DEFINING THE TIME COMPONENT OF THE PEDESTRIAN LEVEL OF SERVICE CONCEPT

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ABSTRACT

For pedestrians, a number of density-based Level of Service (LOS) schemes exist in the literature. Although their values differ substantially, several common principles can be identified as necessary assumptions of this LOS concept. From these assumptions follows the importance of the time aspect of the LOS. Pedestrian flows are typically characterized by strong, often short-term, fluctuations. The LOS thus depends strongly on the chosen measurement interval. This link is highly relevant when designing infrastructures, as time-aggregated pedestrian counting data are often used in practice. Despite this fact, the time-dependency of LOS is hardly discussed in the literature.

This paper attempts to provide a conceptual basis for the pedestrian LOS based on a comprehensive review of the literature. With the increasing availability of continuous counting data, the time component of the pedestrian LOS concept can be examined in more detail. A case study described in this paper, together with a recently published LOS concept, illustrates the influence of flow variations on the LOS and the perceived quality of the flow. Results show that the time interval can be incorporated into an LOS scheme in a meaningful way, although certain limitations remain. It is furthermore argued that facility design should be based on ensuring a certain minimum LOS for a defined share of users, provided that detailed continuous counting data is available. Such an approach would best enable the construction of cost efficient as well as comfortable pedestrian facilities.

Keywords: Pedestrian transport, Level of Service, Pedestrian flow, Fluctuations in traffic volume
INTRODUCTION
When designing pedestrian infrastructures several aspects have to be taken into account. The most important parameter is the demand, which determines the pedestrian flow and density on the facility. One of the further requirements is the level of comfort that should be offered to travelers, which requires a scheme for determining traffic flow quality as a function of the measured or expected demand. The so-called Level of Service (LOS) concept is widely used for this purpose, having become a key factor in the design of pedestrian transportation facilities since its introduction in the 1960s. The pedestrian density is often used as a proxy for the traffic quality, as higher densities restrict movements and thus reduce the quality of the flow. Although the density-based LOS has been applied in praxis for several decades, some of its basic assumptions and considerations are not well described in literature. It is for example widely known that the pedestrian demand exhibits high fluctuations and therefore the chosen time interval for determining the LOS will strongly affect the results. However, the implications of this fact are rarely discussed.

The first part of this paper will review and discuss the literature about existing pedestrian LOS schemes will be reviewed and discussed in terms of the main assumptions that underlie density-based LOS concept. These assumptions are then needed to evaluate the time component of the LOS, as they will lead towards the question of the most useful time interval. In the second part, the connection between time interval and LOS will be analyzed based on data from two railway stations. The results are then compared to a newly developed LOS scheme (1) which attempts to address the issue of the missing time component. Lastly, new insights concerning the time component of the LOS will be presented and discussed.

LITERATURE REVIEW
Given enough space and an unlimited budget, there would be no reason not to design spacious pedestrian facilities that always offer comfortable densities. Since engineers and planners usually work under restrictions, they must be able to compromise between the cost-effectiveness and quality level of a project. Pedestrian density is commonly used as a criterion because of its measurability. Rather than one density value for all purposes, a scale with different levels is used, since individual infrastructures can differ greatly in both function and expected flow characteristics over time.

It should be noted that besides density, other aspects of the pedestrian experience like safety, quality of surroundings and surface quality, are not covered by density-based LOS schemes. The approach is therefore mostly relevant for the design and operation of heavily used infrastructures, like railway stations or airports, where densities are actually high enough to be perceived as uncomfortable. Ironically, situations with very few pedestrians can also be perceived as low quality because of a felt lack of security or liveliness. This aspect is obviously not reflected in the density-based LOS, either.

