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# Rough-Set Theory in Solving Road Pavement Management Problems (Case Study: Ahwaz-Shush Highway)

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**Keywords**

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Decision making,
Pavement management system,
Neural network,
Regression method.

**Abstract**

Rough-Set theory as a mathematical tool for data mining, verifies the relationship among various factors and determines the shortest decision algorithm. In this study, the ability of the Rough-Set theory in the pavement management system has been evaluated with an empirical study using the collected data by the Ministry of Road and Urban Pavement Engineering on the Ahvaz-Shush highway (Southwest of Iran). The results of the Rough-Set theory procedure has been compared with other methods such as the artificial neural networks which is based on the data mining and regression method which is based on the mathematical correlation equations and AASHTO 93 method that is based on the deflection's data. The results of this study confirm the stronger performance of the Rough-Set theory for determining the best decision algorithm in comparison with the other applied methods. The amount of data needed for modeling the problem would be decreased using the Rough-Set method and the efficiency of processing can significantly be increased.

## 1. Introduction

In the constructed pavements, the different types of failure may occur due to the dynamic loads, heavy trucks, poor basement application, complication of mixing, climate changes and many other factors. If restoration and maintenance are taken in the early stages of collapse and sudden deterioration of the pavement, it can prevent more than 50% of the cost of repairs.

Additionally, closure of roads in a long period of the movement of vehicles and detours creation would be prevented. The pavement management system is a helpful tool for the engineers to be aware of the critical points in the life cycle of the pavements [1]. Obviously, changes in the behavior of the pavements can result in a variety of failures and will affect the constructional functions [2].

Determination of the procedure type of the maintenance which is a serious problem in the pavement management system (PMS), depends on the condition of the pavement. Although the data history of the road network is always taken into consideration in the recovery and maintenance strategies, an appropriate strategy is selected to ensure that. many other factors, such as the functional classification of the roads, traffic volume and types of failure need to be observed in the current road surface conditions [3].

The production of the reliable models for studying and analyzing the pavement has always been an important issue in the pavement management. For this purpose, identifying the most important decision-making parameters in the analysis is a fundamental step for the researchers to achieve a better understanding of the problem and to make models more accurate as well as reliable.

There can be found various available methods which have been proposed for the pavement management [4]. One of the newest and most powerful mathematical tools for determining the shortest decision algorithms in the pavement management is the Rough-Set theory.

Rough-Set theory, introduced by Pawlak [5], is a mathematical tool to deal with vagueness and uncertainty. This theory has been used in a lot of decision making and data mining problems such as image processing and medical diagnosis [6], Discerning landslide susceptibility [7], road and transportation engineering [8-11]. This method has been used to simplify the dam location [12], in site selection decision making for the water reservoirs [13] and in water treatment plant site location [14].

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In this study, the applicability of the Rough-Set theory in the data reduction and determining the shortest decision algorithms based on thevpavement management problems has been investigated and the results have been compared with the other applied methods.

## 2. Rough-Set Theory

Rough-set theory is a mathematical tool for those cases which are uncertain or vague. This theory has codified by Pawlak, at the Institute of theoretical and practical sciences at the University of Poland in 1991. Rough-set theory is an obvious generalization of the pair theory (Known in mathematics) [8].

The original concept of the approximation space in Rough-set can be described as follows

Given an approximation space, $apr = (U, A)$

where, $U$ is the universe which is a finite and non-empty set, and $A$ is the set of attributes. Then, based on the approximation space, we can define the lower and upper approximation of set.

Let $X$ be a subset of $U$ and the lower approximation of $X$ in A is

$$apr(A) = \{x|\ x \in U,\ U/ind(A) \subset x\} \quad (1)$$

The upper approximation of $X$ in A is given by

$$apr(A) = \{x|\ x \in U,\ U/ind(A) \cap x \neq \emptyset\} \quad (2)$$

where

$$U|ind(a) = \{(x_i, x_j) \in U.U,\ f(x_i, a) = f(x_j, a)\ a \in A\} \quad (3)$$

Eq. (1) represents the least composed set in A containing $X$, called the best upper approximation of $X$ in $A$, and $A$. Furthermore, Eq. (2) represents the greatest composed set in $A$ contained in $X$, called the best lower approximation.

