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Introducing New Index in Forest Roads Pavement Management System

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Abstract

Forest road pavement needs an evaluation methodology based on a comprehensive assessment of road conditions. This research was conducted to evaluate the performance of a method for rating the surface condition of forest roads and eventually to adapt the method to the situation prevailing in a forest road network. The rating method selected as the basis for this experiment was the pavement condition index (PCI) developed by the U.S. Army Corps of Engineers. A 53 km of forest roads were selected contained the most influential factors and conditions variability. Eventually, 201 road segments were delineated between 150-300 m in length. Within the given segments, sample plots were set 20 m in length consecutively. It was concluded that the panel scores for distress and surface condition of sample unit and section differed from forest road pavement condition index (FRPCI) and PCI. Linear regression was used to derive equations between distress and PCI score to determine effective FRPCI parameters that provide a numerical rating for the condition of road segments within the road network, where 0 worlds are the worst possible condition, and 100 is the best possible condition best. Also, regression analysis showed the FRPCI model with a 0.87 correlation for the total of the road is a performance index used for the first time in forest roads. This study showed a range of FRPCI from 7.8 to 96.3, different from PCI and URCI ratings (0.85-45 and 1.2-53). The FRPCI index helps forest managers in road maintenance, harvesting, and planning to use road information.

Keywords: Forest Road Distress, Pavement Management System, Unpaved Road Index, Maintenance, Deterioration.

Introduction

Forest roads are a fundamental prerequisite for the sustainable management of forest resources (Heidari et al., 2018). Forest roads provide many benefits, such as access to timberland, timber removal, fire prevention, recreation, protection, and research. These benefits have led to an increasing demand to construct new roads and further extend the forest road network. However, road construction and maintenance are generally some of the more expensive activities in the timber transportation process (Akay et al., 2014). Due to budget limitations and increasing pavement maintenance and rehabilitation challenges, Pavement Management System (PMS) has become a beneficial management tool for road maintenance agencies. Well-considered pavement management strategies can only accomplish pavement design utilizing low-cost and up-to-date principles for material usage of forest roads. Concerning this, appropriate rules must be established in the pavement management of forest roads. Comparing the difference between the needed and the actual expenses for maintaining standard conditions of the pavement, the proper strategy, and the optimum timing can be chosen (Kosztka, 1996).

The performance of forest road pavements has long been recognized as an essential parameter during design and maintenance operations. In order to measure and develop a model for pavement performance, it is necessary to clearly define the pavement performance (Adlinge and Gupta, 2013). The Pavement performance is defined as “the serviceability trend of pavement over a design period, where serviceability indicates the ability of the pavement to serve the demand of the traffic in the existing conditions” (Highway and Officials, 1993). The Pavement performance can be obtained by observing its structural and functional performance or predicting pavement serviceability from its initial service time to the desired evaluation time (Adlinge and Gupta, 2013). Pavement deterioration can be attributed to age, climatic variables, traffic, environment, material properties, pavement thickness, pavement strength, and subgrade properties that affect the mechanical characteristics (Heidari et al., 2018).

The pavement condition assessment is a qualitative relationship between the pavement condition and the influential factors (Elhadidy et al., 2014). The pavement condition is helpful to develop a pavement management system (PMS) or Maintenance Priority Index (MPI). The Pavement condition index (PCI) prioritizes the pavement maintenance schedule based on distress severity and its condition (McManus, 2013). The PCI is a subjective method of evaluation based on inspection of the road segment. However, it is neither a complex nor time-consuming exercise (Shahnazari et al., 2012). Knowledgeable and experienced public works officials drive the road network and systematically evaluate its condition. The data are entered into a database to calculate the PCI of road segments (Elhadidy et al., 2014). Road pavement should be evaluated using PCI annually to evaluate changes in road conditions (Arhin et al., 2015). In order to evaluate pavement conditions, the road network must be divided into manageable segments. The sections with relatively uniform pavement structures, design, and traffic volumes will have similar performance characteristics (Mulry et al., 2015). A pavement deterioration model, which acts as the hub of analysis component, is the engine of whole management activity (Peshkin, 2011). It is an analytical method for rating the surface condition to support where, when, and why to implement maintenance and repair actions. Unfortunately, the matter of rating surface conditions has scarcely been treated in the literature. It was probably owing to two facts: (a) the cost of surface rating made according to an adopted method may seem to be prohibitive if compared with an overall subjective evaluation made by an experienced technician and (b) the actual task and value of objective rating methods have not yet been appraised by management authorities. The U.S. Army Corps of Engineers, the American Public Works Association, and others have developed pavement management systems (PMSs) such as PCI for unpaved roads. These PMSs cannot currently be used for forest or gravel (unpaved) roads because of the nature of the PCI method that does not include all situations of unpaved roads (Obengn and Tuffour, 2020). An unsurfaced road component that can stand alone or be used with any of these PMSs would provide local highway agencies with a comprehensive roadway management system that would be more suitable for their needs. In Unpaved road, researchers (Eaton, 1998; Miller and Bellinger, 2003) introduce the Unpaved Road Condition Index (URCI) that types of distress found in unpaved roads are categorized and listed in the manual forum. There is a description of the type and severity level, an illustration, and a measurement method for each type of distress listed. The manual also includes inspecting unsurfaced road conditions, a field inspection worksheet, and a family of deduct-value curves for the distress types and

