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Managing sidewalk pavement maintenance: A case study to increase pedestrian safety

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ABSTRACT

Comfort is a major requirement in planning pedestrian facilities. Pedestrians walk where they feel comfortable and when they do not feel at ease, they walk elsewhere. A typical example is that filthy, distressed, or too narrow sidewalks induce pedestrians to walk on carriageways. This behaviour jeopardizes road safety and highly dangerous to most users, leave them vulnerable. Unsuitable pavements can be the result of irregular maintenance operations to restore evenness after shock damage, weather phenomena, installation of equipment (e.g., posts, fences, urban furniture) with a reduction of walkable surface, or substandard repair work on pavements and patches due to emergency operations. These problems can be solved with an appropriate maintenance management system, which optimizes financial resources to make smart decisions about how to intervene with an adequate and lasting maintenance operation. This paper defines an evaluation index for sidewalk conditions as a part of an efficient set-up of a Sidewalk Management System, which is similar to the better known Road Management System. The study relies on surveys, as well as the classification and analysis of sidewalk distresses. The authors adapted an index already standardized by ASTM for roads and airports: the Pavement Condition Index (PCI). PCI has been modified to consider the specific types on the sidewalks studied within this paper. To validate the method, a case study of a residential district in Rome, Italy, was carried out. The chosen area lacks regular maintenance and has therefore resulted in a network of unsafe sidewalks. Frequent detour routes were surveyed and related to the level of distresses within a general assessment of safety. This study concentrates on sidewalks with flexible pavements because this type of pavement is the only one adopted in the survey areas and, in general, throughout Italy.

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1. Introduction

Pedestrians of every age travel erratically, deciding to walk on pavements they feel comfortable on or attracted by. When they do not feel at ease, they detour from the current route towards a more comfortable one (Marisamynathan, 2014; Ren et al., 2011). A typical example is a filthy, distressed or too narrow sidewalk which induces pedestrians to jaywalk or simply travel directly on the carriageway. Although extremely unsafe, this kind of behaviour is quite common, even among older pedestrians. The literature in this field highlights the need of high-quality walking surfaces for older pedestrians (Dunbar et al., 2004; Heinonen and Eck, 2007; Zegeer et al., 2013). However the real environment often does not meet such requirements and is usually ignored by road managers.

Subpar sidewalk conditions can be aggravated by adverse weather conditions, shocks, poor maintenance or cleaning, installation of inappropriate urban furniture or equipment, substandard execution, low quality materials, and other deteriorating factors. Emergency operations are the promptest solution to restore evenness conditions, as evidenced by the large number of patches. As a result sidewalks are not safe nor comfortable, and least of all, attractive.

Rome's infrastructure exemplifies this and serves to emphasize the need to plan regular sidewalk maintenance operations.

Therefore, this paper introduces the methodology of Sidewalk Management System (SMS), as derived from the better known Road Management System. The method includes survey, classification, and analysis of sidewalk distresses to adapt an index already standardized by ASTM for roads and airports: Pavement Condition Index (PCI).

A case study was carried out in Rome to validate the procedure, and this paper describes the main outcomes and provides final recommendations to improve the quality of sidewalks for pedestrians. The results obtained also allow administrations to plan maintenance treatments according to user perceptions and standard technical practices. The purpose is coherent with the need of the Italian Public Administration to survey the state of roadways and sidewalks and launch a comprehensive action plan based on existing maintenance plans.

2. The case study

The case study was performed in the Second District in Rome (Fig.1), a northern residential district where the lack of regular maintenance resulted in a network of unsafe sidewalks.

This district, subdivided into several smaller sub-districts, as shown in Table 1, is a typical medium-to-high income Roman neighbourhood with a medium population density area built between 1920s and 1960s. Residential and business activities prevail in this district. The built environment is of high-quality with low-rise buildings that seldom exceed five stories and landscaped areas with planted strips and plenty of vegetation. This area also contains several landmarks such as parks, churches, and a full provision of sidewalks that make the district ideal for walking. According to 2006 Municipality study (Cecconi, 2007) the walking share in the local modal split was higher than Roman average value (respectively 6.9 vs 5.6, as in Table 1). No more recent data on local modal split are available. However the reference scenario for the whole city provided by the Roman Urban Traffic Plan (Rome Municipality, 2015) suggests that no considerable changes have occurred so far.

Although theoretically ideal for walking, the area is far from ideal for pedestrian travelling. As shown in Fig. 2 road accident data are represented by black spots and they concentrate in specific areas. The larger, central cluster (yellow area in Fig. 2) is located in a residential zone, the Trieste area.

Surveys from a previous study focused on two main squares (Piazza Mincio and Piazza Caprera) of Trieste area. Their surroundings highlighted that modest motorized traffic (estimated $\leq$ 5000 passenger cars/day) and strong pedestrian flows (estimated $\leq$ 4000 pedestrians/day) resulted into a walking occupancy of carriageways, as shown in Fig. 3, where the surveyed pedestrian routes and flows are reported. A contributing factor was the sidewalk unsuitability, as the paths were too narrow and uneven, which were mainly due to potholes, chinks and exposed tree roots. In addition, drivers moved well below the speed limit, yielding priority to pedestrians (Corazza and Di Mascio, 2003).

