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# Flexible Pavement Distress Evaluation and Analysis

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***Abstract*- Flexible pavement needs to be inventoried periodically, and evaluated for surface performance, distresses intensity and frequency. Flexible pavement distress data need to be updated to implement the required maintenance program. The pavement surface can't therefore be kept perfectly and comfortably in service. The evaluation and analysis of flexible pavement surface conditions can be reflected and expressed in term of pavement serviceability rating (PSR) which denotes a scale of a lower limit of 10 to an upper of 100. Also, the cost of maintenance and rehabilitation program can be predicted based on PSR. 18 sections were selected and surveyed for the distress types, intensity and extension. Also, the PSR was evaluated through the client PSR by the engineers and technicians in the Ministry of Public Works and Housing and user PSR through drivers, costumers on the road. The cost of maintenance was estimated by the client staff and modeled with client and user PSRs. Validation of models showed the usage of results to predict PSR value depending on distresses appearance, so cost can be calculated for maintenance.**

***Index Terms*— Flexible pavement analysis, distress.**

## I. INTRODUCTION

Pavement distress is a feasible imperfection in shape, performance, and felt-bad serviceability of pavement surface in time-scale of the life cycle of the pavement. Pavement structure is an inventory that needs tracing. Evaluation of surface conditions helps keep an eye, focus on pavement conditions and level of maintenance. It is introduced as pavement maintenance management systems (PMMS) and conducted a periodic survey to follow the distress conditions of pavement surface. Distress survey, includes detailed identification of distress types, severity, extent, and location. To combine these details, an index is assigned to each pavement in a general rating. Every highway agency either develops its evaluation procedure or selects a developed one for pavement survey. It is neither based on highway system size nor on complications of PMMS, PMMS show support at two levels: network level is related to management with board-based data of the entire system, information for planning purposes and financial and fiscal planning. Project level provides information for engineering design, construction, and cost [1]. Highway pavement management systems (PMS) are used throughout the United States (U.S.) to identify the roads and pavement sections which require repair, maintenance or reconstruction. They are also used by the Federal Highway Administration [2] to allocate federal money to state transportation agencies for the maintenance of roadways.

Pavement management seeks to improve the efficiency of decision making regarding pavement designs, maintenance, and repair [3]. The Highway Performance Monitoring System (HPMS) Field Manual (FHWA) outlines data requirements as well as format and specifications. Required data related to pavement management includes: International Roughness Index (IRI), Present Serviceability Rating (PSR), surface type, depth of rutting, average vertical displacement due to faulting, percentage of fatigue cracking area, and length of transverse cracking [4]. In addition to the HPMS, most states have their own national pavement management systems and models. Examples of the overall indices being used by state transportation agencies include [5]: Pavement Condition Index (PCI), Present Serviceability Index (PSI), Pavement Distress Index (PDI), Pavement Quality Index (PQI), and Remaining Service Life (RSL).

According to Colorado DOT Pavement Design Manual [6], The Federation of Canadian Municipalities and Canadian National Research Council [7], the performance of any pavement is highly dependent on the pavement construction techniques followed, and the quality of construction achieved. Proper construction techniques include the following: prepare the substrate properly, thoroughly cleaning old or milled surfaces, removing any old patches or thin asphalt concrete areas that may de-bond, uniformly tacking prepared surfaces at the appropriate application rate, producing, placing, and compacting hot-mix asphalt at appropriate temperatures (i.e., avoid overheating), avoiding segregation with proper aggregate stockpiling, and hot-mix asphalt production, transportation, and placement techniques, placing a uniform and smooth mat, constructing transverse and longitudinal joints properly for durability and prevention of the ingress of water, achieving the compaction (density) requirements, and following an appropriate quality control plan to achieve the proper construction techniques and overall quality.

