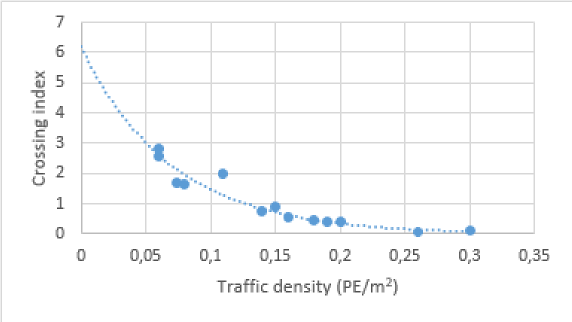


*Figure 4. Traffic density against the crossing index (Equation: CI = 6,1844e-14,36*density)*

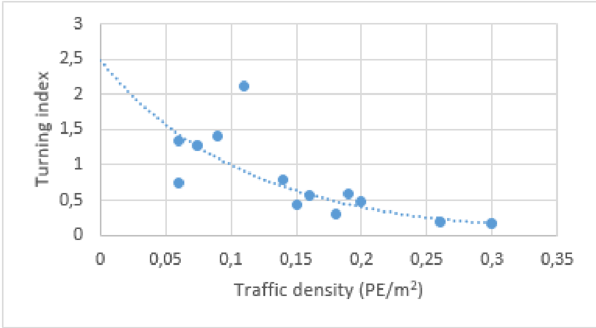


Figure 3. Traffic density against the turning index (Equation: $TI = 2,479e^{-9,111*density}$)

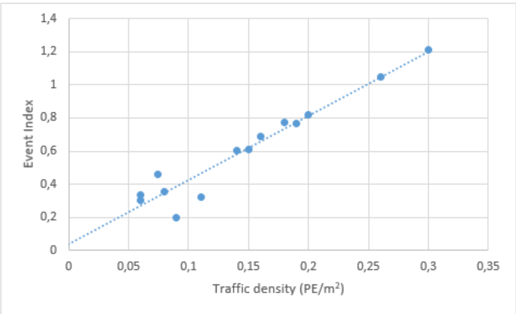


Figure 6. Traffic density against the event index (Equation: y = 3,9387x + 0,0271)

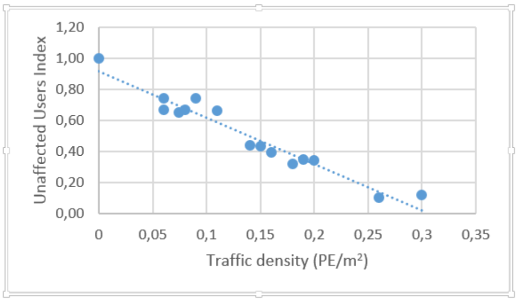


Figure 5. Traffic density against the unaffected users index

Looking at figures 3, 4 and 6, it can be seen that for lower densities the spread of the obtained indices is larger. This can be explained in two ways. First, the difference in amount of data is significant. An increase in density is accompanied by a noticeable increase in users and events as well. This means that more observations are made, reducing sensitivity to one single event. For instance, the values for indices at higher densities are determined based on e.g. 180 events, while for lower events the basis is only e.g. 13 events. This lower amount of events is way more sensitive to a single event, resulting in a spread of the obtained data.

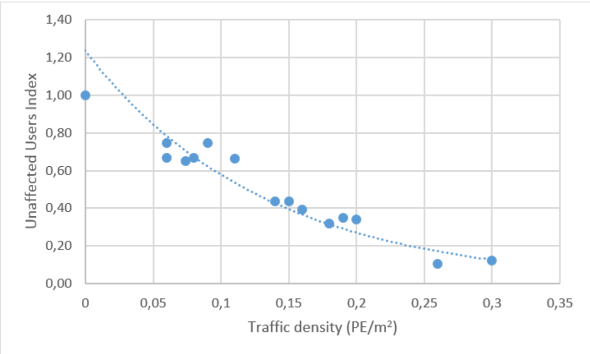
The second explanation for the spread is the way of determining traffic density. This parameter is measured five times during a minute. The value for the traffic density that is the basis for the sequence of the results in table 11 and for the graphs in figures 3, 4, 5 and 6, is the average of these five measurements. However, these five measurements might be a bad reflection of the real effective traffic densities when the change in density over time is large. To see if this is a basis for an explanation, the indices are plot against the area usage as well. The plots are not shown, but have the same shape of the graphs based on traffic density. The comparison is made based on the values for R^2. A higher R^2-value indicates a better approximation.