Development of the pedestrian Level of Service concept
The LOS concept was first introduced for motorized traffic in the 1960s in the Highway Capacity Manual (2). It is based on the assumption that low traffic volumes correlate with higher perceived quality by the driver. To determine the LOS, the operating speed and the service volume to capacity ratio were used. Based on these criteria, six levels, from A to F, were distinguished.
During the same period, a LOS concept for pedestrians was developed. A first, but widely unnoticed, approach for a description of traffic quality was suggested by Oeding (3). Based on pedestrians’ freedom to choose their walking speed, walk side to side or overtake others, he proposed four quality levels plus a crowded state. Several years later, Fruin developed his LOS concept for pedestrians based on the LOS principles for motorized traffic from the Highway Capacity Manual (4). In addition to the criteria developed by Oeding, he introduced the probability of conflicts for cross-flow traffic as a determinant of the LOS (5). Apart from walkways, he also developed LOS parameter for stairways and queues (6). Fruin’s LOS levels are still used as reference values in many applications today.

Following Fruin, the LOS concept for pedestrians was further developed and adapted to different situations. Pushkarev and Zupan researched pedestrian platoons and the right time interval for determining LOS (7). They concluded that situations with predominantly platoon flows require a time interval of 15 to 30 minutes, corresponding with the observed cyclical variation. As the work of Fruin was based on flow characteristics typical for the United States, several publications focused on transferring the concept to different locations (8, 9). Another LOS classification based on the number of conflicts was proposed by Schopf (10) who researched the space demand in various walking situations. The LOS is then determined based on the walkway width and the traffic volume. This concept assumes that the width needed for an encounter follows a certain distribution.

The concrete mechanisms that underlie the influence of density on the perceived quality were long underrepresented. In an attempt to address this, Weidmann (11) used existing literature to compile a list of eight criteria that can be used to distinguish the different LOS levels:

1. Possibility to freely select walking speed
2. Frequency of forced speed changes
3. Necessity to react to other pedestrians
4. Frequency of forced direction changes
5. Hindrances when crossing a pedestrian flow
6. Hindrances when walking in opposing direction
7. Hindrances when overtaking
8. Frequency of unintentional physical contact

Some scholars have suggested using alternative parameters like delay time or the number of conflicts with other traffic as a measure for quality, rather than density (12–14). Indeed, the perceived quality does not solely depend on restrictions imposed by other pedestrians. To account for this, other quality concepts were developed which are widely applied today. They consider for example attractiveness of surroundings, motorized traffic volumes, safety aspects or network parameters (15–20). This branch of LOS schemes overlaps with the idea of walkability (21, 22), which focuses more holistically on the quality of the walking experience. Lastly, in recent years researchers have increasingly focused on developing multimodal level of service concepts (23–25).

**Existing density-based Level of Service limits**

Several LOS schemes based on pedestrian density can be found in the literature. A comparison of LOS for walkways is presented in TABLE 1. For different situations and infrastructures like
platoons on walkways (26, 27), stairways (1, 6, 11, 25, 28, 29), queues and waiting areas (1, 6, 27, 29–31), crosswalks (32), places (1) and mechanical pedestrian infrastructure (1), separate LOS schemes were proposed in literature. In accordance with the original LOS concept proposed in the Highway Capacity Manual (2), most LOS schemes have levels ranging from A to F.

### TABLE 1 LOS limits for walkways from literature (upper limits). Schemes that use a different notation than letters have been converted for better readability. Subclasses are omitted.

<table>
<thead>
<tr>
<th>Source</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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<th>H</th>
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<td>0.72</td>
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<td>2.15</td>
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<td>0.08</td>
<td>0.27</td>
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<td>0.67</td>
<td>0.98</td>
<td>5.38</td>
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<tr>
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<td>0.36</td>
<td>0.54</td>
<td>0.72</td>
<td>1.08</td>
<td>&gt; 2.15</td>
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<tr>
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<td>&gt; 2.00</td>
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<td>TRB (31)</td>
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<td>0.63</td>
<td>1.02</td>
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<td>2.70</td>
<td>&gt; 2.70</td>
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<td>&gt; 1.80</td>
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<td>0.50</td>
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<td>&gt; 2.63</td>
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</table>

The different values of the LOS vary considerably. For example, the upper limit for LOS A ranges between 0.02 and 0.6 P/m². As it is unlikely that such big differences can be explained by local or cultural factors alone, it can be assumed that the underlying principles for determining the limits are not consistent between schemes.