Despite of the fact that some functions and businesses changed in the surveyed area in the last decade (a high school closed permanently on one square, a redesign program was carried out on the other one, with sidewalks slightly widened and a number of new supermarkets opened nearby), a recent survey confirmed the habits and the features previously observed. Sidewalks maintenance is still poor and due to the same problems, pedestrians still favour carriageways instead of sidewalks. Traffic and pedestrian flows are not markedly different; drivers still travel well below the speed limit. The new aspect to consider is the increased amount of elderly pedestrians, especially in the morning hours. As for this specific category, the observed behavioural patterns include walking with shopping trolleys (35% surveyed), walking with pets (25%), and general strolling (30%). The majority (around 65%) performed these duties jaywalking, detouring from sidewalks, or walking directly on carriageways.

Further recurring habits have been observed among the general pedestrian population, and especially among older pedestrians. They prefer walking on the sunny side of the street in winter (the survey took place on average working days in wintertime). Probably they would choose the shadowed side in summertime. When carrying shopping bags or walking pets they tend to avoid sidewalks perceived too narrow or crowded (due to furniture, trees, etc.) and even when plenty of space was available to walk on. Once they left the sidewalk for any reason, they continued to walk on carriageways until having to cross the street or change direction.

3. A methodology to improve pedestrians safety

Unsafe behaviour and the observed recurring black spots in the survey areas demonstrated the unsuitability of the case

Fig. 1 – Second District location in Rome.

study's sidewalk network. The next part of the research concentrated on a feasibility study of an efficient maintenance management system aiming to improve the local pavement quality, making it more attractive to and safe for pedestrians. This methodology is based on a three-step procedure:

(1) Set-up tools to identify the test field within the study area
(2) Define the sidewalk condition index and its application to the test field in line with prospective maintenance management plans
(3) Analysis the results

Table 1 – Case study district.

Indicators		Second District		Rome
Inhabitants (units)		123,000	The Second District area within sub-districts	2,800,000
District area (sqkm)		13.67		1284.8
Population density (inh/sqkm)		8996		2180
Local modal split (%)	Pedestrians	6.9		5.6
	Transit	10.3		27.0
	Private cars	51.7		52.1
	Powered two-wheelers	31.0		15.3
Green areas (% of whole district area)		22.10		4.15
Pedestrian areas (% of whole district area)		0.01		0.12
On-street parking areas (% of whole district area)		0.60		0.29
ZTLs (% of whole district area)		6.00		2.10

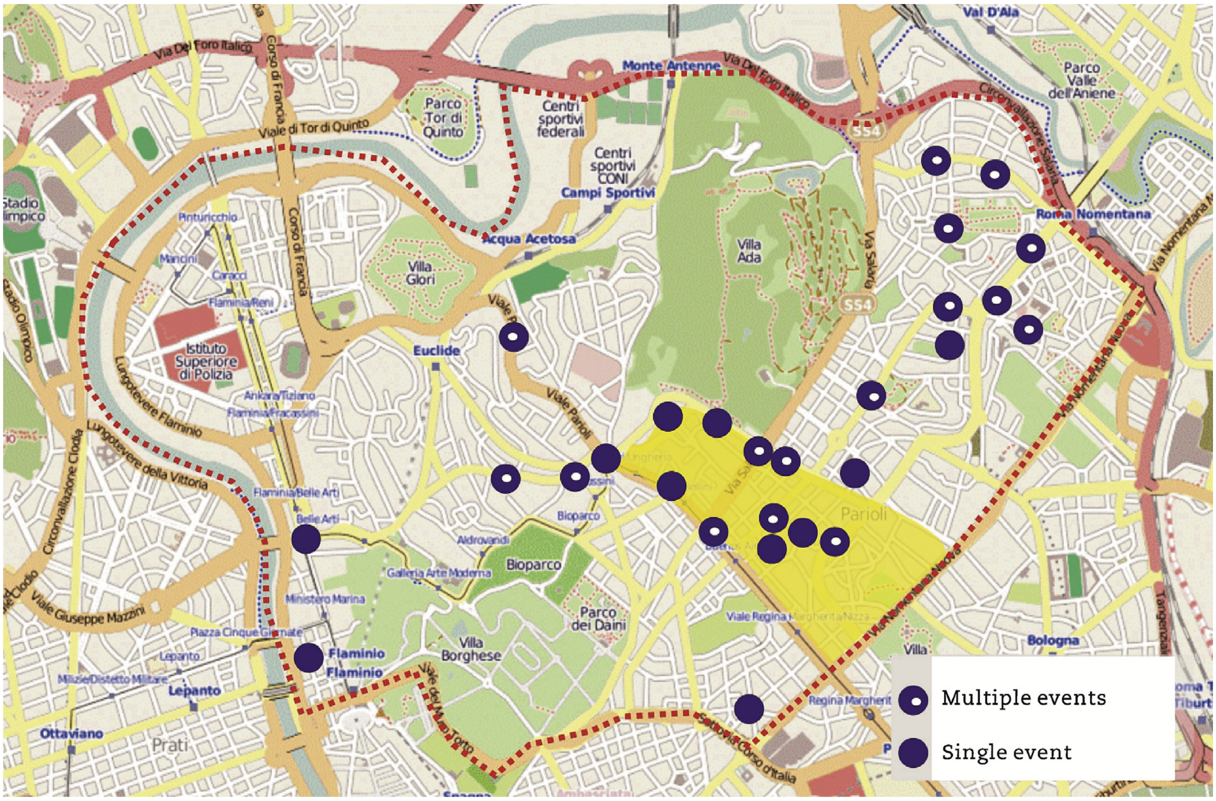

Fig. 2 – Road accidents involving pedestrians aged 65 and over in case study district during 2010–2012.