The following Rehabilitation Method can be selected: Mill and Overlay with Asphalt Concrete, Rut Filling Using Spray Patching, Thin Overlays, or Micro-Surfacing, Rut Filling Using Spray Patching, Thin Overlays, or Micro-Surfacing, White-topping (Conventional and Concrete Inlay), Ultra-Thin White-topping, Thin Composite White-topping (TCW), Roller Compacted Concrete (RCC), Interlocking Concrete Pavements, Hot in Place Recycling (HIR), and Cold in Place Recycling (CIR).

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Distress probability appears to increase gradually based on the increase of pavement age, pavement conditions, age, traffic level (type and size of traffic load), and severity. A new constructed pavement has a slower rate and propagation of distress than an old or aged pavement. The periodic testing of flexible pavement is necessary at intervals (seasonally or yearly) to evaluate the rating or index of the pavement. According to Colorado DOT Pavement Design Guide [6], during warm summer months the sun radiation and the exhaust of the slow/standing vehicles raise the pavement temperature. At higher temperatures a reduction in the HMA stiffness, may induce instability rutting in intersections and tend to soften the asphalt [7]. For existing pavements, the structural capacity of the in-place materials must be checked [8] and [9]. A new design has to be carried out. Replacing the asphalt with the same mix design or paving on top of existing failed pavements will most likely result in recurring failures.

The current study aims to describe distress types that commonly appear on the surface of pavement and affect the performance and comfortability of the pavement surface. Also, it seeks to develop a model about the client and the user PSR using the collected data about distresses, it further relates the cost of maintenance for distresses with the PSRs in order to estimate the cost required.

## II. Types Of Pavement Distresses

According to [10], [11], and [12], types of distresses include:

Rutting which is defined as the longitudinal permanent deformation or plastic movement of the asphalt pavement under the action of repeated loadings over the wheel path. Rutting is usually caused by the densification and shearing of different pavement layers. It is visually identified by the depression in the pavement surface along the wheel paths. Even though visible on pavement surface, rutting may occur on any of the layers. Three main mechanisms lead to the following three types of rutting:

Structural Rutting: The deformation of one or more layers underlying the HMA layer results in structural rutting. Base and/or subgrade materials are unable to sustain load stresses resulting in depressions, lack of support to the superior layers. Figure 1 represents the structural rutting.

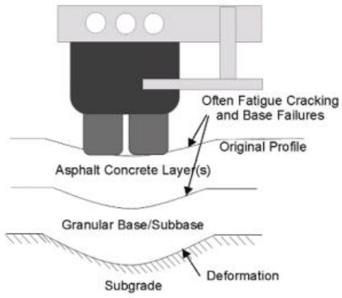


**Figure 1 Structural rutting [7]**

Instability Rutting or plastic flow is the type of rutting that results from an inadequate HMA mix design rather than a structural design. It is reported that the shear deformation rather than densification is the primary rutting mechanism in HMA surface mixtures when the supporting layers are reasonably stiff. This kind of rutting is visually recognized by the humps formed on the sides of the rut.

This type of distress is more visible in slow trafficked areas such as intersections which represent a variance in the loading conditions applied to the pavement. Braking, accelerating, turning, standing, and slow moving stresses at intersections induce instability rutting. It may also be contributed to factors such as: high pavement temperatures, improper materials, rounded aggregates, too much binder and/or filler, insufficient or too high air voids.

Surface/Wear Rutting is the consolidation in wheel paths of the HMA layer due to insufficient compaction efforts which are usually reflected on the achievement the target density. Consequently additional compaction to the asphalt layer is generated by vehicle loading without any base/ sub-base yielding or the formation of HMA hump. According to the Colorado Department of Transportation [5], the following list of factors contributes to this type of rutting: insufficient compacting effort within the lower base layers, not enough roller passes while paving, HMA cooling before target density, asphalt moisture or dust, low asphalt content in the mix, lack of cohesion in the mix (tender mix, gradation problem).

Shoving of an asphalt concrete pavement is defined as the longitudinal surface displacement of the HMA. Shoving is usually caused by an unstable asphalt layer that is not strong enough to resist horizontal stresses.

