



## NEW CONDITION INDICATOR FOR SIDEWALK MAINTENANCE MANAGEMENT

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### Abstract

Maintenance of sidewalks is often limited to actions reacting to observations by personnel of the municipality or to users' complaints. For a systematic maintenance management approach for sidewalks the manager of the network must dispose of a sidewalk inventory and of a condition assessment of the sidewalks. The Belgian Road Research Centre (BRRC) built a "measuring chair" that produces a "comfort score". The scores are reported on blocks of 1 or 5 m, and as the average score for each sidewalk section. Furthermore, BRRC developed a methodology for the visual inspection of sidewalks for maintenance management purposes and defined a distress indicator based on the inspection results. In this contribution a new condition indicator is proposed, based on the block values of the comfort score, and better suited for decision making on prioritization of maintenance works. The goal of each of these indicators is to assign an adequate maintenance action to each sidewalk section: either local repairs, total surface treatments, or full reconstruction. A visual inspection and a measurement campaign with the measuring chair were conducted on the sidewalk network of a Belgian municipality. All indicators were computed. For the elaboration of a maintenance plan, sections were classified using only the distress indicator, using only the comfort score and a tedious manual verification of the values per block, and using only the new "triple indicator" proposed in this contribution. From the comparison we conclude that the triple indicator significantly improves the accuracy of the maintenance plan based upon the direct interpretation of the comfort scores. The example also shows that the optimal approach for the condition assessment of sidewalks is a combination of the triple indicator with the distress indicator since the latter does provide additional information.

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### 1 Introduction

Road asset management in urban environments includes sidewalks and pedestrian crossings. The expectations of the users of this part of the mobility infrastructure are high and inclusiveness is of high importance. In 2013 the regional road administration of Brussels looked for a means of objective evaluation of the comfort of newly paved sidewalks and BRRC built its first "measuring chair" for this purpose [1]. Based on accelerometer data, a comfort score is reported on 5 m long blocks. The average of these values over the total length of a sidewalk – usually limited on either side by a road crossing - is the comfort score of the sidewalk. For the interpretation of the comfort score of newly paved sidewalks, thresholds are used to define three categories: good, acceptable, and poor comfort. The comfort score and thresholds were fine-tuned through interactions with a panel of users representing the wide variety of expectations [2]. Members of the panel also included visually impaired, wheelchair users, and elderly.

The Region of Brussels now usually requires a comfort score of at least 8 in tenders for newly paved sidewalks. The comfort score was also used to evaluate the comfort level that can reasonably be expected from different paving materials used for new surfaces of sidewalks, and this information is presented in regional guidelines [3].

But then the measuring chair and the comfort score was tried out for the collection of condition data over the whole network of sidewalks of the centers of a few municipalities outside Brussels too [4]. These trials produced a map of the sidewalk network on which the classification based on the comfort score per section was visualized with three colors, accompanied by a more detailed map with the classification applied to each block of 5 m. The objective behind this kind of request is the determination of a plan of action on investments, to maintain or improve the network of sidewalks. Whereas a newly paved sidewalk section usually will present a homogeneous comfort level, sidewalks that are in use for a long time will not. While the deterioration of the condition of roads is mainly due to climate effects and the to be expected wear caused by heavy traffic loads, the causes of surface defects of sidewalks are not related to their ordinary use by pedestrians. Distress more likely appears after interventions of utility companies at the utilities underneath the sidewalk, and after inappropriate use of sidewalks by heavy vehicles. These distresses can be very local, resulting in local variations of the comfort score. As a consequence, the interpretation of the network-wide classification of sidewalk sections becomes tedious. A sidewalk with a high average comfort score can have local distress, so that one or two 5 m blocks will have a very low comfort score. And exactly these local uncomfortable blocks may very well make the section unfit or unusable for some users. The sidewalk manager must therefore get a close look at the detailed 5 m block data for decisions on maintenance actions. The new condition indicator presented in this contribution easily detects such cases, and is designed to support the manager in the decision making process.