Table 11. Comparison between approximations based on either traffic density and area usage

Indices	Value for R^2	
	Traffic density	Area usage
Crossing index	0,925	0,768
Turning index	0,763	0,744
Event index	0,930	0,792
Unaffected users index	0,941	0,869

Based on the R^2-values, traffic density can be considered a better basis for the level of service, as for all four compared indices the values are higher. Simultaneously, this comparison disintegrates the statement in the methodology that area usage in time would be needed to come up with clear levels of service; traffic density turns out to have a tighter relation to the indices.

In figure 6, a linear trend line is used to approximate the data points. This trend line seems valid for the analyzed data, but the approximation will not be linear, because the unaffected user index will never become exactly zero. For the highest level of service, the index will approach zero. This indicates an exponential relation, with zero as the asymptote of this decreasing index, just like for the crossing and turning indices in figures 3 and 4. In practice, this situation will never be observed. The new approximation is shown in figure 8. A note to this new approximation is that the starting value actually should be 1,00. All these negative exponential relations can be explained by the behavior of the total number of events in relation to the traffic density, as this is increasing exponentially (see figure 7). The relation between amount of events and the amount of unaffected users is negative, so the relation between the indices as well. The exponential growth of the number of events indicates that the different levels of service in the final standard will correspond to a range in number of events that is increasing exponentially. For instance, the range for level A is given by 0 – 10 events, but the range for level E is given by 120 – 200 events.



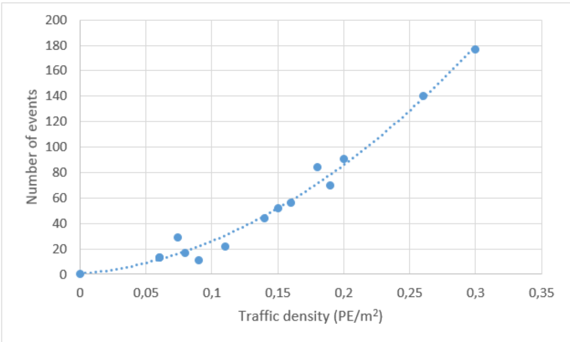


Figure 7 and 8. Traffic density against the unaffected users index (y = 1,2348e$^{-7,593x}$) and the exponential growth of number of events.

4.2 Turning index

The indices describing the ease to turn do not relate to the traffic density in the way that was expected on forehand. Expectations were that an increase in traffic density would cause the ease to turn to decrease slower than the ease to cross, because turns can be made at the sides of the area as well. The results show however that for lower traffic densities, the ease to turn already decreases, as the lowest measured densities result in a medium ranking. This will be adjusted in the format that was prepared in the methodology.

The sequence of the rankings is not as expected either. The lowest densities do not result in the highest rankings for the turning index, these rankings are scored for higher densities. To cope with this situation, the scale could be changed. However, differences in indices are that large (values between 0,75 and 2,19) that this is not considered to be an appropriate measure. Instead, the first moment a lower ranking is observed, this ranking is considered to be normative. This means that the section between traffic densities of 0,06 PE/m^2 and 0,14 PE/m^2 is all ranked medium. Not only some high rankings are unexpected. The same holds for low rankings; these are not only found for the highest traffic densities. The same approach is used to cope with this situation, so first it is checked whether adjusting the scale is a suitable solution. In this case it is considered to be appropriate, as the values do not very much (0,44 until 0,59). The adjusted scale defines every turning index below 0,60 as uncomfortable. As crossing and turning are researched and interpreted equally, the change of scale is applied on the scale for the crossing index as well. The adjustments to the scale can be found in table 13. For the final ranking of the turning index, see table 12.