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Acceleration and deceleration of vehicles represent a continuous load in the same direction that generally causes shoving as shown in Figure 2. Excess binder in the mix, mistakes on the gradation and erroneous temperatures during compaction are parameters that cause a weak asphalt mixture.

**Figure 2 Shoving of asphalt pavement [10]**

Fatigue Cracking in asphalt pavement manifests itself in the form of cracking from repeated traffic loading [13]. The three main factors that affect the initiation and propagation of fatigue cracking are the mix design, pavement structure, and construction procedures. The main visual characteristic of fatigue cracking is the interconnection of cracks in a chicken wire/alligator pattern as seen on Figure 3.

**Figure 3 Fatigue cracking on asphalt pavements [10]**

Cracking and other defects are sometimes caused by inadequate base materials in flexible pavement systems. In these cases, resurfacing of the road with another hot mix layer will not solve the problem. Full Depth Reclamation (FDR) can be implemented on these roads to strengthen the base materials [14]. The new base formed from a combination of the existing pavement and part or all of base materials along with a stabilizing agent is often times stronger than the original materials. For this reason, roads that have undergone the FDR process are often considered to be structurally sounder than the original flexible pavement.

Raveling and Weathering: Wearing away of the pavement surface is caused by the dislodging of aggregate particles and loss of asphalt binder. Raveling ranges from the loss of fines to the loss of some coarse aggregate and ultimately to a very rough and pitted surface with obvious loss of aggregate. Raveling is caused by oxidation or aging of a paved surface and bad workmanship or materials.

Raveling is aggravated by hot and wet weather which causes oxidation and stripping of the asphalt binder.

*Bleeding:* Excess bituminous binder is found on the pavement surface, usually in the wheel paths. Bleeding may range from a local discoloration relative to the remainder of the pavement, to loss of surface texture because of excess asphalt, a condition where the aggregate may be obscured by excessive asphalt with a shiny, glass-like, reflective surface that may be tacky to the touch. Bleeding is usually caused by too much asphalt binder in the pavement mix, excessive prime coat or tack coat, and low air void content in the pavement mix. Bleeding is aggravated by hot weather, which causes the softening and expansion of the asphalt binder.

*Longitudinal Cracking:* Cracks are predominantly parallel to the pavement centerline (or traffic direction). The location of longitudinal cracks within the lane (wheel path versus non-wheel path) is important. The cracks occurring on the centerline or outside of the wheel path, usually results from a poorly constructed paving joint. Longitudinal cracks occurring in the wheel path, however, result from excessive deflection, and loss of foundation support probably due to water, insufficient pavement structure or weak support materials. Longitudinal cracks within the wheel path are much more serious; and are indicative of early-stage fatigue cracking.

*Transverse Cracking:* Cracks are predominantly perpendicular to the pavement centerline. These are caused by pavement expansion and contraction due to temperature changes or shrinkage of asphalt binder with age.

*Edge Cracking:* it applies only to pavements with unpaved shoulders. Crescent-shaped cracks or fairly continuous cracks intersect with the pavement edge; and are located within 2 feet of the pavement edge, adjacent to the shoulder. Longitudinal cracks outside of the wheel path and within 2 feet (0.61 m) of the pavement edge are included. Edge cracking is caused by the loss of foundation support due to water, insufficient pavement structure, weak support materials or unstable shoulders.

*Patch Condition:* It is a portion of pavement surface that is greater than 4.0 $in^2$ (25.8 $cm^2$ been removed and replaced or additional material applied to the pavement after the original construction. The patches may have been placed for any number of reasons, such as utility work, potholes, or adjacent construction. They are evaluated only to determine the condition or intactness of the patch.

## III. Data And Technical Work

It refers to client and operating agencies such as the municipality and public work authorities which should conduct a comprehensive evaluation program for the pavement conditions prior to any maintenance program. The evaluation includes the determination of the type of distress, severity and extension of the pavement distress.