3.1. *The test field*

The identification of a restricted area or test field for the study of the proposed methodology was then based on the results of several checklists. This procedure aimed at assessing the "walkability" of the environment around the two squares in connection with the location of the black spots. Relationships between walkability and pedestrians requirements have been studied widely (Marquet and Miralles-Guasch, 2015; Negron-Poblete et al., 2014). Although walkability checklists, surveys and analyses abound in grey and scientific literature (Galanis and Eliou, 2012; O'Hanlon and Scott, 2010; Kelly et al., 2011; Maghelal and Capp, 2011), for this study a set of dedicated checklists were specifically developed. These lists addressing specific issue (comfort, safety, accessibility, attractiveness) were applied to each street of the Trieste area.

Each list includes several scoring requirements in accordance with the following criteria:

(1) "Adequate" with a score of 2 if the requirement was met at more than 75% of the street.

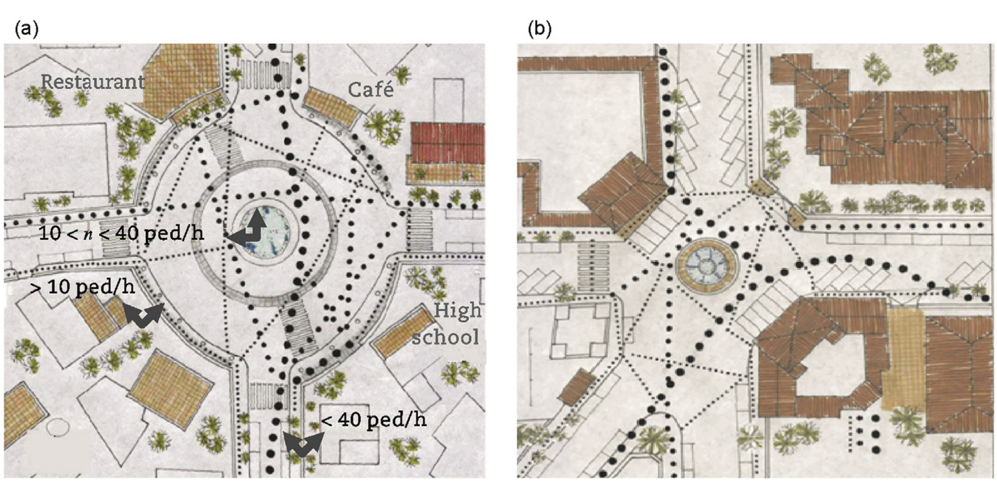

Fig. 3 – Pedestrian routes of two squares within study area (Corazza and Di Mascio, 2003). (a) Piazza Caprera. (b) Piazza Mincio.