Table 12 and 13. Updated scale for turning index and crossing index and updated ranks for turning index

Ranking	Turning index (TI)	Crossing index (CI)
+	>1,5	>1,5
±	1,5 – 0,6	1,5 – 0,6
-	<0,6	<0,6

Density		TI	
Range	Av	Index	Rank
0,03-0,07	0,06	1,33	±
0,05-0,09	0,06	0,75	±
0,07-0,10	0,07	1,29	±
0,06-0,07	0,08	6,00	±
0,08-0,10	0,09	1,4	±
0,08-0,12	0,11	2,19	±
0,12-0,20	0,14	0,80	±
0,11-0,23	0,15	0,44	-
0,11-0,19	0,16	0,58	-
0,14-0,20	0,18	0,30	-
0,17-0,27	0,19	0,59	-
0,19-0,23	0,2	0,48	-
0,25-0,27	0,26	0,20	-
0,25-0,33	0,3	0,16	-

= change due to rescaling
= change due to normative values

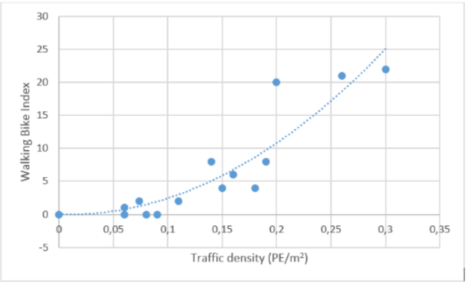


Figure 8. Traffic density against the walking bike index
Equation: $y = 295{,}38x^2 - 5{,}0788x$

4.3 Heavy measures index

The heavy measures index varies a lot for small traffic densities. When density increases, the order of the ranking proceeds as expected. The fact that some low rankings occur for low traffic densities can be attributed to speed. It is observed during video-analysis that at lower densities, less users need to reduce their speed due to conflicts. This results in higher speeds at the shared space area. These higher speeds make it, especially for pedestrian, harder to cross the road. Observations show that pedestrians are more likely to fully stop walking and wait for bicycles with high speeds before crossing. As this event is registered as being a full stop, contributing to the heavy measure index, this value can be pretty high for low densities. For higher densities (e.g. starting from 0,10 PE/m^2), the heavy measure index indeed describes different levels of service. The format for the final result therefore will be adjusted: the lowest level (A) of course is still ranked with a plus sign, as the amount of events is so small. However, for level B, the standard for HMI cannot be defined and will therefore be given by '+/±/-'. From level C, the HMI-rank will be a plus sign again.

4.4 Unanalysed indices

Some indices that were specified before, are not taken into account. This is the case for the arriving index (not applicable on this shared space area) and the waiting index (not enough influence to draw conclusions). These values might be applicable on other shared space areas, but in the final standard defined in the next chapter, they are not included.

5 QUANTIFICATION OF FINAL STANDARD

Finally, quantification of the corresponding traffic densities can be performed. The different indices will be quantified based on the graphs shown before by use of intersection. The values, which scale corresponds to the different levels in the format, are provided in the table below. For every index, the border according to the defined scale is presented. The resulting values can be related to densities through intersection.

Table 13. Borders according to scaling of indices. Densities (D) are in PE/m².

LOS border	CI	D	TI	D	EI	D	UUI	D	WBI	D
A-B			1,5	0,055	0,2	0,043				
B-C	1,5	0,10					0,6	0,095		
C-D			0,6	0,16					0,1	0,19
D-E	0,6	0,16			0,8	0,20	0,2	0,24		
E-F									0,33	0,35

Based on table 14, the final standard presented in table 15 can be defined. Two rankings need to be adjusted. The WBI scores a plus at level D, instead of a medium score. The other one is the CI, scoring a minus at level D, instead of a medium score. Furthermore, the HMI was not investigated for its borders because of the large spread in data. However, to make sure the defined standard holds for the HMI as well, the score for level C is change into medium. This standards holds for all found data, by neglecting the extreme found values. Due to the usage of the indices, time dependency is not an issue.