### Assumptions and complications

LOS concepts for pedestrians aim to provide a measure of the quality of the flow as perceived by the user, which in turn can be described as the degree of interference between individual road users (39). Upon careful examination of the density-based LOS concept, several assumptions can be identified that have to be fulfilled in order for the concept to be a viable measure for quality.
By understanding these assumptions, one might gain more insight into of the density-based LOS approach and its limits:

1. The perceived quality is based upon the amount of hindrances experienced while walking.
2. Hindrances are mainly the possibility of freely selecting the walking speed, walking direction and the distance to others.
3. The perceived quality is similar for different sets of pedestrians in the same circumstances.
4. The number of hindrances and thus the available choices depend on the number and location of pedestrians in the vicinity.
5. The number and location of pedestrians can be adequately described by the pedestrian density in an area around the pedestrian. The pedestrian density can thus be used as a proxy for the perceived quality.
6. The quality depends on the average perception within a certain time interval, though high densities will always represent poor qualities.
7. If pedestrian flow values are used, these values have to be transformed to densities. Here, the fundamental diagram can be used, considering, that it is not intended for unsteady flows (41).

Explicitly writing down these assumptions reveals several weaknesses of the concept. For example, different groups of pedestrians might have a different perception of the same situation. Furthermore, the composition of a group is likely to have an influence on the type and number of mutual hindrances. For the concept to be usable, these deviations must be within an acceptable range (Assumption 3).

Perhaps the most important assumption is the correlation between pedestrian density and the perceived quality (Assumption 5). One possible weakness of density as an indicator is that pedestrians walking in front will have a stronger impact on a person’s perceived walking quality than pedestrians walking behind the subject in question. A further complication is caused by the various methods that can be used to determine the density (41). When the density is calculated in the most basic way, as the number of pedestrians within a certain area, the size of the area is relevant. To a certain degree, smaller observation areas will improve the correlation between density and the perceived quality, as it can be assumed that the quality mainly depends on pedestrians in close vicinity. However, at the very least an area must include all relevant pedestrians to describe accurately the assumed relation between the experienced restrictions and the density. This minimum has so far not been systematically determined. A more fundamental problem of density as an indicator is the fact that individual locations of pedestrians are not represented. Other density measurement methods, such as the Voronoi density (41), have similar shortcomings. Surely, the size of the measurement area used to determine the LOS should cover the relevant influence area of a pedestrian, but further research is needed to find the optimal size and to link the area to the perceived quality. Overall, it can be assumed that the pedestrian density correlates only with the average perceived quality. In other words, ensuring a certain LOS cannot guarantee a minimum perceived quality, it only provides an average value.

A less fleshed out aspect of LOS is the time component, tied to the large fluctuations that are typical for pedestrian traffic. This problem has only been addressed in the literature to a certain degree, for example by introducing an LOS for platoon flow (7, 26). If longer time
intervals are used to determine the LOS, the correlation between the average density and the
quality perceived by individual pedestrians is weaker, because their “felt” density deviates more
from the mean. For this reason, caution is advised when comparing LOS values that stem from
measurements over different time spans. For example, an hourly flow might have LOS B on
average, whereas the busiest 2-minute time interval within the same hour might yield a value in
LOS E.

A further complication of the time aspect of LOS is the fact that for individual
pedestrians, densities will change considerably during a walk. If LOS should reflect the quality
of the flow perceived within a certain time interval, it is unclear whether each individual
perceives an averaged quality, a momentary impression, or some other influence like the worst
experienced quality. No literature was found on the relation between time interval, density
variation and perceived quality. Some researchers conducted interviews to relate the density to
the perceived quality level, but they only asked for instantaneous impressions or about situations
that just occurred (32, 36, 42).