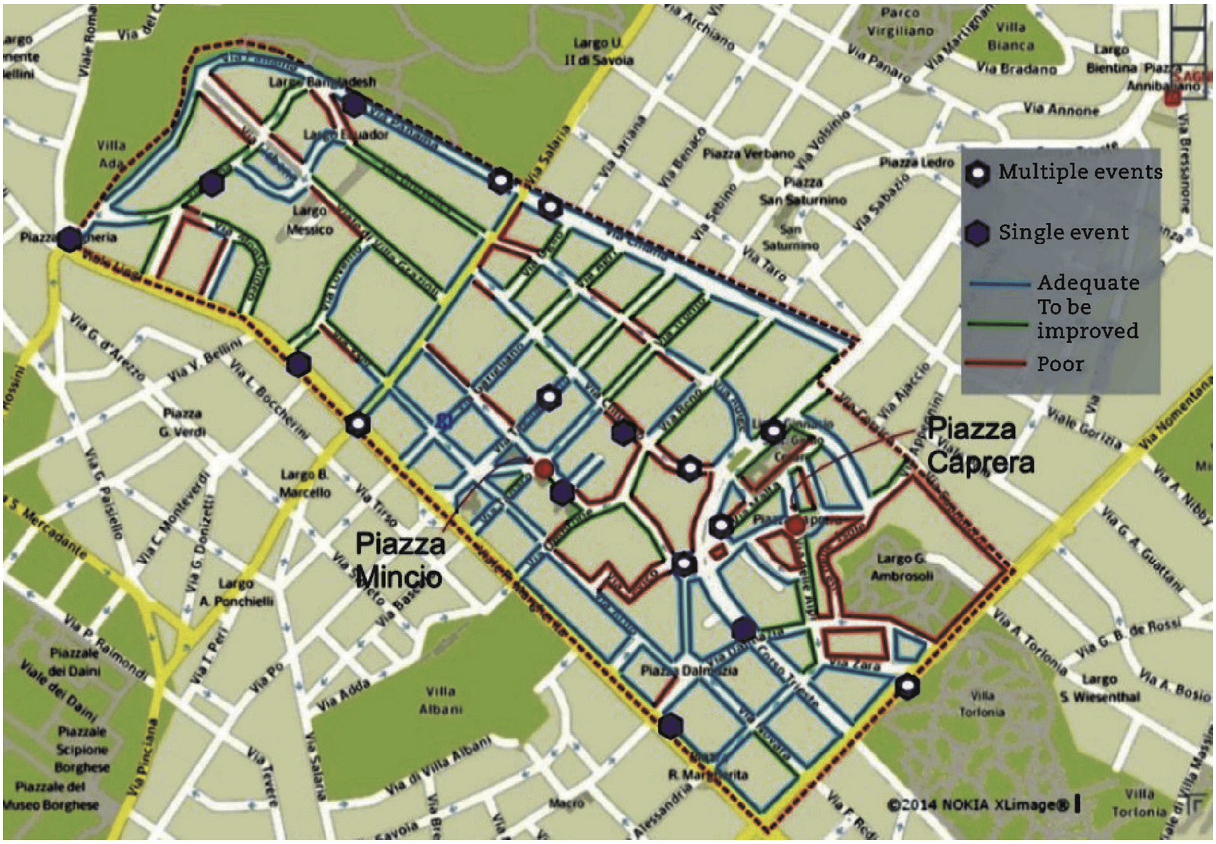

Fig. 4 – Trieste Test Field.

(2) "To be improved" with a score of 1 if the requirement is met between 50 and 75% of the street.
(3) "Poor" with a score of 0 if the requirement is met for less than 50% of the street.

Scores were provided qualitatively based on a visual inspection of each street. Those with the lowest scores (i.e. "poor" streets) became eligible for the test field. The criterion of continuity was then introduced: connecting "poor" streets were clustered so as to become "poor" routes. These routes associated with black spots were likely candidates for test field.

At the end of this process one area resulted more appropriate than the others due to the additional higher recurrence of accidents involving pedestrians (Fig. 4). In this 5500 m^2 area virtually corresponding to the yellow-highlighted one in Fig. 2, called the Trieste Test Field (TTF), the whole pedestrian pavement network was analysed, excluding the private access areas with interrupted sidewalks (for example driveways) as further described.

Pedestrian flows in the TTF were slightly higher (about >50 pedestrians/h along the "poor" route) than the average flow surveyed in the whole area. In the morning hours the amount of elderly pedestrians walking alone was around 35% which is a not negligible group if compared to other ones observed. About 25% of the pedestrian were teenagers and young people (two high schools are nearby) and 40% aged in-between. For what concerns pedestrians walking in groups (two to four people) percentages slightly change: 38% young people, 39% old people (the majority of groups were formed by one elderly and one younger person) and 23% people aged in-between.

3.2. *Definition of a sidewalk condition index and its application to the test field*

After the TTF selection the study proceeded with the analysis of sidewalks and the assessment of the applicability of the Sidewalk Management System (SMS) derived from the better known Road Management System. The method relies on a number of surveys, classifications and analyses of sidewalk distresses adapting an index already standardized by the American Society for Testing and Materials (ASTM) for roads and airports: Pavement Condition Index (PCI), as further described.

3.2.1. *Sidewalk condition index*

In 1970s, when the concepts of the maintenance management system started to be applied to roads, experts focused mainly on the Pavement Management System (PMS). During 1980s and particularly after the first North American Pavement Management Conference held in Toronto, Canada in 1985, the PMS was recognized as a major tool aid in road engineering. Since then, the PMS has been used by road administrations worldwide to define maintenance and rehabilitation strategies for pavements of road networks under their jurisdiction (Ferreira et al., 2002). However few procedures on the transportation infrastructure other than roads have been developed to define the PMS and others have been defined to calculate the level of service of sidewalks (Kang et al., 2013; Singh and Jain, 2011; Tan et al., 2007). A Transportation Infrastructure Maintenance Management System (TIMMS) was developed for a small town in Utah, USA (Cottrell et al., 2009). The objective of the TIMMS was to maximize the maintained portion of infrastructure and its serviceability as well as minimizing resident complaints.

Later on, a Pedestrian Safety Indicator was defined in a case study conducted in the city of Palermo, in Italy. It considered the presence of fixed obstacles, width and pavement of sidewalks to calculate a specific sub-index, dedicated to assess the pavement wearing condition of both sides of a street (Amoroso and Caruso, 2008).

A global index was further developed including all the components of the road space in order to support the manager in his/her decisions for maintenance strategies. These included also sidewalks and their characteristics of walkability, disconnections, cracking, potholes and missing ramps which were estimated to assess a condition index (Loprencipe et al., 2011).

A PMS is made up of several steps: pavement distresses survey, pavement evaluation, life cycle cost analysis and, finally, definition of maintenance strategies (D' Andrea et al., 2013; Moretti, 2014; Moretti et al., 2012). A proper definition of PMS allows reducing the overall road costs (construction and maintenance) as well as traffic disruptions (Moretti et al., 2012, 2014). Although mobility has always dealt with the vehicular traffic as a consequence of cultural and economic reasons, the recently increasing attention to environmental impacts and road safety has steered the research towards sustainable mobility particularly pedestrian mobility.

Along the same line TTF application relies on a Sidewalks Condition Index (SCI) to quantify sidewalk conditions and the amount of the distresses that can be dangerous and uncomfortable for pedestrians. Transferring knowledge from the field of motorized traffic the SCI was derived from the Pavement Condition Index (PCI) largely recognized in scientific literature and practice. PCI became standardized for both airports (ASTM D 5340-11) and roadways (ASTM D 6433-11) in 1998.

