Identification and Prioritization of Accident-Prone Segments using International Roughness Index

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Abstract

During last decades, owing to the increase in a number of vehicles, the rate of accident occurrence grows significantly. Efforts must be made to provide efficient tools to prioritize segments requiring safety improvement and identify influential factors on accidents. This objective of the research was to determine the safety oriented threshold of International Roughness Index (IRI) to recognize Accident-Prone Segments (APSs) using new segmentation method. The modified Floating Fixed-length Segmentation (FFLS) was performed based upon the determined safety oriented IRI threshold with respect to the available literature. Floating fixed-length patterns with lengths of 100, 200 and 500 meters were moved over an entire length of a selected highway to detect segments with IRI values higher than the threshold. To diminish the lack of heterogeneity in characteristics of segments, it was proposed to analyze adjacent road segments with a similar pattern of IRI variation, as a unit. Owing to the limitation in road maintenance and rehabilitation costs for safety improvement, the entire APSs cannot be treated. Therefore, prioritization and selection of APSs were followed by imposing constraints upon the preservation of different percentages of the highway. Results indicated that the assumed safety oriented threshold of IRI and the modified segmentation method led to correct recognition of segments with high IRI associated with low level of safety. Application of the proposed method using 200-meter floating segment resulted in the shortest length of APSs for safety improvement. The outcomes lead to preserving the most deteriorated segments considering budget constraints. Furthermore, the validation supported the outcomes in which most of the segments were selected from sections with PCI values of 30 or 19. The latter supports the results achieved by the determined IRI threshold and segmentation method. Therefore, considering safety issues as well as maintenance operations would result in optimal use of available budget.

Keywords: Road safety, International Roughness Index, road segmentation, accident-prone segments, prioritization

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1. Introduction

Traffic safety has received the considerable attention of both researchers and road managers during last decades. Human behavior, geometrical features (e.g. slope, pavement condition, roadway curvature etc.) and traffic characteristics are the main sources of accident associated with various effects on their occurrence [Elyasi et al. 2017]. The accidents can be studied by two different approaches; namely, treatment and prevention [Vistisen, 2002]. In the treatment approach, the accident statistics are used to identify High Crash Road Segments (HCRSs). While, in preventive approach, the effective factors and indices on accident occurrence are defined to recognize the segments, which are more prone to accident. One of the contributing factors in accident occurrence is pavement characteristics [AASHTO, 2010]. A subjective definition of road safety is the main concept of the research is known as the feeling of users regarding safety while driving [Farnsworth, 2013]. When it comes to how a driver and passengers feel, the most important factors affecting their comfortability is the road roughness demonstrating Ride Quality (RQ) [Abulizi et al. 2016]. The road safety is highly affected by road roughness expressed in term of International Roughness Index (IRI) indicating the effects of pavement deterioration on its smoothness [Anastasopoulos, Sarwar and Shankar, 2016]. IRI varies inversely with RQ [Dewan, 2006]. Thus, an accepted level of IRI can assure the safe ride. Traffic safety definition has generally been defined as a procedure used to detect and evaluate safety characteristics [Harms-Ringdahl, 2013]. To improve the safety, various accident prevention tools such as identification of HCRSs using segmentation methods have been utilized. In doing so, certain road geometry variables (e.g. grade and curvature), as well as pavement characteristics (e.g. IRI, PCI and rut depth) would be considered to recognize black spots [Alian, Baker and Wood, 2016, Boroujerdian et al. 2014].