After constructing upper and lower approximations, the boundary can be represented as follows

$$BN(A) = apr(A) - apr(A) \quad (4)$$

According to the approximation space, we can calculate reducts and decision rules. Given an information system $I = (U, A)$. Then the reduction, $RED(B)$RED, is a minimal set of attributes B⊆A such that $r_B(U) = r_A(A)$ where

$$r_B(U) = \left(\frac{\sum card(B - x_i)}{card(U)}\right) \quad (5)$$

denotes the quality of approximation of $U$ by $B$.

The decision rules can be finally induced by overlaying the reductions on the information system [15].

The advantage of the induction based approaches is that it can provide the intelligible rules for decision-makers and can help them to realize the contents of data sets [11].

## 3. Experimental Study

This study is done on the Ahvaz-Shush highway. The evaluated piece measures are approximately 100.5 km, from 0 to 100.5 km of Ahvaz-Shush highway.

This highway is divided into two pieces in terms of the traffic zoning and general terms, and the data is provided in Table 1.

**Table 1.** Details of Ahvaz-Shush

| Row | Section name | Standard Code | Length (km) | Number of direction | Number of lane |
|---|---|---|---|---|---|
| 1 | Ahvaz-Shush | KZ01A | 100.5 | 1 | 2 |
| 2 | Ahvaz-Shush | KZ01AR | 100 | 1 | 2 |

The study of the pavement failure was done on the Ahvaz-Shush at the request of the Urban and Road bureau in Khuzestan province on 2012. The assessment of the pavement condition was performed base on the (PCI) index. The type, severity and extent of failure were measured in the sample units with an area of 180 $m^2$.

According to the visual impressions from surface, the path is divided into two pieces. Beginning and end part's kilometer and PCI index is provided in Table 2.

**Table 2.** PCI index in Ahvaz-Shush (KZ01AR)

| Section | From (km) | To (Km) | PCI Index |
|---|---|---|---|
| 1 | 0 | 77.8 | 86 |
| 2 | 77.8 | 100.5 | 76 |

Amounts of the damage of Ahvaz-Shush are presented in Table 3. In this study, five different models were considered each of which have six items considered as the fixed inputs which are the road width, longitudinal slope, transverse slope, type of failure, failure severity and density.

Then, each of these models that are shown with I, II, III, IV and V, have been analyzed with other inputs in addition to the 6 cases. In model I, inputs IRI, RN and PCI were studied. Furthermore, in model II inputs RN and PCI, in model III, RN, in model IV, PCI and in model V, IRI were studied.

**Table 3.** Measured failures in Ahvaz-Shush (KZ01A)

| Section Code | From (km) | To (km) | Length (m) | Distress | Severity | Quantity | Unit | Mode | PCI |
|---|---|---|---|---|---|---|---|---|---|
| KZ01AR01 | 0 | 77.8 | 77800 | L&T CRACKING | L | 212.17 | M | Climate/Durability | |
| KZ01AR01 | 0 | 77.8 | 77800 | L&T CRACKING | M | 212.17 | M | Climate/Durability | |
| KZ01AR01 | 0 | 77.8 | 77800 | WEATHERING/RAVELING | L | 32583.03 | SqM | Climate/Durability | |
| KZ01AR01 | 0 | 77.8 | 77800 | BLEEDING | M | 3939.82 | SqM | Other | 89 |
| KZ01AR01 | 0 | 77.8 | 77800 | BLEEDING | H | 5014.82 | SqM | Other | |
| KZ01AR01 | 0 | 77.8 | 77800 | BUMPS/SAGS | L | 212.17 | M | Other | |
| KZ01AR01 | 0 | 77.8 | 77800 | PATCH/UTILITY CUT | L | 2121.72 | SqM | Other | |
| KZ01AR02 | 77.8 | 100 | 22280 | BLOCK CRACKING | M | 184.61 | SqM | Climate/Durability | |
| KZ01AR02 | 77.8 | 100 | 22280 | L&T CRACKING | M | 1335.64 | M | Climate/Durability | |
| KZ01AR02 | 77.8 | 100 | 22280 | L&T CRACKING | L | 6775.59 | M | Climate/Durability | |
| KZ01AR02 | 77.8 | 100 | 22280 | WEATHERING/RAVELING | H | 404.3 | SqM | Climate/Durability | |
| KZ01AR02 | 77.8 | 100 | 22280 | RUTTING | L | 433.18 | SqM | Load | |
| KZ01AR02 | 77.8 | 100 | 22280 | BLEEDING | M | 2389 | SqM | Other | |
| KZ01AR02 | 77.8 | 100 | 22280 | BLEEDING | L | 37062.85 | SqM | Other | 76 |
| KZ01AR02 | 77.8 | 100 | 22280 | BUMPS/SAGS | L | 144.39 | M | Other | |
| KZ01AR02 | 77.8 | 100 | 22280 | CORRUGATION | L | 8 | SqM | Other | |
| KZ01AR02 | 77.8 | 100 | 22280 | DEPRESSION | L | 28.88 | SqM | Other | |
| KZ01AR02 | 77.8 | 100 | 22280 | LANE/SHOULDER DROP | L | 50 | M | Other | |
| KZ01AR02 | 77.8 | 100 | 22280 | PATCH/UTILITY CUT | H | 43.32 | SqM | Other | |
| KZ01AR02 | 77.8 | 100 | 22280 | SLIPPAGE CRACKING | L | 2.64 | SqM | Other | |
| KZ01AR02 | 77.8 | 100 | 22280 | SLIPPAGE CRACKING | M | 7 | SqM | Other | |