Without further knowledge, it has to be assumed that the perceived quality corresponds to
the average experience in a certain time interval. This is partly confirmed by the research on the
measurement of subjective well-being. Kahneman et al. (43) suggest a U-index, defined as the
fraction of time spent in an unpleasant state, meaning that the most intense feeling reported for
that episode is a negative one. At the same time, specific occasions of being in a negative mood
(such as the stress caused by a short experience of very high density) do not seem strongly
related to a person’s general well-being. Relatedly, Glass and Singer (44) write that stress has no
immediate influence on task performance. They did however find a decrease in performance on
tasks carried out in the period after a short, acute, stressful situation. For this reason, highly
crowded situations might lead to poor perceived qualities, irrespective of the duration. For an
LOS concept this means that the quality of a route can be calculated by averaging over the time
spent in each quality class, as long as the density does not exceed a certain threshold. This
threshold might be different in different situations. For example, the acceptable range of
densities when leaving a football stadium is different from that for a Sunday outing in a park.

In summary, the underlying assumptions of the LOS concept show that the relation
between pedestrian density and perceived quality is far more complex than often assumed. The
pedestrian density and therefore the quality changes continuously during a walk. How well the
average corresponds to the perceived quality is largely unknown because of the absence of data
linking rapidly changing traffic situations with human perception.

BASIC PRINCIPLES OF A TIME ORIENTED LEVEL OF SERVICE CONCEPT
To be able to capture the large volume fluctuations typical for pedestrian infrastructures, the
measurement window should be relatively small. A typical value used in praxis is two minutes
(1, 38). Count data for even shorter intervals is generally not available. Since even such short
aggregation periods might have varying underlying distributions, the time dependency of flow
and LOS will be further examined in the following case study. The used counting data was made
available by SBB (Swiss Federal Railways) and city of Zurich, supplemented by own
measurements. The SBB data were collected at the railway stations Zurich Stadelhofen, an inner-
city rapid transit hub, and Bern, an important national network node, both exhibiting suitably
high pedestrian volumes. Railway stations are good case studies for the application of the
density-based LOS, as the high traffic demand necessitates good design, and causes the type of
large, short-term flow fluctuations that are of interest. Furthermore, continuous and high-
resolution counting data is not yet widely available. The main goal of the case study is to
determine the counting periods that result in suitable peak values for the design of pedestrian
infrastructures. Secondly, an existing time-based LOS scheme is tested using the same data.

**Determining the peak values**

Although it is common practice in pedestrian transport to design for the peak hourly volume, a
formal method to determine the peak hour was not found in the literature. Pedestrian demands
are commonly obtained from short manual counts or estimated based on simulations. Only
recently have automatic counts enabled long-term measurements. Since such measurements also
include rare peaks, a design for the absolute peak hour might lead to oversized and expensive
infrastructures.

For motorized traffic the 30th to 100th highest hourly flows per year are used for design
purposes, which correspond to the 98.86th to 99.66th percentiles (27, 45). The authors propose
using the same range for pedestrian traffic, as the additional costs of designing for even higher
values would likely outweigh the additional benefits for the road users (46). Flows in the highest
percentile are mainly caused by rare events, like accidents or big events (47).