A database generated for implementation of pavement management system provides departments of transportation with efficient alternatives to assure safe and reliable transportation [Wolters, Zimmerman and Schattler, 2011 and Shahnazari et al. 2012]. Road safety is highly affected by pavement condition index (PCI) since different types of pavement deteriorations deduct from RQ [Li, Liu and Ding, 2013]. As it was mentioned earlier, as the roughness variation of pavement increases, RQ decreases if and only if the pavement distress is located in the wheel path of vehicles [Semnarshad, 2016]. Besides, a number of research studies used different pavement performance indicators (e.g. IRI and PCI) to assess the crash occurrence and its severity. In 2002, the effects of road roughness on accident occurrence were investigated by developing a regression model. The results revealed that riding quality in terms of Present Serviceability Index (PSI) reduce the accident rates significantly [Bester, 2002]. In 2009, Rut Depth (RD) as an indicator of pavement deterioration as well as pavement roughness indices (i.e. IRI and PSI) were studied using negative binomial regression models to study the relationship between pavement condition parameters, crash frequency, and crash types. The result indicated that IRI and PSI had the high correlation with each other and it was suggested to develop safety performance function using those parameters with other types of pavement performance indicators such as RD [Chan et al. 2009]. The role of various pavement condition indicators such as IRI, Skid score, surface condition (e.g. dry or wet) and condition score was used to study the effects of pavement characteristics on crash severity. The result indicated that by the increase in the level of deterioration, more severe crashes were likely to happen. In striking contrast, however, the most deteriorated pavement (i.e. very poor pavement) was associated with less severe crashes. The results of ride score and IRI score revealed that as a result of the higher ride and IRI scores, severe crashes could be occurred [Li, Liu and Ding, 2013]. Recently in 2017, a research was carried out in which pavement deterioration effects on accident injury-severity rates were examined. The Seemingly Unrelated Regression Equations (SURE) model was used to forecast changes in IRI, rutting depth, and pavement condition. Also, multivariate Tobit model was used to predict the estimated accident injury severity rates. The findings showed the detrimental effects of pavement deteriorations on accident injury-severities. Therefore, it was suggested to include safety issues in pavement management system to save both money and passengers' lives [Sarwara and Anastasopoulos, 2017].

Appropriate Maintenance and Rehabilitation (M&R) programs improve the level of RQ so that a number of accidents were reduced. RQ, as well as initiation of M&R activities both, are relevant to IRI values [Fakhri, 2010]. Therefore, there must be an exact threshold value of IRI to reach acceptable and safe ride. With regard to safety oriented pavement treatment initiation, the objective of the research was to use novel segmentation method to identify and prioritize accident-Prone Segments (APSs) based upon the proposed IRI threshold.

To carry out the research, a list of safety oriented IRI thresholds was provided based on available literature. Then, an appropriate IRI value was chosen with regards to safety matter. In the next step, IRI data collection as well as novel segmentation method accounting safety oriented IRI threshold were explained. Located in the eastern part of Iran, a highway between two cities; namely, Sarbishe and Shusf was segmented based on recorded IRI data and the proposed method. The obtained segments were then prioritized, and the limitation index of M&R costs for safety improvement was investigated. Finally, the resulted segments were validated, and research outcomes were outlined. The most significant contribution of this research is to introduce and examine an IRI threshold values relevant to the safety issues. Towards this end, carrying out the available literature regarding different segmentation methods, a modified one was utilized to overcome any shortcomings. The results provided would help decision makers to identify the least lengths of APSs with the most safety improvement.

2. IRI Threshold Determination

Threshold values are used to determine the reliable ranges of a parameter. Apart from affecting the trigger of preservation activities on roads network, appropriate safety oriented IRI threshold may reduce the number of accidents caused by deteriorated pavement [Anastasopoulos, Sarwar and Shankar, 2016]. This section is devoted to offering preceding research works carried out to determine appropriate thresholds of IRI considering road safety.