## 4. Pavement Management by Rough-Set Theory

To investigate the problem with the Rough-Set theory method, failure information and relevant M&R strategies have been recorded, and finally, data are collected as presented in the Table 4. In this table, the first column is the number of collected data; columns 2 to 10 are classified as state properties which are as follows

Geometric condition (A), the longitudinal slope (B), transverse slope (C), type of failure (D), failure severity (E), failure density (F), IRI index (G), RN index (H), PCI index (I) and the last column is M & R strategy.

This study has identified 11 columns of the highway failures which are given in Table 5.

**Table 4.** Database analysis

| Sample | Condition Attributes | | | | | | | | | M&R |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | |
| L1 | 1 | 2 | 2 | 3 | 1 | 2 | 1 | 1 | 1 | a |
| L2 | 2 | 2 | 2 | 3 | 1 | 2 | 2 | 1 | 1 | a |
| L3 | 2 | 1 | 2 | 3 | 1 | 2 | 1 | 1 | 1 | a |
| . | . | . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . | . | . |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| L98 | 3 | 1 | 2 | 3 | 1 | 2 | 2 | 2 | 1 | c |
| L99 | 3 | 1 | 2 | 1 | 1 | 1 | 2 | 2 | 1 | c |

**Table 5.** Failures of Ahvaz-Shush

| | | | | | |
|---|---|---|---|---|---|
| 1 | LONGITUDINAL/TRANSVERSE CRACKING | 5 | PATCH/UTILITY CUT | 9 | DEPRESSION |
| 2 | WEATHERING/ RAVELING | 6 | BLOCK CRACKING | 10 | LANE/SHOULDER DROP |
| 3 | BLEEDING | 7 | RUTTING | 11 | SLIPPAGE CRACKING |
| 4 | BUMPS/SAGS | 8 | CORRUGATION | | |

Failure severity is divided to low (L), Medium (M) and high (H). Failure density is also divided to 1 (local), 2 (middle), 3 (wide) and M&R. The strategies used in this study are divided into three categories presented by codes a, b and c which include sealant and spots surface damage (a), sealant and spots surface damage and coatings performance (b) and sealing and spots surface and in the next period evaluation, performance covers (c). Deterministic rules are presented in Table 6 and obtained cores for each model are presented in Table 7.

