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# INVESTIGATION AND OPTIMISATION OF A SIDEWALK RESTORATION PROGRAM IN HUMAN TRANSPORTATION IN AN ANCIENT SUSTAINABLE CITY

**Summary.** Sidewalks play a very important role in the dynamism maintenance as well as the development of cities especially historic cities. To ensure the maintaining service quality of sidewalks, the first step is to prevent distress occurrence, thereafter repair the distress that occurred in the sidewalks. In historic cities, the lack of suitable sidewalks for walking led to the gradual elimination of pedestrians. Yazd is a historic city recorded as a world heritage site by UNESCO, which attracts many tourists from all over the world every year. Therefore, preserving the quality of sidewalks in this city is of great importance. In this research, the SCI method was used to investigate the condition of the sidewalks in the studied area. This method is similar to the pavement condition index (PCI) method. The results showed that the condition of sidewalks in the studied area is in the range of 55-70, which is relative.

**Keywords:** safety, sidewalk pavement, sidewalk condition index (SCI), maintenance

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## 1. INTRODUCTION

Walking and public transportation are the most natural, oldest, and most essential forms of human movement in an environment and are still the most important option for visiting places, activities, and discovering the values and attractions in the environment [26,28]. Despite the increasing spread of the use of motor vehicles, walking is still one of the most important ways of transportation. In this regard, recognising the effective factors on people's perception of walking quality can be the first step for providing a desirable environment for users and promote walking [5,17].

A sidewalk is one of the road facilities for pedestrians. The American Association of State Highway and Transportation Officials (AASHTO) provides the importance and advantages of walking, hence, sidewalks are considered as significant parts of urban streets [1]. Today, sidewalk pavements are made of different materials, which were more commonly used in older areas than traditional materials [19]. The wide use of land in urban areas such as schools, trade centres, and industrial centres creates high pedestrians' traffic flows, which should be facilitated by the sidewalks [14]. Increase in the number of pedestrians coupled with limited facilities of a sidewalk will increase the physical collision between pedestrians and motor vehicles resulting in increased accidents [6,15,24,29].

Ideally, sidewalks should be capable of meeting the needs of pedestrians. Therefore, it can be said that good sidewalks are those that are constructed with the consideration of all groups of users and the safety assurance of pedestrians [22]. The aim of encouraging walking and constructing appropriate sidewalks in different cities around the world, especially in the historic texture, is to the reconstitution of textures. Achieving this goal prevents historic and old centres of cities from being empty, attracting tourists and provides opportunities for introducing both cultural and historical identities. Accordingly, repairing pavements' distress of streets and roadway is of equal significance as the repairing and maintaining sidewalks [23]. If designed and maintained appropriately, sidewalks can provide relatively little displacement costs [10].

All sidewalks need appropriate maintenance; without maintaining the sidewalks, which are the first encouraging factor for walking, they can prevent the movement of pedestrians and put them in the risk of being injured. Thus, to improve the problems pedestrians face, streets in form of sidewalks should be constructed. These sidewalks increase public participation and allow pedestrians to enjoy their walk experiences. Therefore, to satisfy safety and accessibility criteria, sidewalks should have the following principals: proper size, proper pavement, proper drainage, public access, safe side access, fantastic spaces, permanent security, and clear signs and panels [11,12,18,30,31].

The role of civil infrastructure in architectural and urban development has been widely studied; therefore, this research aimed to investigate the quality of sidewalks in the central region of Yazd's historic city. This region hosts many tourists every year, and as a result, the quality of its sidewalks and walking cannot be overlooked.

## 2. REQUIREMENTS FOR REGULAR MAINTENANCE OF SIDEWALKS

In planning for the construction of any type of facility and equipment for pedestrians, convenience is one of the central factors to be considered. When walking becomes difficult and complicated for pedestrians, they change their pass. Sudden path change by pedestrians onto the streets puts them in danger. If a special age group with different targets use these sidewalks,

then maintenance and repair of these types of sidewalks should be in the top priority level [25]. The age groups and their characteristics are as follow:

- range of 0-4: movement needs to be under the trained the supervision of parents. Increase in the environmental vision and perception depth;
- range of 5-12: increase in the independency, prone to move fast and getting out of the intersections and entering the streets;
- range of 13-18: feeling invulnerability for entering the street and passing the intersections;
- range of 19-40: energetic, full awareness of the surrounding traffic;
- range of 41-65: slow reactions and long reaction time;
- range of >65: difficult pass from the intersections, low vision and hearing problems [2].