Data collected may be converted to the pavement condition index or urban distress index (UDI). Which is a combination of local index of fifteen pavement distresses developed for the Pavement Maintenance Management System (PMMS). The index ranges from zero to 100, where 100 represents excellent pavement condition. The UDI is calculated based on pavement distress types, severity and density for a specific section [15]. Four pavement condition ratings are adopted for the UDI system: Poor, Fair, Good and Excellent [4]. The index has to be updated periodically to reflect and represent the existing pavement condition. Pavement performance models were developed to update UDI at the network level [16]. The PMMS should distinguish between the maintained streets and roads and the non-maintained to give an accurate evaluation of the pavement conditions existing.

Cost analysis is necessary for pavement construction and maintenance. Cost analysis is a technique for the evaluation of multiple alternatives and identification of the lowest cost alternative using financial principles. Three basic types of cost analysis evaluation were described by [17]: cost allocation, cost-effectiveness analysis, and cost-benefit analysis. Cost allocation is the simplest of the three methods since it consists of setting up budgeting and accounting systems in a way that will let program managers determine a unit cost. To relate the total cost of projects, it is necessary to define the Life-Cycle Cost Analysis (LCCA) is defined by the Federal Highway Administration (FHWA) as an analytical tool that provides a cost comparison between two or more competing design alternatives and equivalent benefits for the project being analyzed. The typical LCCA of pavement system includes costs for initial design and construction, operation and maintenance, rehabilitation and salvage.

## IV. Distress Data Analysis

Data were collected in terms of distresses of pavement such as Longitudinal, Transverse, Block, Alligator, and Joint Reflection cracks, Lane Shoulder Drop off, Bleeding, Pumping, Rutting, Potholes, and Patches. 18 sections of pavement surface were selected to study the distress and to collect the required data on distresses. Also, the collected data included pavement serviceability rating ( PSR) that has the value for rating from 0 to 100 as an index on the condition of serviceability of pavement surface. And here, he PSR scale was collected as client scale (Ministry of Public Works rating), and average users' scale or rating for drivers and users.

Also, the cost of rehabilitation was obtained from the Ministry of Public Works according to their program depending on the existing qualifications and budget and resources. A field survey was conducted by choosing 18 sections, each is 300 m long, and distresses were focused, noticed and counted, measured in dimensions and depth, then distresses were calculated and sum each. The PSR was assumed using client perception and preview, and using users' perception and preview. The data collected assumed to connect between distress quantity or case with PSR and cost. Then data were modeled (PSR as dependent variable on the distress conditions of pavement surface) using SPSS package. Results of the model were tested against the prediction of PSR of pavement surface and cost of rehabilitation and maintenance for extra 3 sections. Table 1 presents the data collected for distress of pavement surface.

**Table 1**
**Distresses' Data Collection**

| Cost | User_PSR | Client_PSI | Patch | Pthole | Rutting | Alligator_C |
|---|---|---|---|---|---|---|
| 3250 | 30 | 50 | 2 | 1.2 | 40 | 131 |
| 1940 | 30 | 50 | 0.4 | 0.8 | 44 | 44 |
| 1100 | 70 | 65 | 0.2 | 0.2 | 2 | 3 |
| 1950 | 70 | 60 | 2 | 0.15 | 87 | 8 |
| 1450 | 70 | 65 | 3 | 1.1 | 4 | 14 |
| 1500 | 70 | 75 | 0.4 | 0.18 | 3 | 12 |
| 1010 | 70 | 70 | 0.3 | 0.75 | 2 | 6 |
| 2750 | 65 | 60 | 2 | 6 | 1 | 0.15 |
| 1000 | 50 | 65 | 1.5 | 2 | 60 | 6 |
| 1200 | 50 | 60 | 2 | 5 | 52 | 10 |
| 2250 | 30 | 40 | 1.32 | 1 | 42 | 8 |
| 1450 | 30 | 40 | 1 | 0.25 | 68 | 68 |
| 1550 | 30 | 40 | 2.5 | 1.1 | 30 | 45 |
| 2150 | 20 | 30 | 5 | 1.25 | 59.4 | 117 |
| 8800 | 20 | 30 | 10 | 5.25 | 186 | 770 |