**Table 6.** Deterministic rules

| Deterministic Rules | | | Model |
|---|---|---|---|
| (A6=2)&(A8=1)→a | (A6=3)&(A9=1)→a | (A3=2)&(A7=1)&(A9=2)→a | |
| (A1=1)→a | (A7=4)→b | (A6=1)&(A8=2)→c | **I** |
| (A8=2)&(A9=2)→c | (A3=1)→c | (A6=2)&(A8=2)&(A9=1)→c | |
| (A2=1)&(A7=2)&(A9=2)→c | (A9=3)→c | (A4=2)&(A9=1)→c | |
| (A6=2)&(A7=1)→a | (A6=3)&(A8=1)→a | (A4=5)&(A5=1)→a | |
| (A1=1)→a | (A4=2)&(A6=3)&(A7=1)→a | (A8=4)→b | |
| (A6=1)&(A7=2)→c | (A4=3)&(A5=1)&(A6=2)&(A7=2)→c | (A7=2)&(A8=2)→c | **II** |
| (A3=1)→c | (A5=2)&(A6=1)→c | (A6=5)→c | |
| (A4=2)&(A8=1)→c | (A8=3)→c | (A4=1)→c | |
| (A6=2)&(A7=1)→a | (A3=2)&(A6=3)&(A7=1)→a | (A1=1)→a | |
| (A4=5)&(A7=1)→a | (A5=3)&(A6=2)→b | (A6=1)&(A7=2)→c | |
| (A3=1)→c | (A4=3)&(A5=1)&(A6=2)&(A7=2)→c | (A2=2)&(A7=2)→c | |
| (A6=4)&(A7=2)→c | (A5=2)&(A6=1)→c | (A4=2)&(A6=1)→c | **III** |
| (A4=6)→c | (A4=1)→c | (A6=5)→c | |
| (A1=3)→c | (A2=1)&(A3=2)&(A4=3)&(A6=3)&(A7=2)→a/c | (A1=2)&(A2=1)&(A3=2)&(A4=2)&(A7=2)→b/c | |
| (A5=2)&(A6=2)&(A7=2)→b/c | | | |
| (A6=3)&(A7=1)→a | (A2=2)&(A6=2)→a | (A1=2)&(A4=3)&(A6=2)&(A7=2)→a | |
| (A4=5)&(A5=1)→a | (A1=1)→a | (A2=1)&(A4=2)&(A6=3)→a | |
| (A7=4)→b | (A4=1)→c | (A1=2)&(A6=4)→c | |
| (A7=3)→c | (A3=1)→c | (A6=5)→c | **IV** |
| (A4=6)→c | (A1=3)→c | (A4=3)&(A6=3)&(A7=2)→c | |
| (A5=2)&(A6=1)→c | (A4=2)&(A7=1)→c | (A1=2)&(A2=2)&(A7=2)→c | |
| (A4=3)&(A6=1)→c | (A1=2)&(A2=1)&(A3=2)&(A4=3)&(A6=2)&(A7=1)→a/c | (A4=2)&(A6=2)&(A7=2)→a/c | |
| (A6=2)&(A7=1)→a | (A6=3)&(A7=1)→a | (A2=2)&(A7=2)→a | |
| (A4=5)&(A5=1)→a | (A3=2)&(A6=3)&(A7=2)→a | (A7=4)→b | |
| (A6=1)&(A7=3)→c | (A3=1)→c | (A6=1)&(A7=2)→c | |
| (A4=6)→c | (A1=2)&(A6=4)→c | (A6=2)&(A7=3)→c | **V** |
| (A2=2)&(A7=3)→c | (A4=2)&(A6=1)→c | (A1=3)→c | |
| (A6=5)→c | (A4=2)&(A7=2)→c | (A4=1)→c | |
| (A2=1)&(A3=2)&(A4=3)&(A6=3)&(A7=3)→a/c | (A1=2)&(A2=1)&(A3=2)&(A4=3)&(A6=2)&(A7=2)→a/c | | |

**Table 7.** Cores

| Model | Core |
|---|---|
| I | PCI, IRI, Density |
| II | PCI, RN, Density, Type of failure |
| III | RN, Density, Severity, Type of failure, Cross fall, Gradient, Width |
| IV | PCI, Density, Type of failure, Cross fall, Gradient, Width |
| V | IRI, Density, Type of failure, Cross fall, Gradient, Width |

Studying five models in the Rough-Set, the rules for each model, the number of cores, the quality and the accuracy of classification have been calculated separately and presented briefly in Table 8.