In the first research work conducted by FHWA, the threshold value of 2.669 m/km was recommended as the safe level of roughness [FHWA, 1999]. Later, the predetermined threshold (2.669 m/Km) was validated. Results confirmed the reliability of the determined IRI threshold for safety improvement. [Shafizadeh and Mannering, 2003]. In 2000, a number of researchers reported IRI average threshold of 1.7 m/km as the trigger of preservation treatment and safety consideration [Hicks, Seeds and Peshkin, 2000]. In 2005, several intervention criteria were determined regarding origin point of (M&R) activities [Lamptey et al. 2005]. As for pavement condition threshold, The IRI of 1.775 m/Km was chosen as the threshold to start M&R operations considering life cycle cost analysis. Also in another research, IRI was used as the pavement performance indicator to measure the treatment effectiveness increasing RQ [Labi et al. 2005]. Various IRI thresholds were gathered when thin overlays were applied to interstate and non-interstate roads. The final values were 1.17 and 1.63 (m/Km) for interstate and non-interstate roadways, respectively. In order to persuade pavement engineers to construct safe roads, District of Columbia Department of Transportation (DDOT) provided companies with guidelines on acceptable IRI at the time of the project delivery [DDOT, 2008]. The determined thresholds were 1.3 to 2.56 m/Km on freeways. In Iran regarding road M&R activities, the values of 2.85 and 4.5 m/Km were reported as the initiation of preventive maintenance and rehabilitation projects, respectively [Fakhri, 2010]. Recently, IRI thresholds of 1.87 to 3.27 m/km considering road safety were estimated and validated taking users' opinions into consideration [Arhin, Noel and Ribbiso, 2015]. In 2016, the safe threshold values of different pavement performance indices were determined using multi-objective optimization and goal programming [Anastasopoulos, Sarwar and Shankar, 2016]. As a result, IRI value of 2.62 m/Km was used as the criterion for initiation of safety oriented pavement preservation. Table 1 summarizes the above-mentioned findings regarding safety oriented IRI threshold values.

With regard to the available literature, a few number of studies have concentrated on identification of APSs based upon safety oriented IRI thresholds. The research was carried out owing to the absence of specific safety oriented IRI threshold in Iran road safety assessment. The main objective of this research was to propose a safety oriented threshold of IRI and evaluate a highway by a novel segmentation method based on determined threshold to identify high-risk segments. In doing so, it was assumed that safety reduction was related to the time of preventive maintenance application. According to Table 1 and Iranian experts' opinion, the threshold value of 2.7 m/Km was chosen as the acceptable range of IRI in order to ascertain APSs.

Table 1. IRI value threshold

Researcher/Year	Safety oriented IRI threshold (m/Km)
FHWA, 1999	2.669
Hicks, Seeds and Peshkin, 2000	1.7
Shafizadeh and Mannering, 2003	2.669
Lamptey et al. 2005	1.775
Labi et al. 2005	1.17 (Interstate roads) 1.63 (Non-interstate roads)
DDOT, 2008	2.56
Anastasopoulos, Sarwar and Shankar, 2016	2.62
Arhin, Noel and Ribbiso, 2015	2.57

3. Methodology

To identify the APSs and their prioritization based upon IRI values, the research methodology is presented in Figure 1. The following includes the explanation of IRI collection process and segmentation methods.

3. 1 IRI Data Collection

The National Cooperative Highway Research Program (NCHRP) first introduced the fundamental concept of IRI in the late 70's. Later it was used to assess the pavement smoothness in 1986 [Sayers, 1995]. IRI can be collected by Road Surface Profiler (RSP). The device is installed on a particular vehicle equipped with computer technology to measure pavement roughness in term of the meter per kilometer [Arhin, Noel and Ribbiso, 2015]. In this research, the IRI was recorded every 100-meter along the first lane in one side of a two-lane highway located in the eastern part of Iran with the length of 88.3 Km. Documented data was then categorized using Implex Software.

Highway 95 located between two cities; namely, Sarbisheh and Shusf, is shown in Figure 2. The axis was coupled with segments with low PCI [Kavussi, Semnarshad, Saffarzadeh, 2016]. Consequently, the road must be preserved to reduce accidents rates due to inappropriate pavement conditions.