As with PCI, SCI is a numerical indicator that rates the current pavement surface condition. It provides a measure based on the distresses observed on the pavement surface that indicate both structural integrity and surface operational conditions (localized roughness and skid resistance). The PCI ranges from 0 to 100 with 0 being the worst possible condition and 100 being the best possible one (Shahin, 2005). In addition the PCI provides feedback on pavement performance for validation or improvement of current pavement design and maintenance procedures.

This research proceeds with the specific aim of defining SCI for TTF by elaborating on a catalogue of pavement distresses. The pavements were divided into branches and sections. The first ones are identifiable parts of the network (e.g., a given link with its own street name or links with the same street name). Since branches are typically large units of the pavement network they are separated into smaller components called “sections” for managerial purpose. Therefore a section is a contiguous pavement area with uniform features such as construction, maintenance, usage history, and conditions.

For the purpose of pavement inspection, each section is divided into sample units that are portions of a pavement section.

The PCI method states the reference dimension of the sample unit for a statistical significance of the survey. The method also evaluates different pavements (e.g., asphalt, concrete, and unpaved). This study considers only asphalt pavement, which is the most recurring type in Italy and the only type present in TTF.

A sample unit is defined as an area of 225 ± 90 m^2 for asphalt surfaced roads and 450 ± 180 m^2 for asphalt surfaced airfields. For TTF, the dimension of a pedestrian sample unit was defined by extrapolating these measures as a function of the width of roadways and airports. As shown in Table 2, the runway width can vary from 20 to 60 m while the road width is generally within 10 m and 30 m and the sidewalk width between 1.5 m, which is the worldwide minimum recommended width to accommodate wheelchair users and 10 m. These dimensions are also consistent with the Italy's enforced standards.

The minimum and maximum values of the areas set in the PCI method were correlated with the minimum and maximum width of roads and airports. The width of the sidewalk sample unit was then proportionally calculated, as shown in Table 2, with a resulting reference value of 100 ± 50 m^2.

3.2.2. *Distress survey on asphalt pedestrian pavements*

According to the PCI method, asphalt pedestrian pavement distress can be classified as follows:

(1) block cracking
(2) diffused cracking
(3) linear cracking
(4) patching and utility cut patching
(5) potholes
(6) corrugation
(7) bleeding
(8) ravelling
(9) weathering
(10) deformation due to roots
(11) deformation due to run-off water
(12) differential settlement of the pavement sub-base layers in comparison to the interspace of buildings
(13) depressions
(14) edge disruption

Table 2 – Definition of sample unit area for asphalt surfaced sidewalk.

Dimension	Infrastructure		
	Runway	Road	Sidewalk
Minimum width (m)	20	10	1.5
Minimum area (m^2)	270	135	50
Maximum width (m)	60	30	10
Maximum area (m^2)	630	315	150

The specially designed TTF distress registry includes a number of sheets, with each representing distress measured in terms of size and severity. Fig. 5 shows the description sheets for potholes and deformations due to roots on a sample street within TTF.

The survey is conducted purely visually, and data is recorded on a spreadsheet similar to the one in Table 3.

Geometrical features (e.g., area, section, branch, code), survey date, amount and severity level of the distresses were recorded for each sample unit. The name, code, and area of each branch (R_i), sections (S_i) and sample unit (U_i) are listed in Table 4. Branches are subdivided into "even" and "odd" sides to correspond with the local street numbering.

Fig. 6 shows the density of the recorded distresses in TTF. The highest density (more than 50%) is associated with patching (4), potholes (5), corrugations (6) and depressions (13).

3.2.3. *Calculation of sidewalk condition index (SCI)*

As with PCI, SCI ranges from 0 to 100 and 0 is the worst possible condition while 100 is the best possible one, it can be calculated as follows

$$SCI = 100 - CDV \quad (1)$$

where CDV is the correct deduct value that considers the relationship among several distresses and can be calculated according to the following four-step procedure:

(1) Definition of distress percent density of each type of distress *i* at each severity level *j*:

$$d\% = \frac{A_{distress}}{A_u} \times 100 \quad (2)$$

where A_u is the sample unit area, $A_{distress}$ is the total area for each type of distress *i* at each severity level *j*.

5 Potholes

Description

Potholes are small—usually less than 0.01 m^2— bowl-shaped depressions in the pavement surface with a lack of asphalt . They are generally caused by weak layers underneath or the evolution of linear or block cracking.

Severity levels

The severity levels of potholes are based on both diameter and depth of the pothole, according to the following table:

	Average diameter		
Maximum depth of pothole	100 - 200 mm	200 - 400 mm	> 400 mm
10 - 20 mm	Low	Medium	High
20 - 40 mm	Medium	Medium	High
> 40 mm	High	High	High

How to measure

Potholes are measured in square meters of distressed surface area.

Low severity Medium severity High severity High severity

10. Deformation due to roots

Description

Deformation due to tree roots includes all pedestrian pavement unevenness that is caused by the roots of trees.

Severity levels

No degrees of severity are defined. However, without the construction of new wearing courses, the distress increases.

How to measure

Deformation due to roots is measured in square meters of the distressed surface area. Any other distress in the area is included in the measurement.