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associated severity levels. The rating method on the URCI method and strategies are compatible with the PAVER PMS developed by the U.S. Army Corps of Engineers and the American Public Works Association. In Forest road, different situation is dominant regarding to heavy vehicle passes, heavy rainfall, unpaved roads, tree harvesting, canopy of trees and topographic problems (high aspect, slope and elevation) (Heidari et al, 2018). A forest road component that can stand alone or be used with any of PMSs would provide local agencies with a comprehensive road management system that would be more suitable for their needs. For these reasons, the mention indexes may not be suitable to evaluate forest road pavement condition. The aim of this research was to develop a method for rating forest road pavement conditions to priotrize maintenance operation.

1. Material and Method

2.1 Reviewing PCI and URCI

The PCI procedure is the road industry standard and the military to visually assess the current pavement condition. The procedure is described by the American Society for Testing and Materials (ASTM) D6433-09 (2009 has been used in this study. The PCI provides a numerical rating for road segment properties (e.g., distress, drainage, ditch) within the each road network, where 0 is the worst possible condition, and 100 is the best (Table 1) (McGarragh and Hudson, 2013).

Table. 1: PCI rating

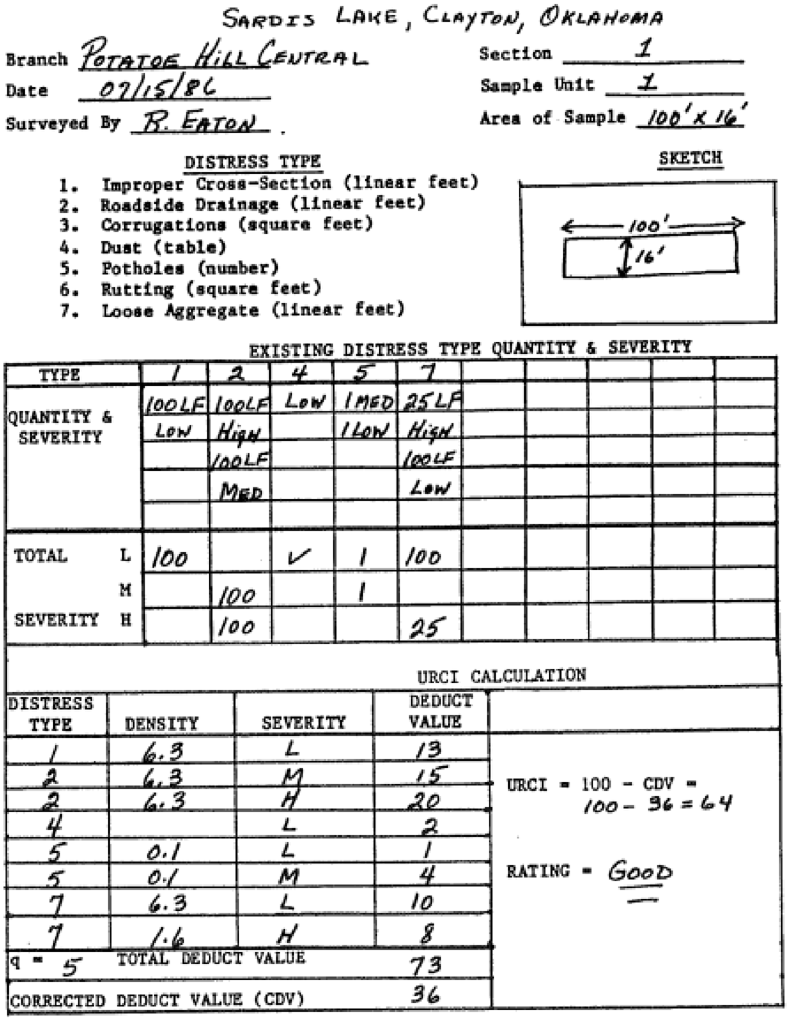
PCI	**Rating**
85–100	Excellent
70–85	Very good
55–70	Good
40–55	Fair
25–40	Poor
10–25	Very poor
00–10	Failed

All indexes are used to:

- Identify immediate maintenance and rehabilitation needs

- Monitor pavement condition over time
- Develop a network preventive maintenance strategy
- Develop road maintenance budgets
- Evaluate pavement materials and designs

In URCI field manual (figure 1) identified six unsurfaced road distresses and two drainage-related distresses, each with a separate index. As a result of the field validation, the manual was modified by combining the two indices to list the following seven distresses: Improper cross-section, Roadside drainage, Corrugations, Dust, Potholes, Rutting, and Loose aggregate.