![FIGURE 1 Hourly pedestrian volume as a share of the average annual hourly pedestrian volume, sorted from highest to lowest. The dark grey area shows the 98.86th to 99.66th percentile, corresponding to the 30th to 100th yearly highest hourly flow. Blue = Data from 2016 for different locations within the city of Zurich (Data: data.stadt-zuerich.ch), Red = Zurich Stadelhofen, Green = Bern (Data: SBB)](image-url)

The principle of using a particularly busy peak hour, while not using the absolute highest
peak, is illustrated in FIGURE 1, showing the 95th to 100th percentile of hourly pedestrian
volumes as measured at a number of locations. For this figure, data from the city of Zurich,
covering different counting sensors found throughout the city (1 year, 15-min intervals), as well
as data from SBB (4 weeks, 1-min intervals) for several cross sections within the railway stations
Zurich Stadelhofen and Bern are used. It highlights the 98.86th to 99.66th percentile range mentioned above, which would result in a design volume of about 3 – 13 times the average annual hourly traffic. When determining the hourly flow used for facility designing, two additional points have to be considered. First, high flows can lead to undesirable crowding, which might pose a safety issue. These situations should be avoided, even for only a few hours per year. Otherwise, alternative safety measures must be implemented. As noted previously, the safety aspect is not included in the LOS and has to be considered separately. Second, the design flow for car traffic is intended to determine the capacity of the road, not the quality of the flow. Therefore, it might be possible to choose a lower percentile and still provide a good quality for the majority of the pedestrians.

**Flow fluctuations**

As mentioned above, available count data is usually aggregated to at least one-minute intervals. The available data therefore does not support measurement intervals that are short enough to account for the specific situations to which pedestrians react. On the other hand, considering the size of an infrastructure element, pedestrians spend a certain time within its extents. Individuals’ perception of quality differs as well. It thus seems reasonable to use an average flow value for designing facilities, as long as the measurement interval roughly corresponds to the individuals’ duration of stay on a particular infrastructure element.

Even when choosing relatively short measurement intervals in the range of 1 to 2 minutes, a considerable amount of the flow variation might be lost in the aggregation. To demonstrate this, counting data was collected for a daily two-hour peak at the entrance of the Zürich Hardbrücke station, another important rapid transit stop, for an aggregation interval of 15 seconds (48). The data show a mean value of 0.41 P/s and a standard deviation of about 0.40 P/s for the 15-second interval values (FIGURE 2). Fluctuations become considerably smaller for aggregation intervals greater than 10 minutes compared to shorter intervals. Most of the information about flow variations is already lost at that point. Even when measuring the commonly seen 2-minutes peak interval, the corresponding 15-second peak flow can be almost double the size. One important conclusion from this is that designing for LOS E, for example in a 2-minute peak, does not provide LOS E for all pedestrians, but only on average. This should be considered for when designing infrastructures, especially when platoons dominate the pedestrian flow. On locations where short peak flows can result in unsafe situations, such as crowding on railway platforms, smaller time intervals than 2 minutes should be used.
FIGURE 2 Mean, minimum and maximum flow for different aggregation intervals. Average flow = 0.41 P/s, standard deviation (15 s interval) = 0.4 P/s. Count data from Hardbrücke rapid transit station previously published by Meeder et al. (48)

Determining the relevant time interval for facility design

The only comprehensive time concept for LOS present in the literature was proposed by Weidmann et al. (1) who links each LOS to a defined time interval. For example, LOS B is considered acceptable within the peak hour, whereas LOS E corresponds to the 2-minutes peak (LOS C: 30 min, LOS D: 15 min). For locations where pedestrian volumes fluctuate sharply, thus exhibiting higher peak flows, this will result in LOS E being the determinant level. For more even flows, LOS B is more likely to be relevant. This approach aims at offering a good LOS for the majority of the pedestrians and an acceptable LOS for the short-time peaks. For the used count data, the peak values for each of these time intervals can be determined and compared to the design values, determining the time interval that should ideally be used for design purposes for each location (FIGURE 3). For the data used, this shows that in most situations, the 60-minute peak is most relevant. Since high but short peaks are expected within railway stations, this indicates that, using this approach, only in exceptional cases shorter time intervals are expected to be relevant.
Perceived Level of Service

Without further knowledge about the density distribution, it can be assumed, that the median and mean value are roughly equivalent. This means, that if the average density value corresponds to a certain LOS limit, about 50% of the time at least this LOS is available. Nevertheless, as higher pedestrian densities in the uncongested regime also mean higher flows and thus more pedestrians, less than 50% of the pedestrians will be provided with this LOS. Different flow patterns will result in different numbers of people served with the desired LOS level. In general, a more uneven load will result in less pedestrians experiencing a good LOS for the same average density.