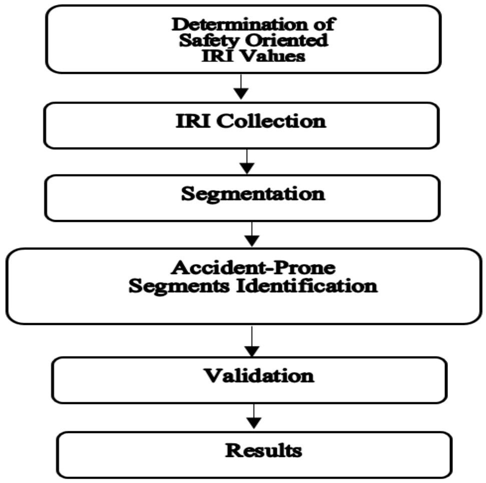

Figure 1. Research Methodology

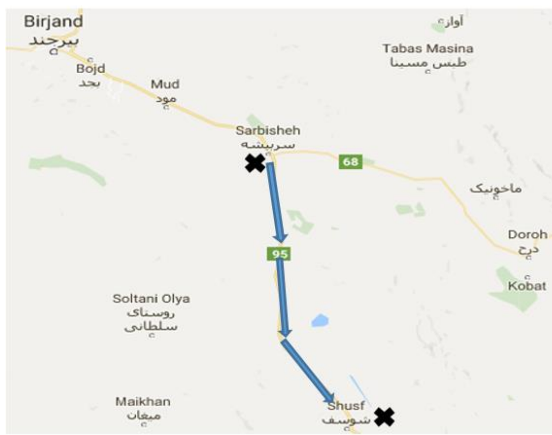

Figure 2. Sarbisheh-Shusf Highway (From: https://maps.google.com)

3. 2 Segmentation

With respect to research objectives, to identify HCRSs or APSs, two segmentation methods are available; namely, Sequential Fixed-Length Segmentation (SFLS) and Floating Fixed-Length Segmentation (FFLS). In The SFLS method, the road is divided successively into a set of fixed-length segments. Counting a number of accidents in each year, HCRSs would be detected. In the FFLS approach, a fixed-length pattern is moved through the length of a road, and a number of accidents occurred in each pattern are counted. Where a number of accidents are maximum, is the first HCRS [Elyasi, Saffarzadeh and Boroujerdian, 2016].

In this paper, instead of a number of accidents, the determined safety oriented IRI threshold (2.7 m/Km) was selected for analysis approach. Recognized segments with IRI values greater than the proposed one, were coupled with the potential for safety improvement. IRI values were recorded every 100-meter defined in this paper as Special Unit (SU). IRI value in each SU (100-meter fixed-length) was taken into account regardless of roadway geometric and traffic characteristic. The simplicity of FFLS is an advantage; however, the lack of uniformity in the length and position of resulted segments with high IRI is known as the demerit in previous segmentation methods. To overcome that shortcoming, it was proposed to analyze adjacent road segments with an identical pattern of IRI variation (i.e. similar potential for safety improvement) as a segment. It leads to correct identification of APSs regardless of lengths of segments.

When the SU is floated over the entire roadway, the sections with same the pattern of IRI variation are categorized in one segment (with respect to the defined segmentation length). It must be mentioned that in the proposed method there is no overlap between two continuous segments. By this assumption, the new method of homogeneous segmentation was proposed based on average values of IRI (mean IRI) recorded from the and the right wheels of RSP. These two recorded values of roughness are the most important one as they represent the roughness experienced by passengers.

In this manner, the floating fixed-length patterns with lengths of 100, 200 and 500 meters were moved individually along the roadway, and segments with higher mean IRI values than the determined threshold were recognized. The selected segments were ones with lower RQ endangering the safety. The method was repeated to identify other segments with higher prioritization. Changing the border of segments reduces the inconsistency in the position of predefined segments with high mean IRI values. As such, to introduce an index based on differences between mean IRI values in subsequent SUs the ratio of maximum and minimum mean IRI values was calculated considering each pair of contiguous units using Equation (1). Defining specific segmentation units (100, 200 and 500 meters), the process was continued. The 200-meter floating pattern means the average amount of R(i) of two subsequent SUs (i.e. 100-meter) and 500-meter floating pattern means the average amount of R(i) of five subsequent SUs (i.e. 100-meter).

$$\mathrm{R(i)} = \frac{Max\{(mean\ IRI)(i),(mean\ IRI)(i+1)\}}{Min\{(mean\ IRI)(i),(mean\ IRI)(i+1)\}} \quad (1)$$

$$i = 1,2,3, \dots, n$$

Where i is the index of the segmentation units, n is the total number of segmentation units, R is a vector of $mean\ IRI$ along a road, $R(i)$ is the ration of maximum and minimum $mean\ IRI$ relevant to ith and $(i+1)$th units of segmentation.