**Table 1**
**Distresses' Data Collection … Continued**

| Cost | Pumping | Bleeding | Shoulder_I | Joint_Refle | Block_Cra | Transverse | Longitudinal_C |
|---|---|---|---|---|---|---|---|
| 3250 | 0.12 | 0.25 | 90 | 8 | 51.2 | 67 | 185 |
| 1940 | 0.1 | 0.15 | 80 | 8 | 38 | 56 | 95 |
| 1100 | 0.08 | 0.1 | 60 | 7 | 21 | 48 | 120 |
| 1950 | 0.1 | 0.18 | 5 | 2 | 38 | 107 | 180 |
| 1450 | 0.08 | 0.1 | 35 | 2 | 33 | 88 | 230 |
| 1500 | 0.06 | 0.14 | 8 | 2 | 32.5 | 77 | 366 |
| 1010 | 0.08 | 0.18 | 2 | 7 | 38 | 36 | 230 |
| 2750 | 0.15 | 0.3 | 1 | 1 | 80 | 90 | 30 |
| 1000 | 0.3 | 0.25 | 20 | 1 | 20 | 30 | 50 |
| 1200 | 0.25 | 0.3 | 35 | 8 | 25 | 42 | 54 |
| 2250 | 0.05 | 0.5 | 23 | 7 | 27 | 40 | 185 |
| 1450 | 7.4 | 0.5 | 55 | 7 | 1 | 21 | 65 |
| 1550 | 0.8 | 0.5 | 40 | 7 | 4 | 50 | 100 |
| 2150 | 2 | 2.1 | 3 | 12 | 38 | 30 | 120 |
| 8800 | 3.8 | 0.5 | 50 | 12 | 41 | 60 | 170 |

Figure 4 presents the modeling of data collected for pavement surface distress to predict the PSR of client as dependent variable.

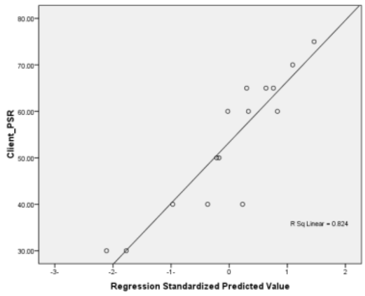


**Figure 4 Client PSR vs. pavement distress conditions**

Also, Table 2 presents the model of Client PSR constants for the pavement conditions modeled.

**Table 2**
**The Model Equation Constants for Client PSR vs. Pavement Distress Condition**

| Model | Un-standard Coeff. | | Standard Coeff. | t | Sig. | 95% Confidence Interval for B | |
|---|---|---|---|---|---|---|---|
| | B | Std. Error | Beta | | | Lower Bound | Upper Bound |
| (Constant) | 71.516 | 26.487 | | 2.700 | .074 | -12.78- | 155.810 |
| Long. Crack | .034 | .080 | .207 | .422 | .702 | -.220- | .288 |
| Transv. Crack | -.105- | .335 | -.182- | -.31- | .775 | -1.169- | .960 |
| Block Crack | .059 | .428 | .077 | .138 | .899 | -1.303- | 1.421 |
| J. Ref. Crack | -1.069- | 2.321 | -.270- | -.46- | .676 | -8.454- | 6.317 |
| Shoulder | -.091- | .222 | -.180- | -.41- | .709 | -.796- | .614 |
| Bleeding | -13.09- | 23.455 | -.446- | -.56- | .616 | -87.73- | 61.556 |
| Pumping | -1.054- | 2.840 | -.149- | -.37- | .735 | -10.09- | 7.983 |
| Allig. Crack | -.001- | .112 | -.020- | -.01- | .990 | -.358- | .355 |
| Rutting | -.051- | .177 | -.167- | -.29- | .794 | -.614- | .513 |
| Pothole | .545 | 4.367 | .074 | .125 | .908 | -13.35- | 14.442 |
| Patch | -.771- | 8.141 | -.132- | -.1- | .931 | -26.68- | 25.137 |

Also, the predicted PSR of User is presented in Figure 5 and Table 3 as dependent variable vs. the pavement distress conditions.