Fig. 5 – Catalogue of pedestrian asphalt pavements distresses with two registry sheets.

Table 3 – Survey data sheet for pedestrian asphalt pavement.

Pedestrian asphalt pavement-condition survey data sheet for sample unit											
Branch Branch area (m^2)			Section Date			Sample unit Sample area (m^2)					
1.Block cracking 2.Diffused cracking 3.Linear cracking 4.Patching and utility cut patching 5.Potholes				6.Corrugation 7.Bleeding 8.Ravelling 9.Weathering 10.Deformation due to roots			11.Deformation due to run-off water 12.Differential settlement of the pavement sub-base layers in comparison to the interspace of buildings 13.Depressions 14.Edge disruption				
Distress type	Quantity						Total		Density (%)	F_i	DV_i
									TDV=		
									CDV=		
									SCI=		

Table 4 – Division in branches (R_i), sections (S_i) and sample units (U_i) for the distress survey activity on the pavements of TTF.

Branch		Branch area (m^2)	Section	Section area (m^2)	Number of sample unit	Sample unit code
Via Brenta (even)	R_1	213.11	S_1	213.11	2	U_1;U_2
Via Brenta (odd)	R_2	222.32	S_2	222.32	2	U_3;U_4
Via Ombrone (even)	R_3	126.06	S_3	126.06	1	U_5
Via Serchio (odd)	R_4	426.61	S_4	426.61	4	U_6;U_7;U_8;U_9
Via Serchio (even)	R_5	199.57	S_5	199.57	2	U_{10};U_{11}
Via Ticino (even)	R_6	204.36	S_6	204.36	2	U_{12};U_{13}
Via Ticino (even)	R_7	253.51	S_7	253.51	2	U_{14};U_{15}
Piazza Trento	R_8	500.84	S_8	500.84	5	U_{16};U_{17};U_{18};U_{19};U_{20}
Via Appennini (even)	R_9	214.11	S_9	138.20	3	U_{21};U_{22};U_{23}
			S_{10}	75.91	1	U_{24}
Via Appennini (odd)	R_{10}	142.47	S_{11}	23.12	1	U_{25}
			S_{12}	119.35	1	U_{26}
Piazza Caprera	R_{11}	345.83	S_{13}	345.83	4	U_{27};U_{28};U_{29};U_{30}
			S_{14}		4	U_{31};U_{32};U_{33};U_{34}
Via Alpi (even)	R_{12}	171.83	S_{15}	171.83	2	U_{35};U_{36}
Via Alpi (odd)	R_{13}	103.58	S_{16}	103.58	1	U_{37}
Via Malta (even)	R_{14}	372.74	S_{17}	372.74	4	U_{38};U_{39};U_{40};U_{41}
Via Malta (odd)	R_{15}	412.66	S_{18}	412.66	4	U_{42};U_{43};U_{44};U_{45}
Via Sebenico (even)	R_{16}	146.17	S_{19}	146.17	1	U_{46}
Via Sebenico (odd)	R_{17}	100.81	S_{20}	100.81	1	U_{47}
Corso Trieste (even)	R_{18}	858.86	S_{21}	858.86	7	U_{48};U_{49};U_{50};U_{51};U_{52};U_{53};U_{54}
Corso Trieste (odd)	R_{19}	382.01	S_{22}	382.01	3	U_{55};U_{56};U_{57}
Via Traù (even)	R_{20}	266.10	S_{23}	266.10	2	U_{58};U_{59}
Piazza Trasimeno	R_{21}	552.99	S_{24}	552.99	4	U_{60};U_{61};U_{62};U_{63}
Via Clitunno (even)	R_{22}	143.90	S_{25}	143.90	1	U_{64}
Via Clitunno (odd)	R_{23}	149.19	S_{26}	149.19	1	U_{65}

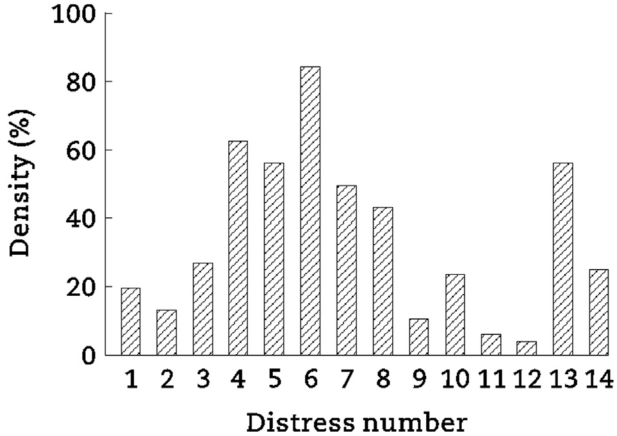

Fig. 6 – Distress density of TTF sidewalks.

(2) Calculation of the deduct value (DV) for each distress

$$\mathrm{DV}_{ij} = p_{ij} \times F_i(d\%) \quad (3)$$

where DV_{ij} is the deduct value, p_{ij} is a weight given to F_i, F_i is the value resulting from the percent density ($d\%$) for the distress i. For example, the relationship between F_i and d is shown in Fig. 7. This example refers to distresses shown in Fig. 5 (potholes and deformations due to roots). These curves were calculated by a proportion assigning the maximum value (100), to the maximum density.