Utilizing the calculated $R(i)$ for any adjacent units on the selected highway, these values were compared with the determined safety oriented threshold value of IRI. With regard to Equation (2), the segments with mean IRI values greater than or equal to the threshold were marked as ones with the potential of safety improvement.

$$\mathrm{B(j) = i;} \quad if \quad R(i) \geq T, \ \ j = 1,2,3, \dots, k \quad (2)$$

Where j is the index of a segment with potential for safety improvement, k is the total number of segments with safety concerns, T is the determined safety oriented threshold of IRI (2.7 m/Km), and B is the vector of hazardous segments.

The collected IRI data and propose segmentation method were inputted into Matlab Software. The ratio of maximum and minimum mean IRI values in each segment being a candidate for safety improvement was compared to the threshold value to ensure the uniform pattern in all adjacent segments requiring safety improvement. The main advantage of the proposed method compared to conventional ones was the consideration of similarity in adjacent 100-

meter segments yielding one homogeneous segment in the evaluation and prioritization approaches. The mean IRI value related to adjacent segments have the potential to consider the entire roadway as well as identifying local similarities. This provides a platform on which segments with the similar amount of mean IRI were prioritized individually.

4. Results and Discussion

Considering the safety oriented IRI threshold value as 2.7 m/Km, the next step was to determine and prioritize APSs for implementation of highway preservation. Thus, collected mean IRI data were used to perform the segmentation method. The fixed-lengths of 100, 200 and 500 meters were floated along the entire length of the selected highway to recognize the APSs.

With regard to restrictions imposed on budget assigned to road agencies for safety improvement, identification and preservation of all APSs are not applicable. Therefore, it was assumed that the best segmentation method is the one being able to detect sections with safety issue in the shortest possible length. To optimize the budget allocation on safety oriented initiation of M&R projects, total lengths of APSs obtained by preserving 10 to 50 percent of the highway were calculated. Finally, the most appropriate segmentation length and the total length of APSs associated with defined limitations were determined.

4. 1 Length of APSs

Firstly, the FFLS method was performed on the selected highway by the means of mean IRI values using floating fixed-lengths of 100, 200 and 500 meters. Then the total length of segments with mean IRI values higher than 2.7 m/Km was determined considering the road M&R cost limitation index for safety improvement. That is to say, 10 to 50 percent of the resulted segments must be maintained and rehabilitated to meet the constraints upon road agency annual budget. Table 2 provides the total lengths of segments calculated based upon floating fixed-lengths of 100 (Not segmented), 200 and 500 meters considering safety improvement limitation. With reference to Table 2, it can be concluded that the total lengths of segments with safety concerns are the shortest when 200-meter floating segments is chosen. The latter is constant in all scenarios. This would result in economic efficiency of prioritization regarding preservation treatment of APSs. In the following, segments with mean IRI higher than 2.7 (m/Km) were recognized by FFLS method using 200-meter floating length. Then the prioritization of segments based on M&R constraints was performed.