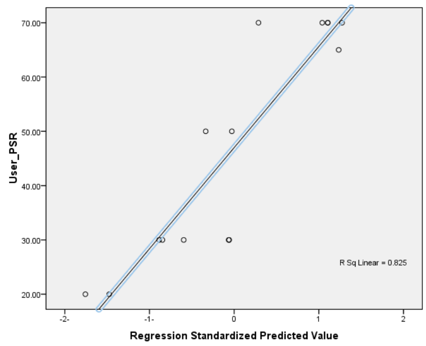


**Figure5 Predicted user PSR for pavement distress conditions**

**Table 3**
**Predicted Constants for PSR of User for Pavement Distress Conditions**

| Model | Unstandardized Coefficient | | Standardized Coefficients | t | Sig. | 95% Confidence Interval for B | |
|---|---|---|---|---|---|---|---|
| | B | Std. Error | Beta | | | Lower Bound | Upper Bound |
| (Constant) | 71.741 | 37.406 | | 1.918 | .151 | -47.302- | 190.785 |
| Longitudinal _Crack | -.032- | .113 | -.140- | -.286- | .793 | -.391- | .326 |
| Transverse _Crack | .145 | .472 | .178 | .307 | .779 | -1.358- | 1.649 |
| Block_Crack | .092 | .604 | .084 | .152 | .889 | -1.832- | 2.015 |
| J. Ref_Crack | .905 | 3.277 | .161 | .276 | .800 | -9.525- | 11.335 |
| Shoulder | -.451- | .313 | -.632- | -1.4- | .245 | -1.446- | .545 |
| Bleeding | -33.35- | 33.124 | -.801- | -1 - | .388 | -138.764- | 72.067 |
| Pumping | .714 | 4.010 | .071 | .178 | .870 | -12.049- | 13.477 |
| Allig. _Crack | -.014- | .158 | -.128- | -.09- | .937 | -.517- | .490 |
| Rutting | -.203- | .250 | -.472- | -.8- | .477 | -.998- | .593 |
| Pothole | -2.917- | 6.167 | -.281- | -.47- | .668 | -22.543- | 16.708 |
| Patch | 2.984 | 11.497 | .361 | .260 | .812 | -33.604- | 39.573 |

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Then, the cost model is predicted using client PSR in Table 4 and Figure 6. Also, the cost can be predicted using the user PSR as presented in Table 5 and Figure 7.

**Table 4**
**Cost of Rehabilitation and Maintenance Predicted on Client PSR**

| Model | Un-standard Coefficients | | Standard Coefficient | T | Sig. | 95% Confidence Interval for B | |
|---|---|---|---|---|---|---|---|
| | B | Std. Error | Beta | | | Lower Bound | Upper Bound |
| Constant | 6090.909 | 1712.107 | | 3.56 | .004 | 2392.1 | 9789.692 |
| Client _PSR | -72.517- | 31.052 | -.544- | -2.3- | .036 | -139.6- | -5.433- |

**Table 5**
**Predicted Model for Cost on User PSR for Rehabilitation of Pavement**

| Model | Unstandard Coeff. | | Std Coef | T | Sig. | 95% for B | |
|---|---|---|---|---|---|---|---|
| | B | Std. Error | Beta | | | Lower | Upper |
| Constant | 4264.522 | 1181.530 | | 3.609 | .003 | 1712 | 6817.1 |
| User PSR | -43.430- | 23.164 | -.461- | -1.88- | .083 | -93.473- | 6.6 |