The measuring chair is a practical data collection tool but the comfort score will only be influenced by unevenness in the area over which the chair rolled. Other distresses than evenness, and distress on the sides are not detected. For this, BRRC developed a methodology for visual inspection at network level of sidewalks and road crossings [5]. This methodology also aims at supporting the decision making process of sidewalk managers. The widely accepted quality requirements for cycling infrastructure [6] also apply to sidewalks: comfort, safety, attractiveness, directness, and coherence and readability. The methodology for visual inspection proposes to report the presence and extension of a limited number of predefined surface defects as well as the observation of predefined user-unfriendly “situations”. For each section and from the reported surface defects, a condition indicator is computed as a weighted sum. This condition indicator gives information in addition to the comfort score, as will be illustrated in this contribution.

## 2 Data collection methods

### 2.1 Measuring chair

The measuring chair (figure 1) consists of a wheelchair equipped with sensors. The chair is pushed at a near constant speed of 1 m/s (walking speed). The vertical accelerations generated by unevenness of the surface and registered with an accelerometer on the chair are translated into a comfort score on a scale from 0 (uncomfortable) to 10 (perfect). A camera is triggered to take a picture of the surface every 5 m. The accelerometer data are also used to determine gradient and cross-fall of the surface.



Figure 1 Measuring chair of BRRC

## 2.2 Methodology for visual inspection on network level

The methodology for visual inspection described in [5] is intended to evaluate at network level the condition of sidewalks, pedestrian crossings, and other public spaces where the pedestrian occupies a central position. Inspecting a whole network may be time consuming and visual inspection is always tedious because of the potentially subjective appreciation of a human inspector. To counter these difficulties, the methodology prescribes that the inspector only reports the existence and extent of six well-defined defects (listed in Table 1). The registered defects on sidewalks (and other paved public spaces and squares dedicated to pedestrians) are translated in a condition indicator. This approach is similar to the methodology of BRRC for visual inspection of communal road networks [7]. The methodology also describes three “situations” to be reported by the inspector. A “situation” is not the result of the changing condition of the infrastructure, but of decisions on its design or of its misuse. These situations are the design width of the sidewalk is not adequate (less than 1.2 m in the case of regulations in Brussels), the free height is insufficient (an overhanging object, tree branch, ...), and the effective free width of the sidewalk is too little due to a permanent obstacle (lamppost, ...).

Table 1 Defects  $D_i$  and their weights  $w_i$  for the definition of the condition indicator

Defect $D_i$	Weight $w_i$	Defect $D_i$	Weight $w_i$
Degraded joint	3	Subsidence	7
Degraded integrated asset	5	Upward unevenness	7
Material distress	2	Missing material	9

The inspector is invited to make pictures of defects and situations. BRRC developed an app on tablet or smartphone for easy registration of defects and situations by inspectors on site. The observations are immediately reported on a map in the geoportal of BRRC. This app is used for training sessions organized by BRRC for inspectors and road managers.

## 3 Sidewalk condition indicators

Measurements with the measuring chair and visual inspections are translated in indicators that are intended to support maintenance and management decisions.

### 3.1 Comfort index

The comfort index is determined from the accelerometer data of the measuring chair collected on sidewalks and other surfaces specifically designed for use by pedestrians. A value for the comfort index is computed for all accelerometer data collected while the measuring chair is displaced over 5 meters. Alternatively, this distance can be chosen to be 1 meter. The index is based on the standard deviation of the vertical acceleration (inspired by the comfort score of bicycle paths obtained with the “measuring bicycle” of the Belgian Fietsersbond [8], and then linearly rescaled to match the comfort evaluation by the panel [2]. But to make it into a repeatable and reproducible evaluation technique, the technical specifications of the measuring chair must be respected, including the frequency of the data acquisition of the vertical acceleration at 100 Hz, a standard weight and the absence of a suspension on the wheels. For a section of a sidewalk with a newly constructed surface, the measuring chair is pushed over the whole length of the section, and the comfort index of the section is defined as the average of all comfort indices reported on the blocks of 5 m. From the comparison with a panel of users [2], a sidewalk with values higher than or equal to threshold = 8 is considered as comfortable, and with values strictly under threshold = 6 as unacceptable. Hence, as a first approach to maintenance management, it was proposed to measure all sections of a network with the measuring chair and to use these thresholds for classification of sections into three categories, as in table 2. The comfort score does not indicate how usable the sidewalk is. A section with comfort score more than 8 can still be very user-unfriendly because of a local distress. Within a section with high average comfort score there can be a local block of 5 m with a low value for the comfort score. Such a block usually englobes a local distress that can be resolved by a local repair. Therefore, it is recommended that the pavement manager also looks at the reported scores per blocks of 5 m.