The deduction curves are derived by interpolating these values and the recorded density, and restraining the curve from passing the points (0,0) and (100,100). Each curve represents one distress, and all curves are exponential. Interviews with pedestrians of TTF were used to define the weight (p_{ij}).

The panel of interviewees represented the average pedestrian population within TTF, including the elderly and physically challenged. All participants provided homogeneous assessments, which were consistent with the level of service evaluated by using SCI.

Among the most vulnerable interviewed pedestrians expressing more severe consideration, were those with walking aids or with some kind of walking impairment (persons in wheelchairs or children in pushchairs).

Table 5 – Distress weights.

Distress	Severity	Weight
Block cracking	Low	0.2
	Medium	0.4
	High	0.8
Diffused cracking	Low	0.3
	Medium	0.5
	High	0.7
Linear cracking	Low	0.2
	Medium	0.4
	High	0.6
Patching and utility cut patching	Low	0.2
	Medium	0.4
	High	0.8
Potholes	Low	0.2
	Medium	0.8
	High	1.2
Corrugation		0.5
Bleeding	Low	0.3
	Medium	0.4
	High	1.2
Ravelling		0.1
Weathering	Low	0.1
	Medium	0.4
	High	1.2
Deformation due to roots		0.8
Deformation due to run-off water		0.2
Differential settlement of the pavement sub-base layers in comparison to the interspacing of buildings		0.2
Depressions	Low	0.1
	Medium	0.5
	High	1.0
Edge disruption	Low	0.1
	Medium	0.3
	High	0.5

The interviewees generally indicated the heavier distresses as high severity block cracking, high severity patching, high severity potholes and deformation due to roots. On the contrary, those assessed as less heavy were: linear cracking, bleeding, weathering and edge disruption, all with low severity levels. The resultant weights are listed in Table 5.

(3) Calculation of the total deduct value (TDV) by adding all the partial deduct values defined previously:

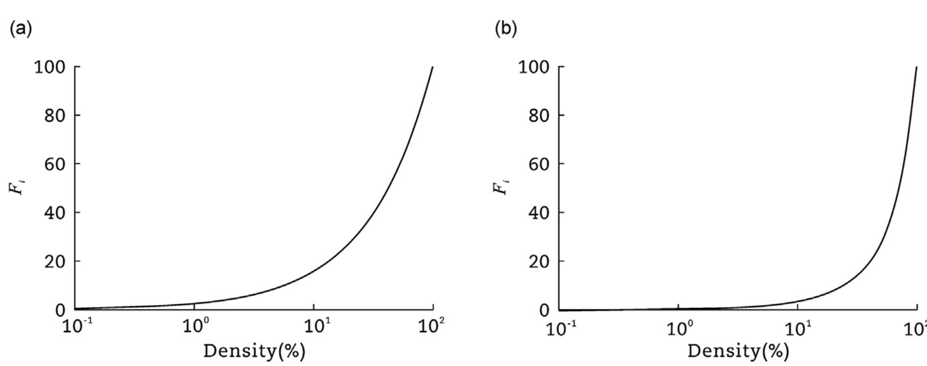

Fig. 7 – Distress density of TTF sidewalks. (a) 5 – Potholes. (b) 10 – Deformation due to root.

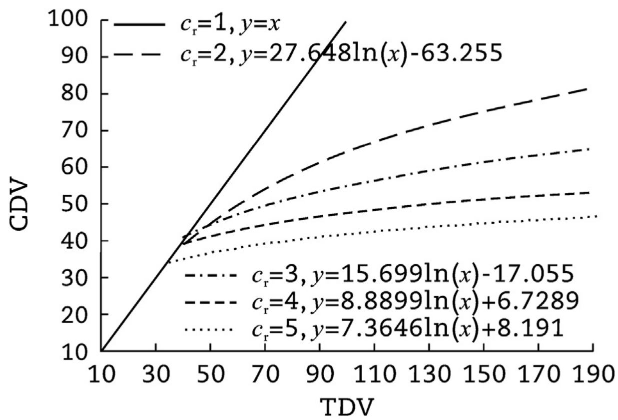

Fig. 8 – Distress density on sidewalks in TTF.

$$\mathrm{TDV} = \sum_{i=1}^{14} \sum_{j=1}^{3} \mathrm{DV}_{ij} \tag{4}$$

where i is the number of distress type, from 1 to 14, j is the severity level, with 1 = low, 2 = medium, and 3 = high.

(4) Definition of the corrected deduct value (CDV)

TDV must be corrected to consider the mutual dependency of some distresses. When correction is neglected, TDV may result in an overly high value (>100) that does not reflect the actual pavement condition. The correction curves were drawn by fitting TDV of all the surveyed sample units with the scores provided by pedestrians walking within the same units under different conditions (e.g., carrying bags, trolleys, prams). The scores range from 0 (worst assessment) to 10 (best assessment). Calculation for each sample unit includes: the average score, its difference from 10 and the correspondent value expressed in hundredths. When TDV is less than 30, no correction is needed. On the contrary, when TDV is greater than 30 with more than one distress with a density greater than 2%, TDV must be corrected. In Fig. 8, the five curves relate to a number of distresses c_r variable from 1 to 5. When $c_r = 1$, no correction is needed. Table 6 shows an example of SCI calculation.