**Table 8.** Comparison of five models proposed by Rough-Set theory at a glance

| Model | Additional input items | Number of rules | Number of cores | Quality of classification | Accuracy of results | | |
|---|---|---|---|---|---|---|---|
| | | | | | a | b | c |
| I | IRI, RN, PCI | 12 | 3 | 1 | 1 | 1 | 1 |
| II | RN, PCI | 15 | 4 | 1 | 1 | 1 | 1 |
| III | RN | 19 | 7 | 0.8980 | 0.77 | 0.25 | 0.87 |
| IV | PCI | 21 | 6 | 0.9286 | 0.63 | 1 | 0.91 |
| V | IRI | 20 | 6 | 0.9388 | 0.7 | 1 | 0.92 |

## 5. Pavement Management by Artificial Neural Network

Artificial neural network is an approximately simulated mathematical model of biological neurons which are the basic functional units of the human brain. The output of a typical neuron is obtained as a result of a non-linear function of weighted sum as follows:

$$y_i = F\left(\sum x_i\, w_{ij}\right) - \theta \quad (6)$$

where F is a non-linear function, $x_i$ and $w_{ij}$ are the inputs and the weights from the $i$th input node to $j$th node and $\theta$ is the entrance value for the artificial neuron [16].

In this study, 1197 data were analyzed that 60% of data for training, 15% for validation and 25% was allocated for network testing. The stopping criterion based on the education on the basis of purpose error considered less than 0.05 that the value is a very low objective error and reflects the high accuracy of education. After network training process and certifying the results observed data were processed using this method.

The results of the analysis by artificial neural network are summarized as presented in the Table 9. Also the five models performance in education and validation are shown in Figures 1 to 5.

**Table 9.** The results of artificial neural network (Neuro Solution 5)

| Model | Hidden Layers | Number of repetition Epoch | Network design | Learning algorithm | Transmission | Learning Network | Network Testing | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Final MSE | MSE Error | R Coefficient of determination |
| I | 1 | 1000 | Multilayer Perceptron | Momentum | TanhAxon | 0.02708 | 0.01551 | 0.96993 |
| II | 1 | 1000 | | | | 0.04493 | 0.03745 | 0.93309 |
| III | 1 | 1000 | | | | 0.03281 | 0.10254 | 0.78985 |
| IV | 1 | 1000 | | | | 0.02004 | 0.03147 | 0.93074 |
| V | 1 | 1000 | | | | 0.04460 | 0.06264 | 0.86926 |