Pavements are the national wealth of countries, which annually has a significant part of the development budget of related organisations, including municipalities, dedicated to their repair, improvement, and maintenance. Supplying enough credit for these operations is a challenge which managers always face [21].

In the past, the focus was only on maintaining pavements. Managing pavements was an unknown determinant factor for choosing the maintenance and repair (M&R) method has been the experience of the engineers, while little attention was been paid to lifecycle costs or priority-based network-level requirements. Researches from the beginning of the 1970s in the laboratories of the USA military birthed an engineering management system (EMS) for paving roads, airports, and parking perimeters known as pavement management system (PMS) [32]. PMS is a systematic process for collecting, managing, analysing, concluding and summarising the pavement information, which is used to support selecting the pavement materials, maintaining and repairing [7]. In other words, PMS is a planning method for maintaining and repairing pavements to maximise the pavement life.

PMS was necessarily inventible given the extent of urban streets inclusive of the sidewalks in the city, heavy costs of repairmen and the costs exerted on the users. The pavements' M&R cost in terms of managing is of great importance in the PMS system [27]. This system is capable of relative-accurate estimation of costs need for repairing the damages and passage coating. Moreover, it provides the managers with optimal solutions for repairing or coating [20].

Today, road managers around the world use PMS to define road repair and renovation strategies. However, to define PMS, some methods and procedures have been developed on the transportation infrastructures, however, the roads and some other methods have been defined to calculate the quality level of the sidewalks [3,4].

One important feature of PMS is that not only does it have the ability to determine the existing pavement network status; it is also able to predict its future status. To obtain a reliable prediction of a pavement status, a repeatable and visual scoring system should be used [16]. One of these methods is the pavement condition index (PCI). The PCI is a numerical sign, which is in the range of 0 for a useless pavement to 100 for a flawless pavement [21].

## 3. METHODOLOGY AND AREA UNDER STUDY

The case study was done in the historic texture part of Yazd city in the Amir- Chakhmaq district. Since it is an area where many tourists annually travel to from all around Iran and world to visit its rich and ancient monuments, there is the need to construct distress-free and standard sidewalks to prevent fatigue on long walks. Alternatively, according to researchers, in rehabilitation projects of the built heritage, effective communication is cost-effective by making

reliable information available for stakeholders at the right time. This will help to sustain stakeholders' understanding of project delivery [9]. Therefore, to summarise the information, numerical indicators are used to evaluate the infrastructure of cities, especially old cities, as the condition of sidewalks (SCI).

For accuracy purposes in the operation of repair and reconstruction, this region can be divided into smaller parts. On the one hand, according to the location of the region and the lack of tall buildings with a modern view, and the other hand, the existence of buildings with low height and traditional view, constructing an appropriate sidewalk and a safe and convenient environment for people and tourists is necessary. In these places wherein are trade locations around the ancient places, there are beautiful landscapes and antiquities related to the area and location. Among the ancient monuments are Amir-Chakhmaq square, water museum, and others, which make this region ideal for walking. More so, it should be noted that according to the region density, traffic accidents cannot be ignored. These accidents are located in congested areas filled with vehicles and pedestrians.

Investigating the region under study, randomly and regularly, the approximate number of vehicles (about 3000 per day) and the number of pedestrians (about 2000 per day) can be estimated, which indicates that it is a dense region in terms of pedestrians. Such factors as the roughness of a sidewalk, presence of trees, width and quality of the path have a great effect on the number of pedestrians. The use of the region has changed over time, and the trade centres and stores have changed to schools or vice versa. The conversion trend of stores to parks and squares or even cross-sections or conversion of unused spaces to stores or trade centres have been existing to satisfy the needs of pedestrians. In these locations, only vehicles on low speeds are allowed to move due to the high density and volume of pedestrians.