3.3. Results

The calculation of SCI highlighted critical clusters of streets within TTF. Fig. 9 graphically represents SCI results for one such cluster, as an example. The red line indicates SCI values less than 50, while those in green indicate SCI value greater than 50 (blue lines refer to surfaces are not considered due to the presence of scaffoldings and other obstructions). Moreover, Fig. 9 addresses two further issues. The first one is the need to plan regular maintenance operations not only in accordance with the distress severity but also in considering the continuity of paths and the quality and quantity of pedestrian flows. This is particularly true in areas such as in TTF, where pedestrian walking behaviour tends to concentrate on certain legs or features of their routes (the former mentioned "sunny side" of the street, "empty" sidewalks vs crowded, etc.).

The second issue relates to planted strips with deformations due to exposed roots. This distress cannot be solved simply by repairing sidewalks. Expert advice from local botany and gardening as well as landscapers, should be implemented as part of maintenance plans.

Table 6 – Example of SCI calculation in TTF.

Pedestrian asphalt pavement-condition survey data sheet for sample unit

Branch R_1 | Section S_1 | Sample unit U_2

Branch area (m^2) 213.11 | Date 07/12/2014 | Sample area (m^2) 132.58

1 Block cracking
2 Diffused cracking
3 Linear cracking
4 Patching and utility cut patching
5 Potholes
6 Corrugation
7 Bleeding
8 Ravelling
9 Weathering
10 Deformation due to roots
11 Deformation due to run-off water
12 Differential settlement of the pavement sub-base layers in comparison to the interspace of buildings
13 Depressions
14 Edge disruption

Distress type	Quantity							Total	Density (%)	DV_i
4 M	1.19	0.03						1.22	0.92	0.65
5 A	0.70	0.49	0.56	0.56	0.74	0.64	1.84	5.53	4.17	10.54
5 A	0.74	0.49						1.23	0.93	3.15
6	0.18	0.18	1.25	0.18	0.20	0.16	1.02	3.17	2.39	3.37
6	0.25	0.20	0.15					0.60	0.45	1.28
7 B	0.06							0.06	0.05	2.01
7 A	0.16	1.52	4.00	1.44	0.60	4.48	8.24	20.44	15.42	12.15
7 A	0.32							0.32	0.24	8.08
13 B	0.14	0.14	0.15					0.43	0.32	0.38
13 M	0.12							0.12	0.09	1.84
14 A	0.40							0.40	0.30	7.50
									TDV=	50.94
									CDV=	28
									SCI=	72

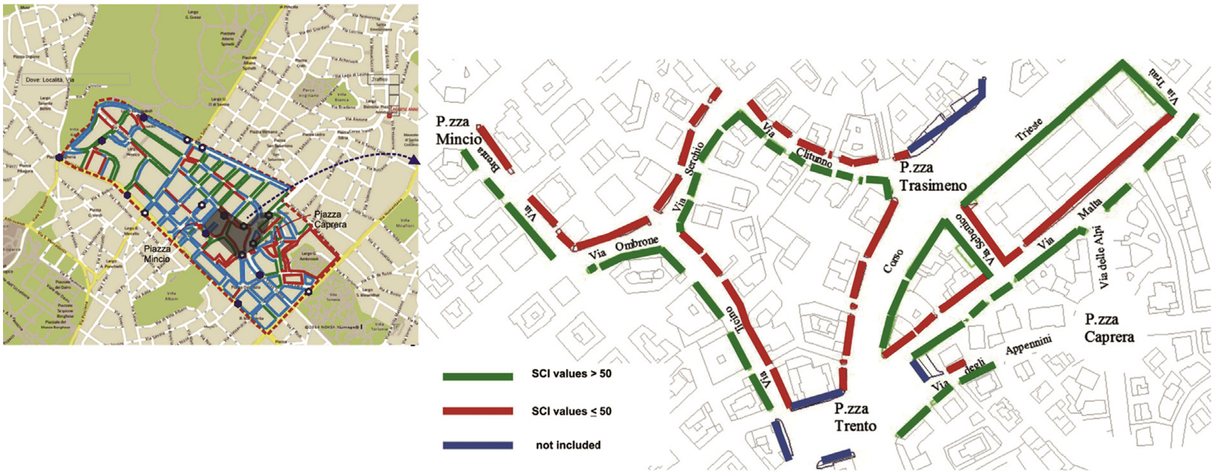

Fig. 9 – Result of SCI calculation for a critical cluster of streets within TTF.

4. Conclusions

This study represents an initial attempt to apply sidewalks assessment methodologies belonging to maintenance programs for motorized modes infrastructures. More specifically, Sidewalks Condition Index (SCI) was studied and calculated to quantify sidewalk conditions and the extent of dangerous distresses that present obstacles for pedestrians. The data come from a survey performed in a real urban environment involving local inhabitants.

The study will be completed with more validation analyses on more test sites. As a matter of fact, the curves and correct deducted values will undergo amendments, each time more data will be processed and different user groups will be included. Moreover, this presented case study considers sidewalk bituminous pavements. However adapting the defined distress curves, the methodology also can be applied to concrete and modular pavements. The application of this methodology to different pavement types is currently in progress, as the analysis of additional test sites. First tests are therefore soon expected, paving the way for more accurate maintenance programs.

In conclusion, the TTF experience and applied method can help road managers define priorities in the maintenance works by consulting SCI values derived from visual surveys.

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