**Table 2** Maintenance categories from comfort score thresholds

Comfort score C	Meeting comfort expectations	Maintenance measure
10 - 8	Excellent	No maintenance
8 - 6	Sufficient	Investigate, may need local maintenance
6 - 0	Insufficient	Investigate, may need global maintenance

### 3.2 New Indicator: the “triple indicator”

The objective of the new “triple indicator” is to automatically detect sections with local distresses despite their “high” average comfort score. This indicator of a section is a triple  $(C, R, Sk_2)$ , where  $C$  is the comfort score of the section,  $R$  is the range of the comfort scores reported on blocks of 5 m (or 1 m) within the section, and  $Sk_2$  is Pearson’s second skewness coefficient  $Sk_2$  [9, 10] for the comfort scores reported on blocks within the section.  $Sk_2$  is a measure of the deviation from symmetry in a data population and can be calculated with a simple formula:

$$Sk_2 = (3(C - m)/s) \tag{1}$$

with  $C$  the average,  $m$  the median, and  $s$  the standard deviation of the comfort scores on blocks in the section. Hence,  $C$  is the comfort score of the section.

The triple indicator allows to refine the section classification solely based on the criterion in table 2 on  $C$ , and to assign the most adequate maintenance measures for each. The finer classification is presented in the form of a matrix in table 3.

**Table 3** Maintenance category matrix from the new triple indicator (C, R,  $Sk_2$ )

C	R ≤ 2	R > 2			
		$Sk_2$ [-0.5;0.5]	$Sk_2$ [-1;1] \ [-0.5;0.5]	$Sk_2 > 1$	$Sk_2 < -1$
10 - 8	No maintenance	No maintenance	No maintenance but do follow-up	Local repairs	Local repairs
8 - 6	Investigate for local repairs	Local repairs	Local repairs	Local repairs	Reconstruction
6 - 0	Investigate general condition	Investigate general condition	Investigate general condition	Local repairs	Reconstruction

Range  $R$  of the comfort scores on the blocks in the section gives a first idea about the homogeneity. If range  $R$  is smaller than 2 then the block scores in the section are quite homogeneous. By definition,  $Sk_2$  is comprised in the interval  $[-3; 3]$ . For  $Sk_2 = 0$  the distribution of comfort scores on blocks in symmetric within the section. When  $Sk_2$  is negative, there are more blocks with low values. When  $Sk_2$  is positive, the condition of the section is better than what the average value  $C$  suggests. Common thresholds for  $Sk_2$  are -1, -0.5, 0.5 and 1 [11, 12]. When  $Sk_2$  lies within interval  $[-0.5; 0.5]$  the distribution is quite symmetrical. If  $Sk_2$  lies outside  $[-1; 1]$  then the distribution is really asymmetrical. One of the advantages of Pearson's second skewness coefficient is that it can also be used on small data populations. Yet, in the case of a very short section and a very small data population,  $Sk_2$  is too pessimistic. Therefore it is still important for a pavement manager to know the size of the sections when interpreting the results.

### 3.3 Condition indicator from visual inspection

From a visual inspection of the defects listed in table 1 a condition indicator for visual distress is computed with the following formula:

$$I_D = \max \left( 0; 0.9 - \left( \sum_{i=1}^6 (P_i \cdot w_i) \right) / S \right) \quad (2)$$

where  $P_i$  is the cumulated surface (in  $m^2$ ) of the inspected section attained by the  $i$ -th defect ( $D_i$  in table 1),  $w_i$  is the weight associated to the  $i$ -th defect (given in table 1), and  $S$  is the total surface (in  $m^2$ ) of the inspected section. The value of  $I_D$  is always within interval  $[0; 0.9]$ . When a whole network is inspected, each of the sections can be attributed to one of 4 classes (as defined in table 4), defined by thresholds 0.8, 0.5 and 0.3 on  $I_D$ .

**Table 4** Maintenance categories from visual distress indicator

Visual distress indicator $I_D$	Maintenance measure
0.9 - 0.8	No maintenance
0.8 - 0.5	Local repairs
0.5 - 0.3	General surface repairs on part or total section
0.3 - 0	Reconstruction

## 4 Application to a sidewalk network

In the development phase of the triple indicator, the effectiveness of it was tested on a data set of previously collected comfort scores on 693 sections based on blocks of 5 m. Almost no sections had  $C \leq 6$  but the exercise showed that the triple indicator would identify sections with local inhomogeneity. No images or visual inspection results were available though.