Table 2. The total lengths of APSs obtained from FFLS based on mean IRI

M&R constraints scenarios	Length of Road (km)		
	100-meter (Not segmented)	200-meter floating segmentation	500-meter floating segmentation
10%	5.24	5.07	5.3
20%	10.48	10.14	10.6
30%	15.72	15.21	15.9
40%	20.96	20.28	21.2
50%	26.2	25.35	26.5

4. 2 Prioritization

Based on results obtained from Table 2, the floating fixed-length of 200-meter was chosen for pavement preservation prioritization. With respect to safety improvement limitation, it was decided to rehabilitate 10, 20, 30, 40 and 50 percent of the APSs. The proposed limitation resulted in the M&R lengths of 5.70, 10.14, 15.21, 20.28 and 25.35 Kilometer, respectively. Table 3 illustrates the prioritization of 50 percent of the entire APSs. With reference to Table 3, the first 27 segments cover 10 percent of the entire APSs. Regarding the prioritization of 20, 30, 40 and 50 percent of the resulted APSs, a number of segments are the first 56, 85, 114 and 146 segments, respectively.

Considering the limited budget and safety improvement potentials, the most proper percentage of APSs could be selected for future repair and safety provisions. Taking into account the 50 percent maintenance of the APSs, almost all segments with IRI higher than 3.8 could be recognized and rehabilitated. Although the threshold for the trigger of safety oriented M&R activities was chosen as 2.7 (m/Km), the first step in safety provisions is to rehabilitate the most deteriorated and hazardous segments.

Table 3. Prioritization of APSs with respect to M&R limitation (50 percent) for safety improvement

No.	From (m)	To (m)	m-RI (m/Km)	No.	From (m)	To (m)	m-RI (m/Km)	No.	From (m)	To (m)	m-RI (m/Km)	No.	From (m)	To (m)	m-RI (m/Km)
1*	34,400	34,500	6.92	41	10,500	10,500	4.92	81	900	1,000	4.40	121	84,200	84,300	4.00
2	6,100	6,200	6.73	42	8,700	8,800	4.90	82	55,400	55,400	4.40	122	41,700	41,800	3.99
3	7,000	7,100	6.43	43	47,000	47,100	4.88	83	48,700	48,800	4.39	123	52,500	52,600	3.97
4	3,800	3,900	6.22	44	54,400	54,500	4.81	84	58,100	58,200	4.38	124	16,400	16,500	3.97
5	5,900	6,000	6.18	45	600	700	4.81	85	56,900	57,000	4.36	125	3,200	3,200	3.97
6	6,300	6,400	6.10	46	3,300	3,400	4.81	86	85,000	85,100	4.36	126	54,600	54,600	3.95
7	7,800	7,900	6.04	47	1,100	1,200	4.78	87	38,700	38,800	4.35	127	84,500	84,600	3.95
8	5,800	5,800	6.02	48	7,200	7,200	4.77	88	37,800	37,900	4.32	128	52,200	52,300	3.93
9	3,600	3,700	6.01	49	48,000	48,100	4.77	89	11,900	12,000	4.32	129	54,300	54,300	3.93
10	8,500	8,600	5.86	50	9,500	9,600	4.76	90	53,600	53,700	4.32	130	6,700	6,700	3.93
11	7,300	7,400	5.79	51	54,100	54,200	4.74	91	200	300	4.30	131	49,900	49,900	3.92
12	4,000	4,100	5.74	52	52,700	52,700	4.73	92	55,200	55,300	4.30	132	48,900	49,000	3.91
13	6,800	6,900	5.61	53	57,600	57,700	4.73	93	47,500	47,600	4.28	133	88,100	88,200	3.90
14	4,900	5,000	5.61	54	53,300	53,400	4.72	94	84,800	84,900	4.27	134	9,300	9,400	3.90
15	8,300	8,400	5.54	55	53,800	53,900	4.71	95	39,500	39,500	4.25	135	85,600	85,700	3.90
16	5,600	5,700	5.50	56	51,300	51,300	4.71	96	50,300	50,400	4.23	136	11,100	11,100	3.90
17	4,300	4,400	5.46	57	56,100	56,200	4.70	97	46,900	46,900	4.21	137	22,400	22,500	3.89
18	51,100	51,200	5.44	58	52,800	52,900	4.67	98	12,700	12,800	4.21	138	38,200	38,300	3.88
19	4,600	4,700	5.44	59	9,700	9,700	4.67	99	56,600	56,600	4.21	139	49,100	49,100	3.88
20	10,300	10,400	5.44	60	39,600	39,700	4.65	100	9,000	9,100	4.19	140	51,800	51,800	3.86
21	51,400	51,500	5.41	61	82,100	82,200	4.65	101	55,500	55,600	4.19	141	56,300	56,300	3.86
22	1,700	1,800	5.32	62	47,200	47,200	4.63	102	50,700	50,700	4.18	142	53,000	53,000	3.86
23	9,800	9,900	5.28	63	57,800	57,900	4.59	103	51,000	51,000	4.18	143	36,500	36,600	3.86
24	6,500	6,600	5.28	64	49,200	49,300	4.58	104	56,400	56,500	4.17	144	45,500	45,600	3.85
25	5,500	5,500	5.27	65	11,400	11,500	4.58	105	54,000	54,000	4.17	145	84,700	84,700	3.85
26	8,000	8,100	5.25	66	49,700	49,800	4.54	106	57,300	57,400	4.14	146	58,400	58,500	3.85
27	5,300	5,400	5.24	67	10,900	11,000	4.53	107	2,200	2,300	4.14				
28	3,500	3,500	5.21	68	11,200	11,300	4.53	108	39,300	39,400	4.14				
29	7,500	7,600	5.20	69	48,200	48,200	4.52	109	13,200	13,300	4.13				
30	4,200	4,200	5.16	70	48,300	48,400	4.52	110	42,300	42,400	4.12				
31	5,100	5,200	5.16	71	49,600	49,600	4.51	111	53,500	53,500	4.10				
32	10,600	10,700	5.15	72	48,500	48,600	4.50	112	40,300	40,400	4.10				
33	50,500	50,600	5.14	73	8,900	8,900	4.47	113	39,800	39,900	4.09				
34	4,800	4,800	5.12	74	10,100	10,200	4.47	114	54,900	55,000	4.07				
35	4,500	4,500	5.07	75	56,000	56,000	4.46	115	50,000	50,100	4.07				
36	7,700	7,700	5.05	76	47,300	47,400	4.46	116	9,200	9,200	4.05				
37	49,400	49,500	5.00	77	51,600	51,700	4.45	117	2,500	2,600	4.05				
38	54,700	54,800	4.99	78	56,700	56,800	4.42	118	57,100	57,200	4.01				
39	47,800	47,900	4.95	79	82,300	82,400	4.42	119	2,000	2,100	4.01				
40	400	500	4.94	80	50,800	50,900	4.41	120	10,000	10,000	4.01				