Table 14. Final standard for pedestrians and bicycles in the shared space area.

LOS	Density (PE/m²)	CI	TI	EI	UUI	HMI	WBI	C
A	0 - 0,05	+	+	+	+	+	+	+
B	0,05 - 0,11	+	±	±	+	+/±/-	+	+
C	0,11 - 0,16	±	±	±	±	±	+	+
D	0,16-0,20	-	-	±	±	±	+	+
E	0,20-0,35	-	-	-	-	-	±	+
F	>0,35	-	-	-	-	-	-	-

Ranking	Turning index (TI)	Crossing index (CI)	Events index (EI)	Unaffected users index (UUI)	Heavy measures index (HMI)	Walking bike index (WBI)	Collisions (C)
+	>1,5	>1,5	<0,2	>60%	<10%	<10%	0
±	1,5 – 0,6	1,5 – 0,6	0,2 – 0,8	20%-60%	10%-25%	10-33%	-
-	<0,6	<0,6	>0,8	<20%	>25%	>33%	≠0

In which:

- \+ = comfortable, shared space functions fine with regard to the specific index
- ± = medium operational conditions regarding the specific index
- \- = uncomfortable, shared space does not provide service desired for the specific index

Looking at these standards, the density values are noticeably way lower than the standards for single mode traffic. These lower values are attributed to the absence of directions, and to multimodality and its related speed differences.

6 CONCLUSION

The main differences between shared space areas and a segregated traffic approach related to the level of service are the multimodality of an integrated design and the absence of boundaries in directions. To take these two aspects into account for the level of service of a shared space area, the methodologies for separated traffic design LOS can be adjusted. In this research, this was done focusing on pedestrians and bicycles.

The proposed methodology is based on several important adjustments. First, traffic density is expressed in a Pedestrian Equivalent, to take into account both bicycles and pedestrians. This equivalent is based on both dimensions and speed. Secondly, Weidmann's eight criteria (1993) and the concept of hindrance as defined by the HCM 2000 are used as a basis to come up with an applicable model for level of service on shared space areas. This model is based on different aims, namely crossing, turning, waiting and arriving. The ease to successfully fulfill an aim was investigated during a video-analysis. Based on the concept of aims, a model for a methodology can be proposed. Because there is a lot of variety in shared space areas, the level of service should be expressed in a relative way. This reduces the influence from factors like area, usage or adjacent facilities, and allows general application.

The relative indices are used to describe the operational conditions for crossing and turning, and the number of events, unaffected users, heavy measures and people walking their bike. Collisions are expressed absolutely, as they are highly undesirable.

The obtained model was quantified by usage of video-analysis. This lead to the formulation of a standard, given by: LOS A: 0 – 0,05 PE/m^2; LOS B: 0,05 – 0,11 PE/m^2; LOS C: 0,11 – 0,16 PE/m^2 ; LOS AD 0,16 – 0,20 PE/m^2; LOS E: 0,20 – 0,35 PE/m^2 ;LOS F: >0,35 PE/m^2. This standard is based on relative indices. Such standards can be used by defining guidelines for the implementation of shared space areas. The development of guidelines can help increasing both safety and effectiveness of shared space areas. The standard is based on a scale for each index, corresponding to different traffic densities. The final standard is presented on the previous page. The indices that are already influenced at low traffic densities are the indices describing the ease to turn and the relative number of events. The index describing the relative amount of people walking their bike is only influenced at high traffic densities.