Fig. 1. The path under study (red path)

## 4. RESULT AND DISCUSSION

The condition of a sidewalk is the most important parameter for the maintenance and repair of the urban pathway. The condition of a sidewalk is measured using SCI, which is a standard criterion. The Value of SCI indicates the capability of the sidewalk for servicing the people [13]. SCI was developed in 2014. This index is similar to PCI, which is defined according to the ASTM D6433 standard. The condition of the sidewalk is evaluated based on the extent and severity of damage of the pavement surface [8].

SCI is conducted via visual inspection by which the type, intensity and extent of distress are determined. The inspectors identify the number and intensity of distress based on their checklist. SCI measures two conditions:
1. Type, extent and intensity of surface distress of the sidewalk (such as cracking and rutting).
2. Smoothness of the sidewalk surface [2].

The evaluation and inspection processes are carried out using a systematic method. The observed evaluations were recorded in a data bank. SCI should be done annually so that changes in the sidewalk condition can be evaluated [3]. In addition, SCI recommended strategies necessary for preserving the quality level, convenience level and safety of sidewalks. SCI is a numerical index, which defines the current condition of a sidewalk surface. This is an index criterion, which indicates the structural integration requirements and surface performance based on the surface distress of the sidewalk. Further, it determines the roughness location and frictional resistance [2].

Same as PCI, the SCI range from 0, which indicate the worst condition, and 100 being the most desirable condition. Table 1 shows this range.

### 4.1. Distress of asphalt pavements

Surface pavements play a significant role in transport, and those in good conditions provide a safe and easy journey to pedestrians and motorists alike. However, sidewalk pavements continuously suffer from the combined effects of person and wheelbarrow loadings and the natural environment. According to the PCI method and ASTM D6433 standard, the distress of the asphalt pavement can be categorised as follow:

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

Tab. 1

SCI index range [2]

| SCI Pavement index range | Condition Description |
|---|---|
| 100 < SCI < 85 | Good |
| 85 < SCI < 70 | Satisfactory |
| 70 < SCI < 55 | Fair |
| 55 < SCI < 40 | Poor |
| 40 < SCI < 25 | Very Poor |
| 25 < SCI < 10 | Serious |
| 10 <SCI < 0 | Failed |

### 4.2. SCI calculation

Like PCI, the SCI can be obtained from the following equation:

$$SCI=100 - CDV \tag{1}$$

where *CDV* is the corrected deduct value considering the relationship between different distress. The *CDV* equal to zero indicates that the distress does not affect the sidewalk condition, while the *CDV* equal to 100 indicate that the distress is highly dangerous. The *CVD* is obtained from the following four steps:

Step 1: determine the density percentage of every type of *i* in every intensity level:

$$D(\%) = \frac{A_{ij}}{A_u} \times 100 \tag{2}$$

where *D*: density percentage, $A_{ij}$: total area of every distress, *i*: with every intensity *j* (1=low, 2=medium, and 3= high), $A_u$ the area of every sample unit.

Step 2: calculation of the deduct value (*DV*) for every distress:

$$DV_{ij} = P_{ij} \times F_i\ (D\%) \tag{3}$$

where $DV_{ij}$ is the deduct value, $P_{ij}$ is the weight dedicated to $F_i$, $F_i$ is the value obtained from the density percentage (*D%*) for every distress *i*. Table 2 lists the value of the weight dedicated to every distress.

Step 3: calculating the total deduct value (*TDV*) by summing the values of the partial deduct value:

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

where *i* is the number of distress from 1 to 14, *j* is the distress intensity (1=low, 2=medium, 3=high).