The center of a municipality was measured with the measuring chair and visually inspected with the tablet app at the same time. All data were transformed in forementioned indicators and reported on a map in the geoportal of BRRC. Rather than reporting on 5 m blocks, the data were presented on blocks with 1 m length to allow a better understanding of matches between local comfort issues and visually identifiable distress. The municipality did not have an inventory of the sidewalks and sections were not pre-defined. The comfort is reported on longer sections, sometimes changing in surface materials. For the visual inspection, sections were defined on the go, taking the surface material into account.

For the measuring chair the network was divided in 66 sidewalk sections and the comfort index was determined on a total of 5014 blocks of 1 m. Of those 66 sections, 13 had comfort score  $C < 6$ , a range  $R > 2$  and  $Sk_2 < 1$ . So, both the evaluation based on  $C$  and on the triple indicator led to the same conclusion: these sections need reconstruction. 11 sections had comfort score  $C$  between 6 and 8. One of them had  $Sk_2 < -1$  and therefore qualifies for reconstruction rather than local repairs, following Table 3. This section had  $C = 7.76$ , an average comfort score not very far under 8. The inspector reported two distresses at the beginning of the section, leading to  $I_b = 0.72$ , which made this section qualify for local repairs. The measuring chair reported very high comfort except on the last quarter of the section where the comfort index per 1 m blocks turned very low. On the photos taken by the camera on the measuring chair one can clearly see subsidence in this part of the section, not reported by the inspector. All other sections had a comfort score  $C$  of at least 8, and 11 of them even got the maximum score of  $C = 10$ . But out of the 42 sections, 19 had  $Sk_2 < -1$ . Only 5 had  $Sk_2$  in  $[-0.5; 0.5]$  (no maintenance). The final 18 sections had a negative value for  $Sk_2$  but within range  $-1 < Sk_2 < -0.5$  (no maintenance but do follow-up). A negative value means that there is a higher non-symmetric contribution of smaller values to the average.

Visual inspections were performed on a large part of the same network but reported on differently defined sections. The inspector registered 293 visual defects and created 58 sections. Of these 58 sections, 11 have  $I_b > 0.8$  (no maintenance needed), 24 have  $I_b$  between 0.5 and 0.8 (local repairs), 9 have  $I_b$  between 0.5 and 0.3 (general surface repairs), and 13 have  $I_b < 0.3$  (rebuild). Comparing the classification of the sidewalks can only be done by visual representation on a map since in this exercise the sections are not the same for the measurements and the inspections. For example, one of the sections measured with the measuring chair is 666 m long,  $C = 7.71$ ,  $Sk_2 = -0.72$ . This corresponds to 6 sections of the visual inspection, of which 2 very short ones with  $I_b = 0$  (one in asphalt with good comfort scores on 1 m blocks but defects next to the wheel path of the measuring chair, the other in cobblestones and bad comfort scores), 2 with  $I_b = 0.54$  and 0.49 (in concrete blocks and with varying comfort scores on 1 m blocks), and the 2 sections at opposite ends with  $I_b = 0.34$  and 0.36 (also in concrete blocks and comfort scores on 1 m blocks not particularly worse). At another location, a section with  $I_b = 0.84$  corresponds completely to a section with  $C = 9.14$  and  $Sk_2 = -1.21$ . These indicators indeed match very well: 2 places with significantly low comfort scores on blocks correspond to observed material distress.

## 5 Conclusion

The comfort index of a section being an average of comfort indices per blocks of 5 m or 1 m along the section measured with the measuring chair of BRRC does not suffice to detect local discomfort. The triple indicator proposed by the author automates the detection of local inhomogeneities in the comfort. Still, surface defects out of the wheel paths of the measuring chair may not influence the comfort score. Hence, visual inspection is a welcome addition for the evaluation of the surface condition of sidewalks. Then, a human inspector can overlook a defect, including subsidence. The optimal approach for the evaluation of the condition of sidewalks at network level, for the determination of maintenance interventions and management of mobility assets, will benefit from combining comfort measurements and inspections. It is recommended that the manager first decides on a well-defined subdivision in manageable sections (and this aspect is also discussed in [5]).

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