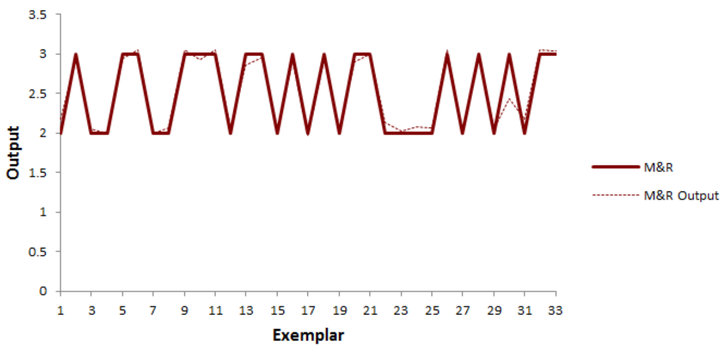


**Figure 1.** Desired output and actual network output- model 1

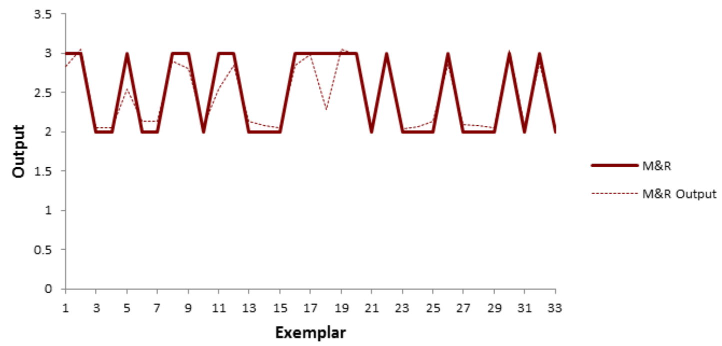


**Figure 2.** Desired output and actual network output- model 2

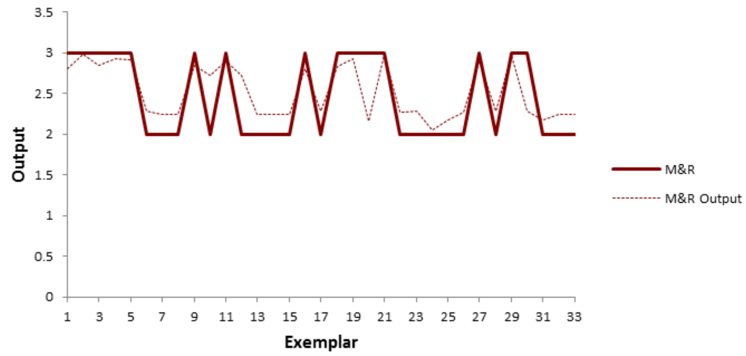


**Figure 3.** Desired output and actual network output- model 3

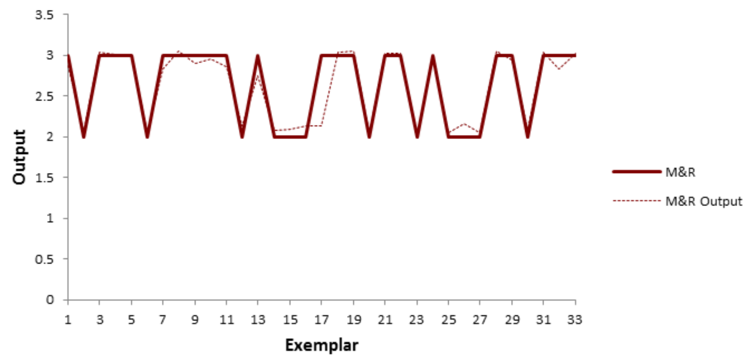


**Figure 4.** Desired output and actual network output- model 4

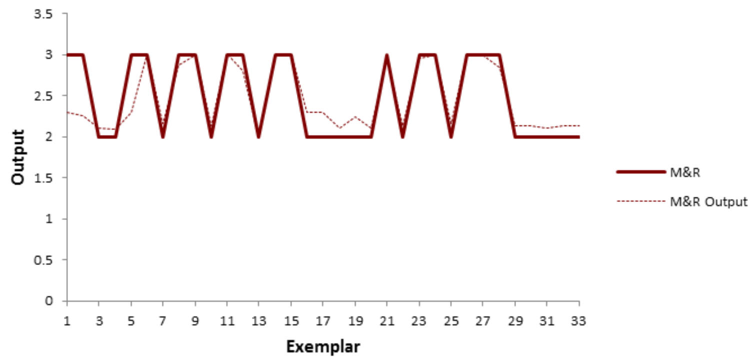


**Figure 5.** Desired output and actual network output- model 5

**Table 10.** Weight of the independent variables in the simulation of artificial neural network output

| Sensitivity | M&R | | | | |
|---|---|---|---|---|---|
| Model | I | II | III | IV | V |
| A | 0.720437875 | 0.99036498 | 0.44117576 | 0.177628887 | 0.820138676 |
| B | 0.667745509 | 0.185725386 | 0.308119208 | 0.070534038 | 0.288612114 |
| C | 0.060805496 | 0.083213356 | 0.076759958 | 0.006973338 | 0.226919117 |
| D | 0.092539982 | 0.104808763 | 0.046015619 | 0.021559197 | 0.142454101 |
| E | 0.026472739 | 0.007094108 | 0.013890816 | 0.020775768 | 0.0672445 |
| F | 0.197512783 | 0.239047929 | 0.006323871 | 0.008515607 | 0.30267776 |
| G | 0.109050844 | - | - | - | 0.25110421 |
| H | 0.48492973 | 0.3859093 | 0.345798133 | - | - |
| I | 0.101423254 | 0.028045547 | - | 0.144896424 | - |

## 6. Pavement Management by Regression Method

In the linear regression, correlation of mathematical equations used to choose the best form of the equations and parameters that requires a lot of experience and studies on the subject under study.

The usual correlation model using regression models are in the following form:

$$Y = a_0 + a_1x_1 + \cdots + a_nx_n \quad (7)$$

where $Y$ is the dependent variable, $x$ is the independent variable and $a_n$ are model parameters that are determined first of all [17].

The data collected in this study were analyzed using the linear regression. It has been concluded that the failure type parameter has the first and most important parameter, correlated with the dependent and after that density parameters, RN index and PCI index, are the important parameters in the information system.

The additional parameters in the equations will cause small changes in the $R^2$ which is negligible. This means that using these four independent parameters M&R can be predicted with high correlation. The results of the regression analysis method (SPSS.16) are as outlined in Table 11.