Note: 34,400 (m) and 34.500 (m) means 100-meter ahead of 34,400 and 100-meter ahead of 34.500. This can apply to the rest of the paper.

5. Validation

In order to validate resulted segments from the proposed segmentation method, the PCI values were calculated. Using PCI, effects of surface distress on the pavement smoothness reduction were evaluated. Based on ASTMD6433, the allowable area of 230±90 square meter has been specified for a sample unit while monitoring flexible pavement conditions. Therefore, in this research, the length of 50-meter (first lane in one side of the two-lane highway) was used for pavements' condition survey. A total number of sample units were derived dividing the highway length to the determined length of each unit according to Equation (3). Moreover, the minimum number of sample units, as well as their distances (random selection), were calculated using equation (4) [ASTMD6433, 2011].

$$n = \frac{NS^2}{\left(\left(\frac{e^2}{4}\right)(N-1) + S^2\right)} \qquad (3)$$

$$i = \frac{N}{n} \qquad (4)$$

Where n is a number of sample units, N is the total number of sample units, e is the allowable error in PCI calculation (±5), S is the standard deviation (for flexible pavement is 10), and i the distance between sample units. The pavement monitoring process was followed by collecting the distress types as well as their quantity and severity. Micropaver Software, Version 5.2, calculated the PCI values of determined segments. Results are demonstrated in Table 4.

According to the comparison between Tables 3 and 4, it was revealed that the recognition and prioritization of segments with low IRI are in the direct relationship with PCI values.