Based on the outcome of the video-analysis, the parameters traffic density and area usage in time were compared on accuracy. Traffic density was concluded to provide a more accurate relation with each set of indices. Almost all indices related in an negative exponential way with the traffic density, resulting in values that tend towards zero. The observed data were not sufficient to come up with an accurate description for a scale applicable on the heavy measure index for lower traffic densities. This resulted in an unknown rank for level of service B. The final standard exists of seven scaled indices. The waiting index and arriving index are left out of the standard as they were not applicable on this particular shared space. Based on the absence of waiting conflicts, it is concluded that transportation is the main purpose of this particular shared space area. The hypothesis for the format of the standard did not match the final result. Adjustments had to be made to both the final format and the scale used, but the developed concept worked out well.

Further research should firstly test whether the defined methodology is applicable on other shared space areas, as this is the expectation. Also the standard should be tested on other areas, to see if the values correspond to other areas as well. This research only takes into account quantities that are observable during video-analysis. This means that only objective values are use, although the level of service has a subjective side as well. Furthermore, the research only focusses on pedestrians and bicycles. All other traffic modes are excluded from the research. Nevertheless, there are shared space areas facilitating motorized traffic as well. Further research should therefore be focusing on including the subjective side of the level of service into the methodology, and on the possibility of application on shared space areas facilitating motorized traffic.

7 DISCUSSION

The research presents a proposal for a methodology to determine level of service for pedestrians and bicycles in shared space areas. An important part of the research is the quantification of the formulated format. For this quantification, few data are used. This is due to time-related issues; manually performing a video-analysis turned out to be very time-consuming. As a consequence of the small amount of data, the approximated lines and formulas, used to determine the different levels of service, are based on data with a high variance. When more data were obtained, the final standard would be more accurate. The used small data set comes from just one shared space area. Therefore, it cannot be guaranteed that both methodology and standard are generally applicable. This should be tested first.

Another unreliable aspect was already mentioned in the report. This concerns the measurement of the traffic density. This parameter is measured five times during a minute. The used value is the average of these five measurements. However, these five measurements might be a bad reflection of the real effective traffic densities when the change in density over time is large. This can also be dedicated to the manual execution of the analysis. A life-action tracking system would be useful, however these kind of software are not as accurate as desired for pedestrians and bicycles. Besides, the used video-data do not provide high-quality footages. Nevertheless, an accurate way to describe traffic densities, especially low values (< 0,10 PE/m^2) would probably reduce the spread of observations for these low densities. Other possible measure is, as described above, to collect more data, especially for lower traffic densities.

The found values for the traffic density for the standard are really low. To a certain extend this can be explained by the characteristics of a shared space. However, the value for level F can be considered very low, as traffic densities of 0,33 PE/m^2 have been observed. This can be related to the little amount of data that is used for analysis. Not enough high values are observed, or a measurement of a minute is too long. The average density then decreases already, but if time slots of 10 seconds would have been analyzed, these densities could be separated. That might have resulted in some higher values.