SARDIS LAKE, CLAYTON, OKLAHOMA

Branch POTATOE HILL CENTRAL
Date 07/15/86
Surveyed By R. EATON.
Section 1
Sample Unit 1
Area of Sample 100' x 16'

DISTRESS TYPE

1. Improper Cross-Section (linear feet)
2. Roadside Drainage (linear feet)
3. Corrugations (square feet)
4. Dust (table)
5. Potholes (number)
6. Rutting (square feet)
7. Loose Aggregate (linear feet)

SKETCH

EXISTING DISTRESS TYPE QUANTITY & SEVERITY

TYPE		1	2	4	5	7					
QUANTITY & SEVERITY		100LF	100LF	LOW	1 MED	25LF					
		LOW	HIGH		1 LOW	HIGH					
			100LF			100LF					
			MED			LOW					
TOTAL	L	100		✓	1	100					
	M		100		1						
SEVERITY	H		100			25					

URCI CALCULATION

DISTRESS TYPE	DENSITY	SEVERITY	DEDUCT VALUE
1	6.3	L	13
2	6.3	M	15
2	6.3	H	20
4		L	2
5	0.1	L	1
5	0.1	M	4
7	6.3	L	10
7	1.6	H	8
q = 5	TOTAL DEDUCT VALUE		73
CORRECTED DEDUCT VALUE (CDV)			36

URCI = 100 - CDV =
100 - 36 = 64

RATING = GOOD

Figure 1. URCI survey checklist (Eaton, 1998)

Forest Road Pavement Condition Index (FRPCI)

Surface condition is related to several factors, including structural integrity, structural capacity, distress, and rate of deterioration (Heidari et al., 2018). Direct measurement of all these factors requires expensive equipment and skilled experts. However, these factors can be assessed by observing and measuring (directly) the distress of the surface.

a. **FRPCI**. The FRPCI is a numerical indicator based on a scale of 0 to 100.

The FRPCI indicates the road's integrity and surface operational condition. Its scale and associated ratings, table 2, are identical to the Pavement Condition Index (PCI) for surfaced roads.

b. **Determination of FRPCI**. The FRPCI is determined by measuring surface distress. The current study evaluated the performance of FRPCI on a 185km forest road.

Table 2. Forest Road Pavement Condition Index Calculating

Rating	**Failed**	**Poor**	**Fair**	**Very Good**	**Excellent**
FRPCI	0-10	10.1-40	40.1-65	65.1-85	**85.1-100**
Factors and Weights					
Distress	**Severity of Distress**				
	Failed 0-1	**Poor** 1.1-3.9	**Fair** 4-6.4	**Good** 6.5-8.4	**Excellent** **8.5-10**
Pothole (cm)	>12	8-12	5-8	3-5	<3
Rutting (cm)	>15	12-15	8-12	5-8	<5
Protrusion(cm)	>10	7-10	5-7	3-5	<3
Ditch rating	N	Full	Half Full	Quarter full	Not full
Drainage rating	N	Full	Half Full	Quarter full	Not full
Shoulder (m)	N	0.1	0.2-0.3	0.3-04	>0.4
Trench Status	Fall	Fall into Road	Fall into Valley	Fall into Ditch	N
Canopy on Road %	>60	50-60	40-50	30-40	0-30
Rise Fall (m/km)	>80	50-80	20-50	10-20	<10
Embankment damage	Very Sever	Sever	Moderate	Low	N
Total Weights	0-10	11-40	41-65	66-85	85-100

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The FRPCI index achieves from the average weight of all sections and shows the rating of the branch. For example, if a skilled expert collected the following information:

A pothole (12 cm), rutting (5 cm), protrusion (6 cm), Ditch (not fill), drainage (fill), shoulder (0.35 m), trench (fall), canopy (10%), rise fall (40 m/km) and sever embankment damage. According to table 2, the FRPCI of this segment will achieve:

1.1+6.5+5.5+10+2+7+1+9+5.2+2.5=49.8 (Fair Condition)

Forest road Survey

A forest road network with a 185 km length was selected to evaluate the performance of FRPCI. Before the forest road network was inspected, it was divided into branches, sections, and sample units (fig 1). The road hierarchy is composed of branches, sections, and sample units. The data were obtained once this division was completed.