That is to say, most if not all segments in Table 3 were chosen from the distances coupled with PCI values of 30 or 19. These low levels of PCI were located in the 0+000 to 17+100 and 33+400 to 58+800, respectively. The latter proved the validity of the proposed segmentation methods. Among 146 segments mentioned in Table 3, 136 segments (approximately 93 percent) were within PCI 30 and 19.

Table 4. PCI values of Sarbisheh-Shusf highway

Km	Distress	severity	PCI
0+000-17+100	Block Cracking	H*	30
	Longitudinal/Transverse Cracking	M** L***	
	Alligator Cracking	HML	
	Edge Cracking	HM	
	Rutting	LM	
	Bleeding	LM	
	Lane/Shoulder Drop	L	
17+100-28+000	Longitudinal/Transverse Cracking	LM	93
	Bleeding	L	
	Lane/Shoulder Drop	M	

28+000-33+400	Longitudinal/Transverse Cracking	LM	65
	Alligator Cracking	LM	
	Rutting	M	
	Bleeding	L	
	Lane/Shoulder Drop	ML	
33+400- 58+800	Block Cracking	M	19
	Longitudinal/Transverse Cracking	HM	
	Alligator Cracking	HM	
	Edge Cracking	M	
	Rutting	HML	
	Bleeding	L	
	Corrugation	M	
	Depression	LM	
58+800-88+300	Longitudinal/Transverse Cracking	M	55
	Weathering/Raveling	M	
	Alligator Cracking	LM	
	Rutting	L	
	Bleeding	L	
	Lane/Shoulder Drop	M	

* High
** Medium
*** Low

6. Conclusion

Defining the concepts of RQ and IRI as well as their effects on safety highlighted the importance of IRI in road safety assessment. The objective of this paper was to determine safety oriented threshold of IRI to recognize APSs on highways. Although a number of accidents are the most important factor in the determination of hazardous locations, the appropriate segmentations and consideration of contributing factors can be suitable for the reliability of results. In this paper, various research works considering road safety via IRI were reviewed to propose the specified safety oriented IRI threshold for Iran highways. The modified segmentation method was proposed to detect and prioritize APSs. The floating fixed-lengths of 100, 200 and 500 meters were proposed for performing FFLS method followed by imposing restrictions on lengths of resulted segments for safety oriented initiation of M&R project. In the last part, the resulted segments were validated to demonstrate the reliability of the segmentation method and recommended threshold value of IRI. In summary, the results are as follows,

1. Carrying out the available literature regarding safety oriented IRI threshold values, 2.7 m/Km was chosen as the threshold for the safety analysis in this research. The proposed threshold was identical to one determined for origination of preventive maintenance activities developed by researchers for Iran roadways' conditions. The validation assured the accurate selection of IRI threshold as well as the supplement relationship between the M&R activities and safety.
2. When 200-meter floating segments was determined for performing FFLS method, total lengths of the APSs were the shortest in all scenarios. This would result in optimal budget allocation on M&R activities to improve the safety of APSs.
3. Validation revealed that the resulted APSs from the proposed method were placed in the most deteriorated segments (i.e. where PCI

values were the lowest). It can be concluded that the proposed segmentation method was applicable and reliable.

4. The recommended segmentation method yield identification of segments with the low level of safety associated with high IRI. Moreover, the validation process confirmed the reliability of recognized segments. When 50 percent of segments were chosen to be rehabilitated, 136 segments of 146 ones were within PCI 30 and 19.

In order to advance the identification of APSs and budget allocation for safety improvement, the research may be continued by considering other pavement performance criteria such as skid resistance which is the main sources of an accident especially when a pavement is wet. This would result in accurate segmentation and efficient reduction in the number of accidents on highways. Generally, due to the limited budget allocated to road agencies for M&R operations, and the fact that road safety plays important role in roads management; therefore, it is suggested to spend available funds both on M&R operations and on safety improvement. In this way, the prioritization of deteriorated segments for M&R treatments and the safety enhancement can be taken place simultaneously.

7. References

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