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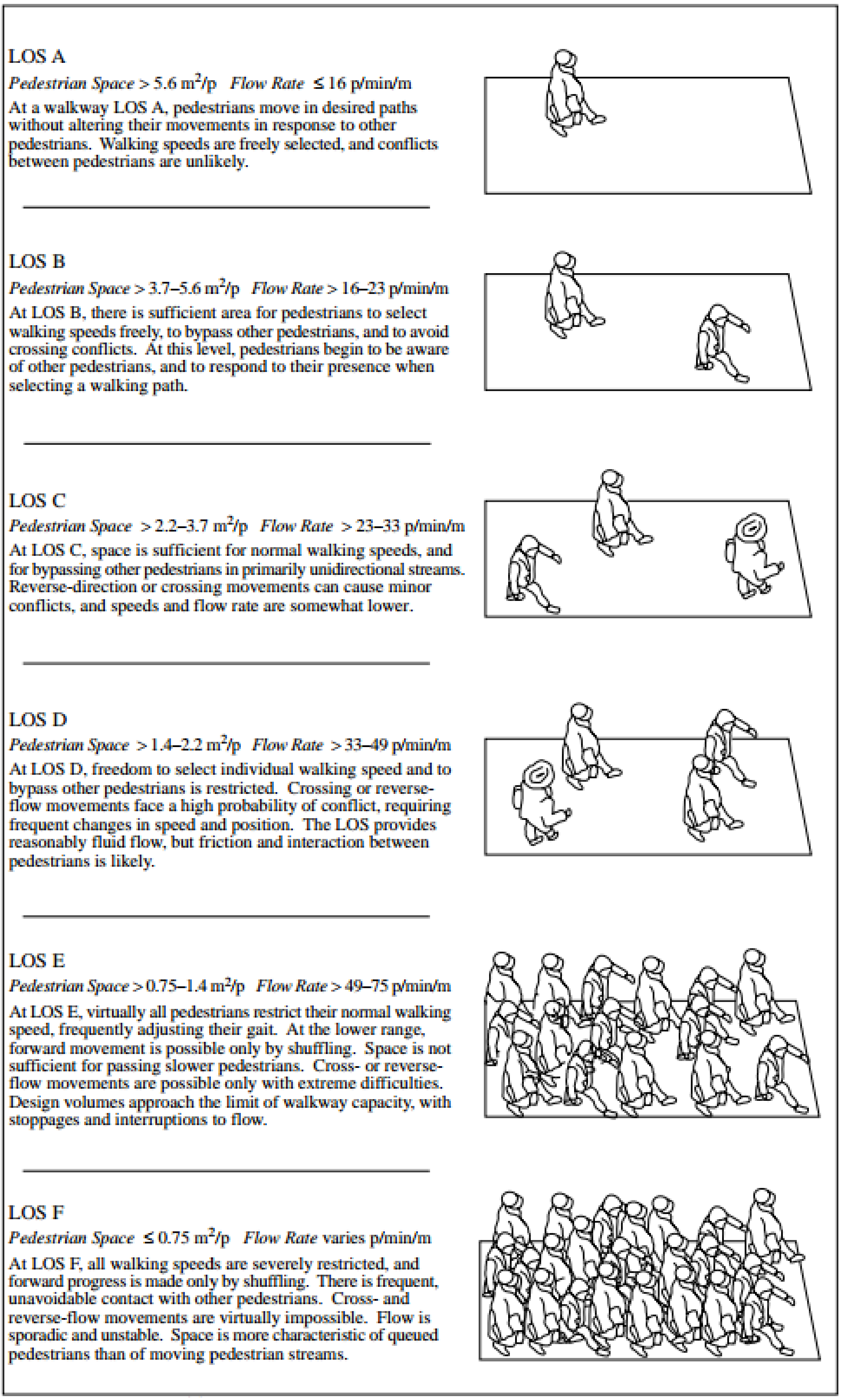
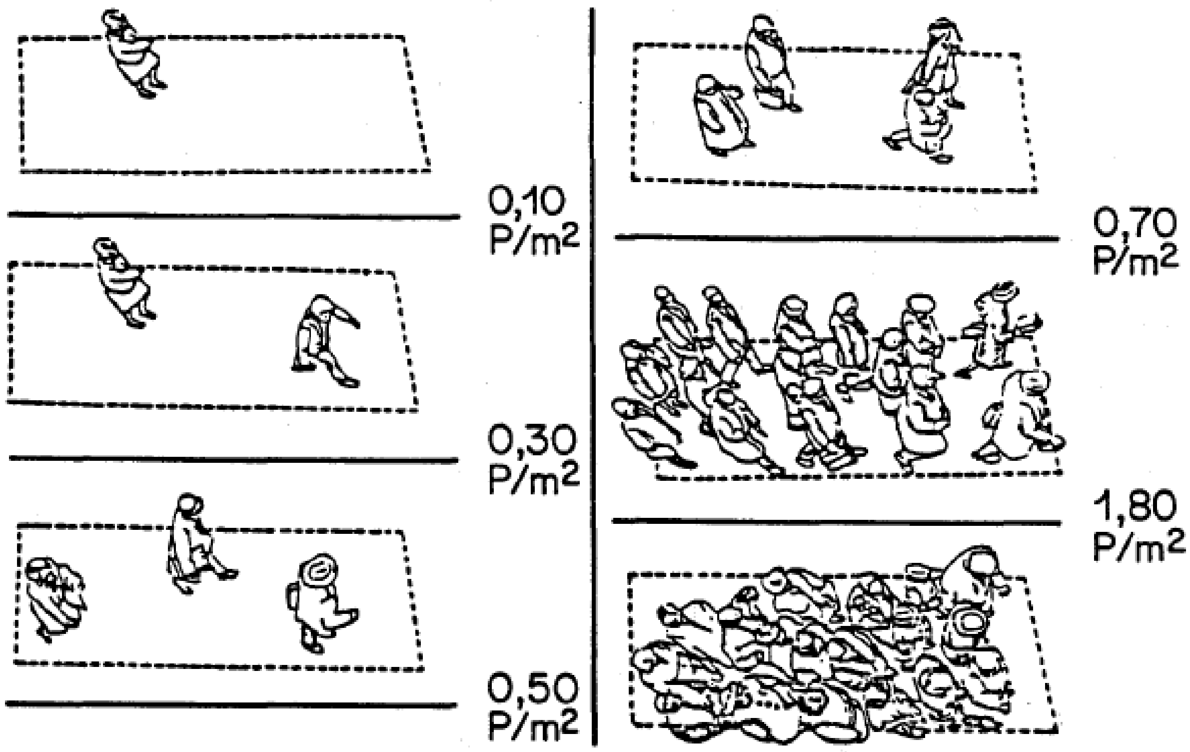
9 Appendix