Branch: A branch is an identifiable part of the forest road network, a single entity with a distinct function. For example, individual roads, depot areas, and range roads are separate branches of a forest road network (Heidari et al., 2018).

Section: A section is a branch division with specific and consistent characteristics throughout its area or length. These characteristics are (1) Structural composition (thickness and materials), (2) Construction history, (3) Traffic (4) Surface condition (Heidari et al., 2018).

Sample unit: A sample unit is an identifiable area of the forest road section; it is the shortest length of the forest road network. For forest roads, a sample unit is defined as an area of approximately 100 Square meters. The detailed sample unit measurements should be conducted to compute the ratings annually. Always make these measurements simultaneously of year-when the roads are in their best and most consistent condition. To make the measurements, the inspector will need to recognize certain kinds of problems called distresses. Table 2 shows the ten distress types of forest roads.

The sample unit shown in figure 2 has 20 meters of severity improper Cross-section. The equipment needed to do a survey was a hand odometer (measuring wheel) used to measure distress lengths and areas, a straight edge, and a ruler to measure the depths of potholes, ruts, or loose aggregate the FRPCI distress guide. If two or more distresses occur together, each one was measureed separately. If it is hard to determine what distress was observed, make a reasonable estimate that the system is flexible enough to calculate an accurate rating. Since the FRPCI is based on these descriptions, the inspector must follow information closely when doing an inspection.

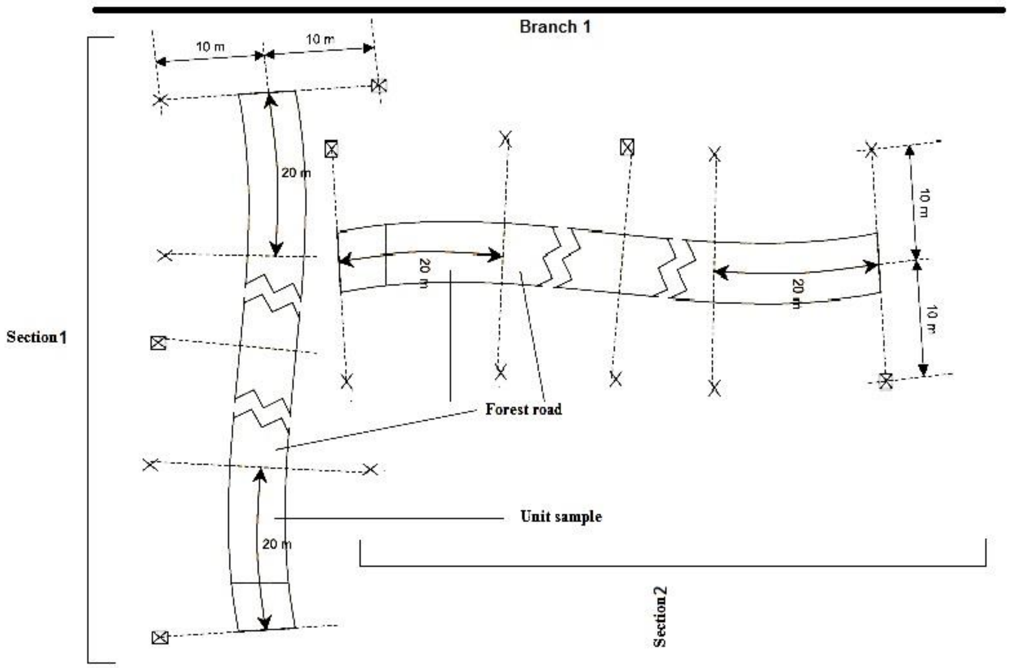

Figure 2. Forest Road with the branch, section, and sample units

Study Area

This research was conducted in Chob-kaghaz Mazandaran maintains approximately 400 km of primary gravel-surfaced low-volume roads located in three separate watersheds in Mazandaran province north of Iran. Altitude ranging from 150 to 850 m a.s.l. and with average annual precipitation of 850 mm. The area is located between 48°44'36"and 48°49'58" of longitude, and 37°37'23"and 37°42'31"of latitude and other features showed in table 3.