**Table 11.** The results of the regression method

| Model | Coefficient of determination $R^2$ | Statistical significance sig. | Equations |
|---|---|---|---|
| I | 0.721 | 0.000 | $Y$=0.898+0.415$x_1$-0.248$x_2$+0.06$x_3$+0.07$x_4$+0.031$x_5$+0.083$x_6$-0.007$x_7$+0.452$x_8$-0.059$x_9$ |
| II | 0.721 | 0.000 | $Y$=0.892+0.416$x_1$-0.283$x_2$+0.059$x_3$+0.07$x_4$+0.031$x_5$+0.083$x_6$+0.445$x_8$-0.059$x_9$ |
| III | 0.711 | 0.000 | $Y$=0.617+0.48$x_1$-0.231$x_2$+0.071$x_3$+0.067$x_4$-0.003$x_5$+0.078$x_6$+0.442$x_8$ |
| IV | 0.590 | 0.000 | $Y$=1.216+0.555$x_1$-0.35$x_2$+0.073$x_3$+0.099$x_4$+0.034$x_5$+0.054$x_6$-0.054$x_9$ |
| V | 0.639 | 0.000 | $Y$=0.668+0.578$x_1$-0.267$x_2$+0.063$x_3$+0.089$x_4$-0.007$x_5$+0.073$x_6$+0.162$x_7$ |

## 7. Pavement Management by AASHTO 93 method

There are different ways to determine the amount of required pavement overlay that in this study the specified method in pavement design guide AASHTO 93 is used, according to deflection data of HWD device. HWD device is paid the world's most attention in recent years due to the specific advantages of the device. Using of this device is not very old in our country and is limited to the present decade.

In order to design the asphalt pavements, resilient modulus should be used that is calculated from Eq. (8) [11]

$$M_R = C\left(\frac{0.24P}{dr.r}\right) \quad (8)$$

*$M_R$*: ground resilient modulus (psi)
*C*: is equal to *0.33*

In the AASHTO 93, the effective structural number is obtained by the following relation [11]

$$SN_{eff} = 0.0045D^3\sqrt[3]{Ep} \quad (9)$$

*D*: total thickness of asphalt and base layer (inches)
*Ep*: elasticity modulus of total pavement layers up to the ground (psi)

With a coefficient of soil resilient pavement design and the total number of 8.2-ton axle transmission, in the design period, the new pavement structure required total number is obtained from Eq. (10) [11]

$$Log\,W_{8.2} = Z_RS_0 + 9.36Log(SN+1) - 0.2 + \frac{\log\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.4+\frac{1094}{(SN+1)^{5.19}}} + 2.32LogM_R - 8.07 \quad (10)$$

*SN* : new pavement required structural number
*$W_{8.2}$* : total of 8.2 tons simple axle

*$Z_R$* : normalized standard deviation
*$S_0$* : standard deviation of predicted traffic and pavement performance
*ΔPSI*: drop indication serving
*$M_R$* : resilient factor design of ground (psi)

The overlay design is done in order to increase the power of pavement resistance.

To determine the overlay thickness, Eqs. (11) and (12) are used [18]

$$SN_{OL} = SN_f - SN_{eff} \tag{11}$$

$$D_{OL} = \frac{SN_{OL}}{a_{OL}} * 2.5 \tag{12}$$

$SN_{OL}$ : structural number of overlay

$SN_f$ : required structural number for the new pavement

$SN_{eff}$ : effective structural number for existing pavement

$D_{OL}$ : pavement overlay thickness (cm)

$a_{OL}$ : layer factor of asphalt overlay

Table 12 lists the existing effective structural number and used parameters corresponding to the Ahvaz-Shush highway. The results of analysis by AASHTO 93, are summarized in Table 13.