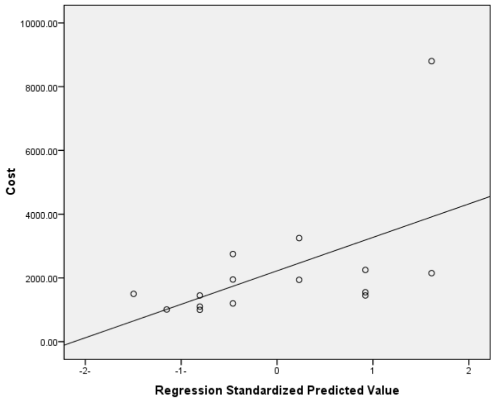


**Figure 6 Predicted cost of maintenance on client PSR**

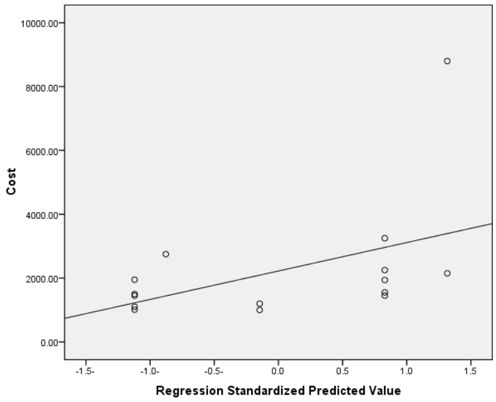


**Figure 7 Predicted cost for maintenance on user psr for pavement**

## V. MODEL VALIDATION

The prediction strength of model was tested for guessing client and user PSRs to prdicted the cost. Results are presented in Table 6 and 7 respectively.

**Table 6**
**Prediction Validity of Client PSR Model**

| Section # | Client PSR | Predicted Client PSR | Difference | Difference Per Centage |
|---|---|---|---|---|
| 16 | 30 | 46.86 | -16.86 | -56.2% |
| 17 | 65 | 49.91 | 15.09 | 23.22% |
| 18 | 60 | 46.57 | 13.43 | 22.38% |

**Table 7**
**Prediction Validity of User PSR Model**

| User PSR | Predicted | Difference | Difference Per Cent |
|---|---|---|---|
| 20 | 41.5192 | -21.5192 | -107.6% |
| 70 | 74.4174 | -4.4174 | -6.3% |
| 70 | 43.5795 | 26.4205 | 37.7% |

The cost of maintenance and rehabilitation required was predicted using the Client PSR and the validation of results is presented in Table 8.

**Table 8**
**Prediction Validity of Maintenance Cost of Section on Client PSR**

| Actual Cost (J.D.) | Predicted | Difference | Difference Per Cent |
|---|---|---|---|
| 1559 | 3915 | -2356.4 | -151.2% |
| 1284 | 1377 | -93.304 | -7.3% |
| 2156 | 1740 | 416.111 | 19.3% |

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Also, the cost of maintenance and rehabilitation required was predicted using the User PSR and the validation of results is presented in Table 9.

**Table 9**
**Prediction Validity of Maintenance Cost of Section on User PSR**

| Actual Cost (J.D.) | Predicted | Difference | Difference Per Cent |
|---|---|---|---|
| 1559 | 3395.922 | -1836.922 | -117.8% |
| 1284 | 1224.422 | 59.578 | 4.6% |
| 2156 | 1224.422 | 931.578 | 231.4% |

## VI. Discussion And Conclusions

The current research showed the common types of flexible pavement distresses. And focused on the relation between distresses types, intensity, and quantity in section with the evaluation of surface conditions or what is known as Pavement Serviceability Rating according to the evaluation of the client agency personnel or staff (engineers and technicians) and the evaluation of the users of road section. So, the rating of distress could be evaluated through the application of the distresses quantity in the model developed. The cost of maintenance of flexible pavement in the section also, is predicted through the relation with the PSR. The models were validated and could be used to express the cost for maintenance for each section or for the whole length of road.

Its concluded that the type of distress, intensity, and extension are related to the rating index such as PSR that could be conducted by a client agent of the road or users and costumers of the road. Also, the cost of maintenance could be successfully related to the level of evaluation of the PSR.

The results and conclusions of the current study will be helpful for people working on pavement distress evaluation and maintenance operations. Further future work is required in rating pavement surface conditions using technological instruments. Also, the maintenance and repairs programs should be activated and implemented periodically.

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