Table 3. General information and Pavement Survey Data in section division of study area

Name of Road	**Aleshrood (sections)**	**Zengaldareh (sections)**	**Sangdarka (sections)**	**Angetarood (sections)**	**Hamsava (sections)**
Wide (m)	5-5.8	4.3-4.9	4.2-5	4-4.5	4.5-5.5
Shoulder (m)	0.3-0.5	0.4-0.6	0.2-0.5	0-0.1	0.2-0.4
Canopy %	0-65	5-80	12-85	3-74	5-90
Embankments(m)	4:1- 1.5:0.2	3.5:1-0.50:0.1	3:0.7-2:0.1	8:1.5-6:1	9:3.2-2.1:0
Material	Mix- Riverine	Riverine	Riverine-Mix	Riverine-Mountain	Mix- Mountain
Thickness (cm)	85-200	65-160	60-130	45-100	30-120
Rating of Drainage	Poor-Excellent	Faire-Poor	Faire-Good	Faire- Poor	Failed- Good
Length of Road (Km)	14	7	13	11	8
Embankment Damage	Poor-Excellent	Poor- Fair	Failed-Poor	Failed- Poor	Failed- Good
Trench Status	Poor-Excellent	Failed- Good	Poor- Excellent	Failed- Good	Failed- Poor
Effectiveness of ditch arrangement	Failed- Good	Fair- Poor	Poor-Failed	Poor- Failed	Excellent-Poor
Rainfall (mm)	840-880	860-920	930-980	990-1100	810-870
Timber Harvesting (m3)	150-2450	190-3012	125-226	55-2850	45-1006
Management Experience (month)	2-62	5-48	2-55	4-53	10-65
Traffic (MADT)	98-827	50-511	74-763	35-748	28-508
Pavement Condition Survey					
Rutting (cm)	2.5-20	5.5-15.3	1.4-16	3-17.2	0.2-15.1
Pothole (cm)	1.6-12	2.5-13	1.1-12.8	2.8-13.4	1.2-15.5
Protrusion (cm)	0.1-9.5	1.5-11.6	1.1-12	2.1-10.6	0.2-13.5
Rise Fall (m per km)	5-96	3-102	6-85	4-140	6-112

Data collection

Following an intensive field survey, the present study selected forest roads at five districts: Aleshrood, Zengaldareh, Sangdarka, Angetarood, and Hamsava. The length of each section or branch was not the same. Each section was further divided into 30 to 60 of 20 m sample units. Intensive surveys have been carried out on all five road sections. Road Inventory included Pavement Condition (rut, pothole, and protrusion), shoulders condition, soil properties soil of roadbed, rainfall, channel (status of filled), properties of shoulders (width), surface drainage arrangement, traffic, the thickness of the pavement, type of material, percent of crown and slope, sub-base, base, and type adjoining land. Also, surface drainage ratings and shoulders have been observed. In the Pavement Condition, rut depth, pothole depth, and protrusion have been measured. Different types of traffic have been counted at the road entrance.

Pavement Condition Survey of all the roads has also been completed with measuring: rutting, pothole, and protrusion in the central portion of each subsection and edge drop. Traffic data of all the roads have been taken, consisting of an average of 3 days' traffic for different vehicle classes. Trucks (2-Axle and 3-Axle), Jeeps, Cars, and Tractor-trailer (Giroud and Han, 2004). The data has been taken six times during peak period (P) and standard (N). Data are presented in Table 3.

Results

The statistical analysis of the data (regression model) presented in Tables 4 to 6 has been completed. Weightings (sum score of each section) have been given to various parameters related to the pavements. Forest roads pavement condition index (FRPCI) has been calculated based on weights.

The following parameters have been considered for determining FRPCI values: Rutting, Pothole, Protrusion, Condition of the shoulder, and Rise fall. The weighting given to various parameters is: For parameters of the shoulder condition and surface drainage arrangement, weights have been given based on excellent, very good, fair, poor, and failed condition (5 for Excellent, 4 for Very Good … and 1 for Failed). For parameters of Rutting, Pothole, Protrusion, Shoulder, and Rise fall, the weighting has been given based on Min. and Max. Values (Heidari et al., 2018):

a) For Rutting: Min. 0.2 cm and Max. 20 cm (10-1)

b) For Pothole: Min. 1.1 cm and Max. 15.5 cm (10-1)

c) For Protrusion: Min. 0.1 cm and Max. 13.5 cm (10-1)

d) For rising fall: Min. 3 m and Max. 140 m (10-1)

The score of parameters cited in table 4 is presented below (calculated from Table 3).

Table 4 weightings of each district are calculated based on score catchment from table 3, and these scores show the rating and value of FRPCI variables.