A. Standards for level of service for walkways by HCM 2000



Figuur 1. Standards for level of service for walkways by HCM 2000 (Transportation Research Board, 2000)

B. STANDARDS FOR LEVEL OF SERVICE FOR WALKWAYS BY WEIDMANN (1991)



LOS	Dichte P/m²	Kriterium K1	K2	K3	K4	K5	K6	K7	K8	Gesamtcharakterisierung
A	0.00-0.10	+	+	+	+	+	+	+	+	absolut freie Bewegung
B	0.10-0.30	+	+	=	+	+	+	+	+	freie Bewegung
C	0.30-0.45	=	+	=	=	=	=	=	+	schwache Behinderung
D	0.45-0.60	=	=	=	=	-	-	-	+	mässige Behinderung
E	0.60-0.75	-	-	-	=	-	-	-	+	starke Behinderung
F	0.75-1.00	-	-	-	-	-	-	-	+	dichter Verkehr
G	1.00-1.50	-	-	-	-	-	-	-	=	mässiges Gedränge
H	1.50-2.00	-	-	-	-	-	-	-	-	starkes Gedränge
I	2.00-5.40	-	-	-	-	-	-	-	-	massives Gedränge

Legende:
+ gut
= mittelmässig
- schlecht

Figuur 2. Standards for level of service for walkways by Weidmann (Weidmann, 1993)

C. Relativity per aim or indicator

Aim / event	Number used for scaling	Name
Ease of turning	$\frac{Users\ experiencing\ no\ conflict\ while\ turning}{Users\ experiencing\ a\ conflict\ while\ turning}$	Turning index (TI)
Ease of crossing	$\frac{Users\ experiencing\ no\ conflict\ while\ crossing}{Users\ experiencing\ a\ conflict\ while\ crossing}$	Crossing index (CI)
Ease of waiting	$\frac{Users\ experiencing\ no\ waiting-related\ conflict}{Users\ experiencing\ a\ waiting-related\ conflict}$	Waiting index (WI)
Ease of arriving	$\frac{Users\ experiencing\ no\ conflict\ while\ arriving}{Users\ experiencing\ a\ conflict\ while\ arriving}$	Arriving index (AI)
Total events	$\frac{Total\ number\ of\ events}{Total\ number\ of\ users}$	Event index (EI)
Unaffected users	$\frac{Total\ number\ of\ unaffected\ users}{Total\ number\ of\ users}$	Unaffected user index (UUI)
Heavy measures	$\frac{Total\ number\ of\ heavy\ measures}{Total\ number\ of\ events}$	Heavy measure index (HMI)
Users walking their bike	$\frac{Total\ number\ of\ cyclists\ walking\ their\ bike}{Total\ number\ of\ bicycles}$	Walking bike index (WBI)
Collisions	–	Number of collisions (C)