Using the 99.66th percentile flow as design load and designing solely according to the LOS concept by Weidmann et al. (1) allows to determine the LOS values experienced. In FIGURE 4, this is done using the 1-minute count data for Zurich Stadelhofen and Bern. The data shows a higher variability in the share of pedestrians experiencing each LOS. For example, at least LOS B is reached for 50 – 93 % of the pedestrians and LOS E for 82 – 100 %. It can be also seen, that cross sections with higher demand generally show better LOS. It has to be noted here that no other design criteria, such as a minimal width or safety issues are considered. Thus, these cross sections are likely to have a higher width than based on this calculation and hence will also show better LOS.
FIGURE 4 LOS experienced by all pedestrians passing a measurement location, when the design concept by Weidmann (1) is applied. The 99.66th percentile flow is used for the design. The bars represent the individual measurement locations, sorted by the total number of pedestrians in ascending order (Data: SBB).

Although the share of pedestrians experiencing minimum LOS differs significantly between different locations, this approach is generally considered useful, as the design also has to include the cost efficiency. When considering only the observed cross sections showing higher flows, the experiences LOS are nevertheless in the same range. In addition, complete counting data is often not available, for which the concept allows to design pedestrian infrastructure using limited data.

Summarizing the considerations about the quality distribution and the timescales shows that the aim of the LOS concept, which is to provide a certain quality for a defined share of pedestrians can be achieved by optimizing the LOS limits and the design load used. If complete
data is available, the design approach can be further extended to define a minimum share of pedestrians experiencing each LOS. This could enable similar quality levels for different facilities while simultaneously achieving a high cost efficiency. For example, it might be decided that 80% of all pedestrians should experience at worst LOS B, 90% LOS C, 95% LOS D and 99% LOS E.

CONCLUSION
The research presented in this paper provides sufficient evidence that a time-based LOS concept can be applied to provide a satisfactory transport quality for the majority of users and at the same time meet the requirements of building cost-efficient and compact pedestrian facilities. Steps were made toward finding the appropriate time-intervals for designing efficient, high-quality pedestrian infrastructures. If facility design is based on the 99.7th percentile flow (or density) values, an acceptable compromise between comfort and economic values can be achieved. Applying the time-oriented LOS system suggested by Weidmann (1) to real world data of flows in train stations, it was shown that in the majority of cases 60 minutes is the most suited counting interval for determining the dimensions of pedestrian infrastructures. In situations where more pronounced peaks in the pedestrian volume over time occur, a 2-minute interval is usually needed.

Furthermore, it is important to stress that in order for an LOS-concept to fulfill its goals, the focus needs to be on the quality as perceived by the individual users. Although LOS is often described in terms of the efficiency of the pedestrian flow, the original meaning has always been a description of the transport quality experienced by pedestrians. Therefore, finding the time interval that best takes into account the relevant peak(s) in the flow can be helpful, as it enables the estimation of the shares of pedestrians that at least experience the various LOS bands. If detailed counting data are available, the LOS can be further developed by setting minimum LOS values for a share of pedestrians rather than a time interval.

One area in which the time-based LOS concept is still lacking is the relation between density and the perceived quality. Although intuitively this connection seems to make sense, and although a density-based quality scale is suggested in various rules and regulations worldwide, there is very little data supporting this concept, let alone providing the best-suited limits for the different LOS bands (A-F). Based on literature from the social sciences on subjective well-being, one possible approach could be surveys aimed at finding out at what densities negative emotions start to be the dominant ones. More research in this area is undoubtedly needed.

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