Table 4. Weightings (V and W showed value and weighting of each parameter)

Name of Road	Aleshrood		Zengaldareh		Sangdarka		Angetarood		Hamsava	
	V*	W*	V	W	V	W	V	W	V	W
Rating of Surface Drainage	Excellent-Poor	10-4	Fair-Poor	6-4	Good-Fair	8-6	Fair-Poor	6-4	Good-Failed	8-1
Embankment Status	Excellent-Poor	10-4	Fair-Poor	6-4	Good-Failed	8-1	Poor-Failed	4-1	Good-Failed	8-1
Effectiveness of ditch arrangement	Good-Failed	8-1	Fair-Poor	6-4	Poor-Failed	4-1	Poor-Failed	4-1	Excellent-Failed	10-1
Rating of Drainage	Excellent-Poor	10-4	Fair-Poor	6-4	Good-Fair	8-6	Fair-Poor	6-4	Good-Failed	8-1
Trench Status	Excellent-Poor	10-4	Good-Failed	8-1	Excellent-Poor	10-4	Good-Failed	8-1	Poor-Failed	4-1
Pavement Condition Survey										
Rutting (cm)	2.5-20	0-9	5.5-15.3	0.9-6.7	1.4-16	0.1-9.6	3-17.2	0-8.6	0.2-15.1	0.9-10
Pothole (cm)	1.6-12	1-9.4	2.5-13	0.1-9	1.1-12.8	0.2-9.6	2.8-13.4	0-8.8	1.2-15.5	0-9.5
Protrusion (cm)	0.1-9.5	1.3-9.9	1.5-11.6	0-9.4	1.1-12	0-9.5	2.1-10.6	0.4-8.8	0.2-13.5	0-10
Rise Fall (m / km)	5-96	1-10	3-102	1-10	6-85	1-10	4-140	1-10	6-112	1-10
Shoulder (m)	0.3-0.5	6-10	0.4-0.6	8.5-10	0.2-0.5	4-10	0-0.1	0-4	0-0.4	0-8.5

Determination of FRPCI value for forest roads district calculates by summing the values in table 4 and compare with PCI and URCI index presented in table 5. FRPCI value is calculated by the sum of min and max weights from table 4, and the mean of them calculates final FRPCI; also, URCI and PCI were calculated by HDM-4 software.

Table 5. Value of PCI for All of Forest Roads Pavement

Name of Road	**Aleshrood**	**Zengaldareh**	**Sangdarka**	**Angetarood**	**Hamsava**
Mean of parameters and sum of them together in table 2 (Weights)					
(FRPCI Value)	96.3	76.9	86.7	68.2	84
	33.6	28.4	24.2	12	7.8
Final FRPCI	64.95	52.65	55.45	40.1	45.9
Final URPCI	45	33	36	29	31
Final PCI	34	28	30	19	27

The FRPCI index has higher values than the PCI and URCI indices, which indicates that the condition of forest roads has been better estimated using this index because, in forest roads, the desired standards are much lower than rural and highways roads.Figure 3 shows the FRPCI value in five districts of the forest roads network. Figure 3 shows that FRPCI varies among the forest road network (7.8 to 96.3). The maximum and minimum FRPCI were obtained at the Aleshrood and the Hamsava branch, respectively. Although the Aleshrood branch had various scores, the final FRPCI showed a maximum score (64.95).