**Table 12.** Existing effective structural number and used parameters to calculate in Ahvaz-Shush

| Section | Station (km) | P (kpa) | a (cm) | r (cm) | $M_R$ (kg/cm$^2$) | $E_p$ (kg/cm$^2$) | $SN_{eff}$ (in) |
|---|---|---|---|---|---|---|---|
| 3 | 1 | 591 | 15 | 120 | 2071 | 63838 | 8.4 |
| 4 | 1.5 | 591 | 15 | 90 | 3688 | 78001 | 8.1 |
| 11 | 4.655 | 578 | 15 | 90 | 3053 | 41085 | 6.7 |
| 18 | 8.5 | 576 | 15 | 90 | 2923 | 30375 | 6.2 |
| 19 | 8.6 | 575 | 15 | 90 | 2015 | 30000 | 6.3 |
| 20 | 9.5 | 578 | 15 | 90 | 2575 | 39329 | 6.4 |
| 33 | 17.5 | 575 | 27 | 90 | 1587 | 11882 | 4.8 |
| 34 | 18 | 578 | 28 | 90 | 1117 | 12435 | 5 |
| 38 | 20 | 574 | 32 | 120 | 2842 | 49236 | 8.4 |
| 42 | 22 | 575 | 36 | 90 | 1445 | 10428 | 5.4 |
| 49 | 26 | 580 | 43 | 120 | 2469 | 27548 | 7.6 |
| 82 | 44 | 569 | 76 | 90 | 1583 | 23567 | 5.3 |
| 115 | 62 | 583 | 109 | 60 | 2012 | 24738 | 4.4 |
| 173 | 94 | 565 | 167 | 120 | 1940 | 62104 | 7.7 |

**Table 13.** Results of AASHTO 93 method

| From (km) | To (km) | Overlaying thickness (cm) | | M&R |
|---|---|---|---|---|
| | | HWD | AASHTO 93 | |
| 0 | 48.5 | 1.6 | 2 | Sealantandspots surfacedamage |
| 48.5 | 55.1 | 16.7 | 17 | Sealantandspots surfacedamageand overlaying performance |
| 55.1 | 100.1 | 4.1 | 5 | Sealantandspots surfacedamage and performance overlaying the next period evaluation |

## 8. Comparing the Results

In order to evaluate the decision-making algorithms better, accuracy and approximation quality criteria is used to evaluate the results of the different methods. In this study, intended 5 different models that in all of them six fixed input items are considered, like: width path, longitudinal slope and transverse slope, type of failure, failure severity and density.

Then, in each of these models which are shown with I, II, III, IV and V, other inputs in addition to the 6 items have been analyzed. In model I, inputs IRI, RN and PCI are also investigated. In Model II, RN and PCI, in model III, RN, in model IV, PCI and in model V, IRI were studied.

The five models were analyzed in several different ways such as the Rough-Set theory, Artificial Neural Networks (Neuro Solution 5), regression method (Spss), and AASHTO 93 and the results of different methods are compared. The summary of the study is provided in the Table 14.

**Table 14.** At a glance comparing the results of the 5 model uses the Rough-Set theory, Artificial Neural Network (Neuro Solution 5), regression method (Spss), and AASHTO 93

| Model | Additional input items | Rough-Set theory | | | | Artificial Neural Network | | regression method | | AASHTO 93 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Quality of classification | Accuracy ofresults | | | Network Testing | | Coefficient of determination | Statistical significance sig. | Accuracy ofresults |
| | | | a | b | c | MSE Error | Coefficient of determination | | | |
| I | IRI, RN, PCI | 1 | 1 | 1 | 1 | 0.01551 | 0.96993 | 0.721 | 0.000 | acceptable |
| II | RN, PCI | 1 | 1 | 1 | 1 | 0.03745 | 0.93309 | 0.721 | 0.000 | acceptable |
| III | RN | 0.8980 | 0.77 | 0.25 | 0.87 | 0.10254 | 0.78985 | 0.711 | 0.000 | non acceptable |
| IV | PCI | 0.9286 | 0.63 | 1 | 0.91 | 0.03147 | 0.93074 | 0.590 | 0.000 | non acceptable |
| V | IRI | 0.9388 | 0.7 | 1 | 0.92 | 0.06264 | 0.86926 | 0.639 | 0.000 | non acceptable |

## 10. Conclusions

Considering the results of Rough-Set theory for 5 models I, II, III, IV and V and comparing them to the results of the AASHTO 93, the Artificial Neural Networks, and the Regression method shows that models I and II are most appropriate to be taken as final models.

Analyzing and comparing the results confirms that replacing the values of four effective items as type of failure, density, RN index and PCI index on the rules obtained from Rough Set model, and using models I and II (obtained by Rough Set theory) instead of time-consuming and costly testing would be proper options of restoration and maintenance.

According to the results, the Rough Set method can certainly help engineers to remove the redundant data, to decrease the attributes and to express the most appropriate strategy for decision making when dealing with a huge amount of data.

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