D. ANALYSIS SCHEDULES

07:30	PBE	4,42	Density				Area usage					
				Total users		Density	Number of users / min					
Time	No of pedestrians	No of bicycle	Bike in PBE	Real number	PBE	PBE/m2	Pedestrian	Bike	Total	PBE	Area	Area usage (PBE/m2/min)
					GEM							

Analysis schedule used to determine parameters and total amount of users

	Change in speed				Change in direction				Total	Unaffected			Walk before start cycling		
	Pedestrians		Bicycles		Pedestrians		Bicycles						Bicycle		
	Speed reduction	Full stop	Speed reduction	Full stop	<45	>45	<45	>45		Pedestrians	Bicycles	Total	No	Start in ssa	start outside ssa
Other/General															
Crossing															
Turning															
Waiting															
Total															

Analysis schedule for events, aims and number of unaffected users

E. RESULTS OF VIDEO ANALYSIS

			Traffic density (PBE/m²)		Area usage		Users			Unaffected					Events								
Day	Time	#	Range	Ave.	PBE/m²/min	u/m²/min	Tot	Ped	Bike	Tot	Ped	Bike	cross	turn	Tot	Walk bike	Cross	Turn	Speed	Full stop	Dir	>45	Heavy
				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mon	07:30	1	0,12-0,20	0,14	1,28	0,41	73	27	46	32	17	15	24	8	44	8	32	10	25	4	18	2	6
	07:30	2	0,03-0,07	0,06	0,75	0,24	43	16	27	32	14	18	28	4	13	0	10	3	12	2	1	0	2
	07:45	1	0,19-0,23	0,2	1,53	0,62	111	63	48	38	27	11	27	11	91	20	68	23	51	16	40	80	24
	07:45	2	0,06-0,07	0,08	0,8	0,27	48	20	28	32	13	19	26	6	17	0	16	0	13	1	4	1	2
	15:00	1	0,07-0,10	0,07	0,69	0,35	63	45	18	41	35	6	32	9	29	2	19	7	12	0	17	0	0
Tue	08:15	1	0,25-0,33	0,3	2,39	0,811	146	63	83	18	10	8	17	6	177	22	134	38	115	43	62	15	58
	08:15	2	0,11-0,19	0,16	1,5	0,45	81	55	26	32	16	16	15	16	56	6	27	26	37	7	19	2	9
	08:45	1	0,08-0,10	0,09	1,93	0,30	59	22	37	41	20	21	34	7	11	0	6	5	10	1	1	0	1
	09:00	1	0,14-0,20	0,18	2,14	0,61	109	28	81	35	10	25	27	8	84	4	56	27	63	7	21	2	9
	09:00	2	0,05-0,09	0,06	0,67	0,22	39	15	24	26	9	17	23	3	13	1	9	4	11	3	2	1	4
Fri	07:45	1	0,11-0,23	0,15	1,25	0,47	85	44	41	37	26	11	29	8	52	4	32	18	31	6	21	2	8
	15:00	1	0,17-0,27	0,19	1,36	0,51	91	45	46	32	21	11	22	10	70	8	51	17	41	7	29	4	11
	17:30	1	0,25-0,27	0,26	1,92	0,74	134	72	62	14	10	4	7	7	140	21	100	35	87	36	53	14	50
	17:30	2	0,08-0,12	0,11	1,06	0,38	68	32	36	45	26	19	28	17	22	2	14	8	12	1	10	0	1