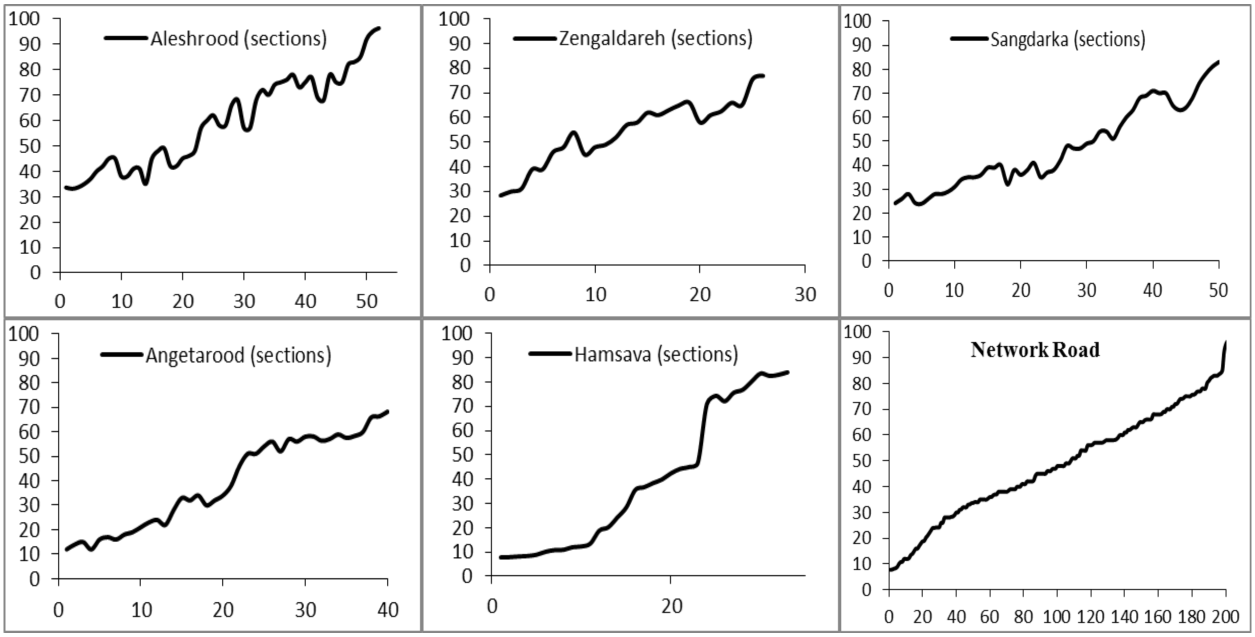

Figure 3. FRPCI in All Districts of Forest Road Network define X and Y-axis

Regression Analysis

The regression analysis has been done considering FRPCI as a function of traffic, annual rainfall, the volume of timber harvesting, forest road management history, and slope as independent variables on total the district.

Table 6 gives data regarding FRPCI and independent variables for various roads used for regression analysis at the section level.

Table 6. Combined Regression Equation for Five Districts and Total District

Name of Road	Equation	Correlation
Aleshrood	$Y= 0.008X_1+ 0.232X_2 + 1.2X_3 - 0.0195X_4$	0.71
Zengaldareh	$Y= 0.2 X_1 - 1.32X_2 + 0.3X_3- 0.0001X_4$	0.75
Sangdarka	$Y= 0.45 X_1 - 2.12X_2 + 8.45X_3 + 0.049X_4$	0.81
Angetarood	$Y= 0.04X_1- 0.95X_2 - 0.07X_3 - 0.006 X_4 + 0.35X_5$	0.75
Hamsava	$Y= 0.12X_1- 0.29X_2 -1.65X_3 + 0.004 X_4 + 0.02X_5$	0.70
Total of Forest Roads	$Y= 0.01X_1+ 0.3X_2 + 0.95X_3 - 0.0183X_4+ 0.001X_5$	0.77

X1= Rainfall (mm), X2= Traffic, X3= Slope, X4= Volume of timber harvested and X5= Management experience

Also, regression analysis for the Hamsava branch that parameters had a positive relationship with distress severity for the forest roads pavement in this branch showed in table 7 and other parameters not significant on FRPCI.

Table 7. Result of Regression Analysis

Branch	variable	coefficient	S.E.	P-value
Hamsava	Intercept	279.54	47.143	<0.0001
	Rainfall	-0.496	0.012	0.0333
	Traffic	0.161	0.044	0.0206
	Slope	0.747	0.822	0.0089
	Volume of timber harvested	0.183	0.053	0.0006
	Management experience	80.652	23.248	0.0612

Discussions

A relationship was found between distress values attributed to the sample units by the FRPCI values obtained as a function of distress density. The same thing applies to the section: the section score agrees with the FRPCI rating (table 7). The experiment was done with roads in use, lacked the necessary amplitude of distress density to test the whole range of possibilities. Another drawback of the experiment is its size. A larger giant experiment will be necessary for calibrating FRPCI values. The experiment should be large enough to guarantee a sufficient number of distresses of each kind.

This research showed that the Sangdarka branch had the highest correlation value, although this site is the second rating according to the FRPCI index (table 3 and 4). The sample units in this branch were riverine, and distress had a normal disturbance. The Angetarood branch is the worst among the five sections based on the FRPCI index with a good correlation (0.75). A notable point in the forest network was that all sample units with fewer scores have the same feature. For example, sample units in Aleshrood, Sangdarka, Angetarood, Zengaldareh, and Hamsava branch with more than 250 vehicles, inadequate drainage, and fewer than six months maintenance fewer scores it was expected from the parameter's score.

The intensive traffic on selected forest roads pavement had the most negative influence on the performance of forest roads. Hence the causes for the distress of these roads can be identified as drainage and construction quality (Furl et al., 2015). Field tests have shown that the proper placement of FRPCI depends on general data, which showed in table 1. The frequency of traffic and road activities such as maintenance grading, ditching, and mowing can result in FRPCI and PCI (Grace III and Clinton, 2007).

The result of the survey represents all the maintenance operations needed to upgrade the forest road network. The sum of the maintenance interventions on each road branch represents one possible alternative in the ranking procedures. The field survey shows that 8% of the total extension of the forest road network is in good condition, while the remaining 92% requires maintenance interventions. Less than 855 maintenance interventions have been identified among 201 sections that show FRPCI needs proposed parameter for FRPCI in our paper to explain the situation of forest roads. Poor drainage due to improper side drain, road chamber, and damaged culvert lead to Pavement deterioration. It occurred when FRPCI scored less than 65.