Step 4: the value of corrected deduct value (*CDV*):

*TDV* should be modified to consider the relationship and correlation of distress. If this correction is not considered, it may round to very high numbers, which do not indicate the real condition of the pavement. The correction plots can be obtained by fitting the sum of the deduct value of all investigated sample units with the values obtained from the pedestrians in the similar sample units under different conditions. The score values are varied between zero (worst case) and 10 (best case). Calculations of each sample unit include mean score with its difference from 10 and the corresponding value expressed in 100. When the deduct value is less than 10, no correction is needed. Whereas, when the sum of the correction values is more than 30 and the sample unit is a distress with density higher than 2%, then correction is necessary [4]. Fig. 2 shows some of this distress.

In Fig. 3, five curves are presented for distress Cr from 1 to 5. When Cr=1, no correction is needed. Table 3 shows an example of calculating the PCI.

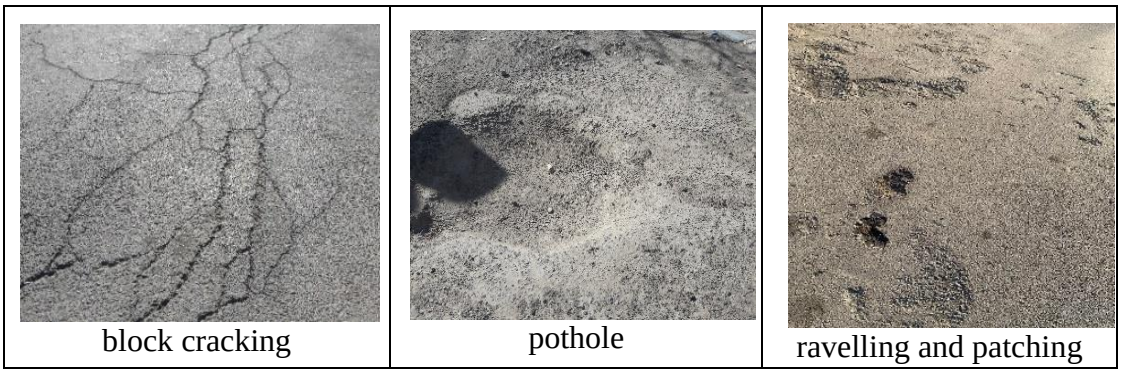


Fig. 2. Some of the distresses in the region

The PCI of the region under study is briefly shown in Fig. 4. The green lines have the SCI in the range of 55-70, indicating relatively good condition. The reason for this is the timely restoration of this area by the relevant agencies (municipality, cultural heritage organization, etc.). Conversely, the red lines have SCI in the range of 40-55, indicating poor condition. This area is located near the unused lands or near buildings that are under repair. The repairing operation of the buildings has negative effects on the condition of the sidewalk (such as settling of the sidewalk, removal of sidewalk pavement due to falling of objects and/or removal of water pipe path for building). The maximum distress is for block cracks in the region; however, their intensity is not so much. Among interviewed pedestrians, the most vulnerable were people with poor walking ability (people in wheelchairs or kids in wheelchairs).

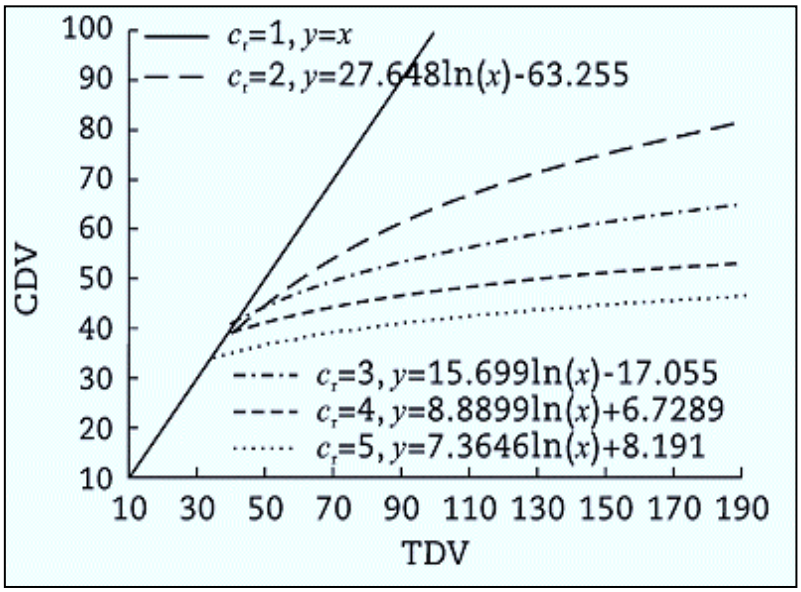


Fig. 3. The CDV graph [3]

Tab. 2.