The ratings calculate using this procedure can be used to manage the maintenance of forest roads effectively. Each forest manager can set stockholder FRPCI ratings to establish a maintenance strategy (Wade et al., 2012). For example, a rating of 50 on a road would require maintenance action to restore the road to a rating of 75 or higher.

This technique could be used as a stand-alone, or manual, pavement management system, or it could be used in conjunction with other traditional methods or any other automated PMS developed in the future (Heidari et al., 2018).

Forest roads are complex engineering structures, which transport efficiency and reliable access to the forest both depend. The constructing of forest roads involves high capital expenditure, and in addition, there is continuing cost for road maintenance (Cao et al., 2013). Forest road maintenance are essential to be considered, especially in Caspian forest with hilly area and weather conditions such as rainfall density. Therefore, FRPCI should be carried out with close observation of the economic aspect and the topographic difficulty, such as forest terrain.

The method of rating unsurfaced roads has been developed and field-validated at five test areas. The current method can be used alone to rate forest roads or incorporated into automatic, computer-aided pavement maintenance management systems for road use. This method should provide the data necessary for optimum allocation of resources and the maintenance of forest roads in the best possible condition at the least cost.

The distresses “improper cross-section” and “inadequate roadside drainage” should be treated differently from other distresses because they are not distressing themselves but are rather sources of distresses. A vehicle can travel by a good cross-section with comfort and security. The same is true with inadequate roadside drainage. For all distresses, the density should ideally be dimensionless, with no exception. In the FRPCI method, the distresses “improper cross section,” “inadequate roadside drainage,” and “potholes.” Based on table 6, the combined regression equation for five districts separately and whole districts showed good significant value for FRPCI (Fig 2). Also, the result in table 5 showed that Rainfall, traffic, slope, the volume of timber harvested, and management experience could be used for quickly calculating forest road conditions because these parameters had the most effect on FRPCI significantly.

From the analysis in table 5, we observed that FRPCI is technology-based and widely used to determine isolation conditions. However, when combined parameters are used, we found that rainfalls contribute negatively impact road conditions. Slope, traffic, and the volume of timber also have a higher effect on FRPCI rating. The least factors in table 7 showed include shoulder condition, drainage as well as overall condition which actually are visually observed. This finding is almost to the reality that for forest roads, using visual to judge road condition is more subjective. The findings also concur with the conclusion drowned by Heidari et al (2018) that potholes, protrusion, and rutting are the most common distress seen on the surface of forest road pavement. The FRPCI and distress data are all independent variables, and therefore the study on the sensitivity of FRPCI to the distress of road surface also concludes that the influence of the road distress on FRPCI is a function of the selected variable applied on this study. It is also observed that when a single parameter is used (table 6), a road network of about 40% is in bad condition. This value is increased to 95% when combined parameters are used.

Conclusions

The main objective of this study was calculating FRPCI for forest roads. The FRPCI decision matrix provides specific guidelines for the improvements required for various road classifications. Using the FRPCI can help identify trigger points for preventive maintenance that can stop a road deteriorating to the point that it needs expensive rehabilitation (Arhin et al., 2015). The FRPCI identifies roads exhibiting distress at the network level that can help categorize maintenance and rehabilitation requirements for budgeting and planning.

The application of the proposed condition method is a cost-effective and straightforward procedure. Defects are evaluated under objective and efficient techniques that result in reduced survey times and good quality data, as proven during the validation process of the forest roads survey guidelines. In addition, the use of linear equations to estimate the FRPCI simplifies the evaluation process and avoids any misunderstanding while applying the method. The method is flexible and adaptable to different locations. When designing the condition limits for unbound gravel, stabilized gravel, and earth roads, multiple climates were considered. In addition, equations were developed, considering and not considering roughness measures assessed with response-type devices because some agencies lack the resources to survey all forest networks with response-type equipment. (Such devices are available in most developed countries but not necessarily in developing countries.) The FRPCI equations and condition limits were validated from questionnaires and a field visit, and the method was improved significantly as a result. Final regressions presented high correlation levels, with R2 > 0.70, good overall significance evaluated with an F-test at a 95% confidence level. Because the method is quite complex in that it involves many distresses and damped additivity of their effects, some degree of determinism may be present. For this reason, an attempt to calibrate the model with field experiments may always have poor coherence, however, its logical foundation is solid, and experts must calibrate it. A similar method could be adapted to other forest road conditions with a larger experiment and an expert panel.

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