Weights of distress

| Severity | Weight | Distress | Severity | Weight | Distress |
|---|---|---|---|---|---|
| Low | 0.3 | Block Cracking | Not. | 0.1 | Deformation Due to Roots |
| Medium | 0.5 | | Not. | 0.3 | Deformation Due to Water |
| High | 0.8 | | Not. | 0.6 | Differential Settlement of the Pavement Sub-Base Layers |
| Low | 0.3 | Linear Cracking | Low | 0.8 | Bleeding |
| Medium | 0.5 | | Medium | 1.2 | |
| High | 0.8 | | High | 0.2 | |
| Low | 0.3 | Patching and Utility Cut Patching | Low | 0.2 | Weathering |
| Medium | 0.5 | | Medium | 0.5 | |
| High | 0.9 | | High | 1.1 | |
| Low | 0.2 | Potholes | Low | 0.1 | Edge Disruption |
| Medium | 0.6 | | Medium | 0.3 | |
| High | 1.1 | | High | 0.6 | |
| Low | 0.3 | Swell | | | |
| Medium | 0.9 | | | | |
| High | 1.2 | | | | |

Tab. 3

Example of SCI calculation

| Asphalt pedestrian- condition of sample unit | | | | | | | |
|---|---|---|---|---|---|---|---|
| Branch: 1 | Section: 01 | | Sample unit: 1 | | | | |
| Sample area: 120 $m^2$ | | | | | | | |
| 1- block cracking<br>2- linear cracking<br>3- patching and utility cut patching<br>4- potholes | 5- swell<br>6- corrugation<br>7- bleeding<br>8- ravelling<br>9- weathering<br>10 swell | | 11- deformation due to run-off water<br>12- differential settlement of the pavement sub-base layers in comparison to the interspace of buildings | | | 13- depressions<br>14- edge disruption | |
| Type of distress | Quantity | | Total | | | Density (%) | $DV_i$ |
| 1 | 2 | 5 | 3 | 3 | 12 | 10 | 17 |
| 2 | 1 | 2.5 | 3.4 | 3.3 | 10.2 | 8.5 | 18 |
| 4 | 1 | | | | 1 | 0.83 | 54 |
| 5 | 0.5 | 0.5 | 0.6 | 1 | 2.6 | 2.17 | 13.2 |
| | | | | | | *TDV* = 102.2<br>*CDV* = 39<br>*SCI* = 61 | |


Fig. 4. General condition of the SCI
(green colour has a relatively good index, and red colour has a weak index)

## 5. CONCLUSION

This study is a primary effort to evaluate the distress condition of sidewalks applying the SCI approach. This index, like PCI, shows the distress of sidewalks as a value and provides the range of distress, risks and limitations it creates for pedestrians. The cases studied investigated sidewalks with asphalt pavement; however, this method can be similarly applied for sidewalks with concrete pavement.

Although, in this research, the sidewalks were in relatively good conditions, however, in the case of lack of appropriate, timely maintenance and repair, the intensity of distress increases, requiring more cost for repair. According to the results, the regular planning of maintaining and repair operation does not solely depend on the distress intensity but equally on the continuity and consistency of pots and the quality and quantity of pedestrian flow as well. Accordingly, the experience and method used in this research can help road managers recognise the maintenance and repair priorities using the SCI method.

Lastly, this study individually, quantitatively studied the relationships among different distress types from the statistical view of the sidewalk pavement in a traditional and ancient city. Researchers are looking for ways to make sidewalks more suitable, at least for many years. Choosing better quality materials may increase the cost of project implementation, and reduce maintenance costs over the next few years.

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