SELECTION OF TENTATIVE SN_{40} GUIDELINES

Different SN_{40} values are required for varying roadway and traffic conditions. Also, much work remains to be done regarding the determination of required SN_{40} values for specific roadway and traffic characteristics, including the determination of the proper relationship between FN and SN. For these two reasons, it appears that accident data will continue for some time to provide the primary basis for identifying high accident sites on wet pavement; survey skid data will be used once sites are selected.

Nevertheless, selecting minimum SN_{40} guidelines is desirable for the purpose of identifying potentially hazardous sites for inclusion in the routine site review process in Virginia's program to reduce wet-pavement accidents. For this purpose, an SN_{40} value of 30 is considered to be the minimum guideline value for Interstate and other divided highways in Virginia, and an SN_{40} value of 40 is considered to be the minimum guideline value for two-lane highways. Sites with values below these guideline values will not automatically be scheduled for treatment, but will be included for evaluation with sites selected by use of accident data. Site treatments should be allocated on a priority basis to achieve the maximum reduction of wet-pavement accidents.

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Rehabilitation Decision Model

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A study was made of Utah's flexible pavement performance system to introduce new procedures and to alter existing procedures. The terminal serviceability concept was revised to consider functional class as well as average daily traffic. Highways with high average daily traffic were assigned a high terminal serviceability index to reduce user costs. A computerized pavement-rating system was developed to aid maintenance personnel in making the most appropriate pavement rehabilitation decision. The system can also be used by planning and programming personnel to

estimate future expenditures in each district. A computer program generates priority listings based on the failure modes of serviceability, distress, structural adequacy, and skid resistance. An overall listing is produced that considers failure modes with respect to average daily traffic, 80-kN (18-kip) loads, running speeds, and functional class.

Maintenance of bituminous-surfaced pavements requires periodic rehabilitation. The need for maintenance, the type needed, and the optimum time for rehabilitation are key elements. Systems designed to accomplish these tasks are needed also to establish administrative policies and to aid in the programming of appropriate amounts of construction and maintenance funds.

A model was developed to help planning and maintenance personnel plan rehabilitation strategies. The model deals only with a limited number of variables and does not consider all of the variables related to pavement aging, economic constraints, and political decisions.

Experience shows that a detailed printout of pavement condition is needed only for projects under consideration for major rehabilitation, i.e., reconstruction, overlay, recycling, and surface seals. The use of field data, such as pavement-distress values, deflection readings, and roughness, is necessary to establish priorities; however, these data supplied in their entirety are overwhelming to anyone attempting to compare pavement conditions of a large number of highway sections. Therefore, detailed analysis is reserved for pavements chosen for rehabilitation. An example of a detailed data sheet is presented in Figure 1. These data are used to review the range and magnitudes of deflection readings, to estimate surface and base structural conditions, and to predict the remaining life of a given pavement. Visual inspection data on the surface condition and objective data related to transverse, longitudinal, and load-cracking conditions are listed. The pavement roughness incorporated into the present serviceability index (PSI) and actual skid-meter data that measure the slipperiness of the surface are made available. These data and the route description, pavement dimensions, and traffic measurements can be used by the maintenance engineer to determine the specific type of rehabilitation needed.

The preliminary analysis is aimed at the selection of those highways that will be upgraded and is based on the output of the computer program that contains a set of condition and priority listings to be used by maintenance and planning personnel.

In the Utah system, ranking the pavements to receive maintenance and determining the most effective method for rehabilitation are based on present pavement condition and deterioration history, properties of the materials and mixes in place, traffic requirements, functional class, highway geometry, and environmental conditions. Information on each of these areas must be gathered to isolate modes of deterioration, extent of progress, and rate at which deterioration is occurring. Once this information has been gathered, a priority listing can be made based on functional class and traffic demands to minimize user costs and future maintenance costs due to pavement deterioration. The number of highways rehabilitated and the extent of rehabilitation are dependent on the funds available and the urgency of the problem (1).

The significance of each of the areas mentioned varies for each highway and failure mechanism in determining the extent of further testing or analysis. For example, deterioration apparently related to materials may lead to tests such as asphalt stiffness or density calculations. Pavements that fail because of increased traffic load should be subjected to increased testing with the dynaflect to check the structural adequacy of each kilometer of the section.

The following sections discuss the major factors related to pavement condition and their use in the preliminary analysis.

PRESENT SERVICEABILITY INDEX

Utah uses the present serviceability index as an indicator of the rideability of a pavement. Data gathered from the Mays road meter is the main determinant of PSI; the meter, mounted in an automobile, is positioned to measure the vertical movement of the rear axle. The PSI rating of pavement is given below.

PSI Rating	Pavement Condition	PSI Rating	Pavement Condition
4 to 5	Very good	2 to 3	Fair
3 to 4	Good	1 to 2	Poor

The following formula for PSI was developed at the AASHO Road Test (2), and customary units are therefore used.

$$PSI = 4.18 - 0.007\,(RC)^{0.658} - 0.0. \quad C + P - 1.34\,RD^2 \qquad (1)$$

where

RC = sum of roadmeter roughness counts per mile,
C = square feet of cracked area per 1000 ft^2 of flexible pavement surface,
P = square feet of patched area per 1000 ft^2 of pavement surface, and
RD = average rut depth measured at deepest part of rut.

As the PSI of a pavement decreases, the cost of vehicle operation increases. Figure 2 shows the relationship between operating costs, running speed, and PSI (3). Pavement roughness also has an effect on highway safety. Figure 3 shows the relationship between the probability of accident occurrence, running speed, and PSI. At any speed, accidents are more apt to occur on rough pavement surfaces.

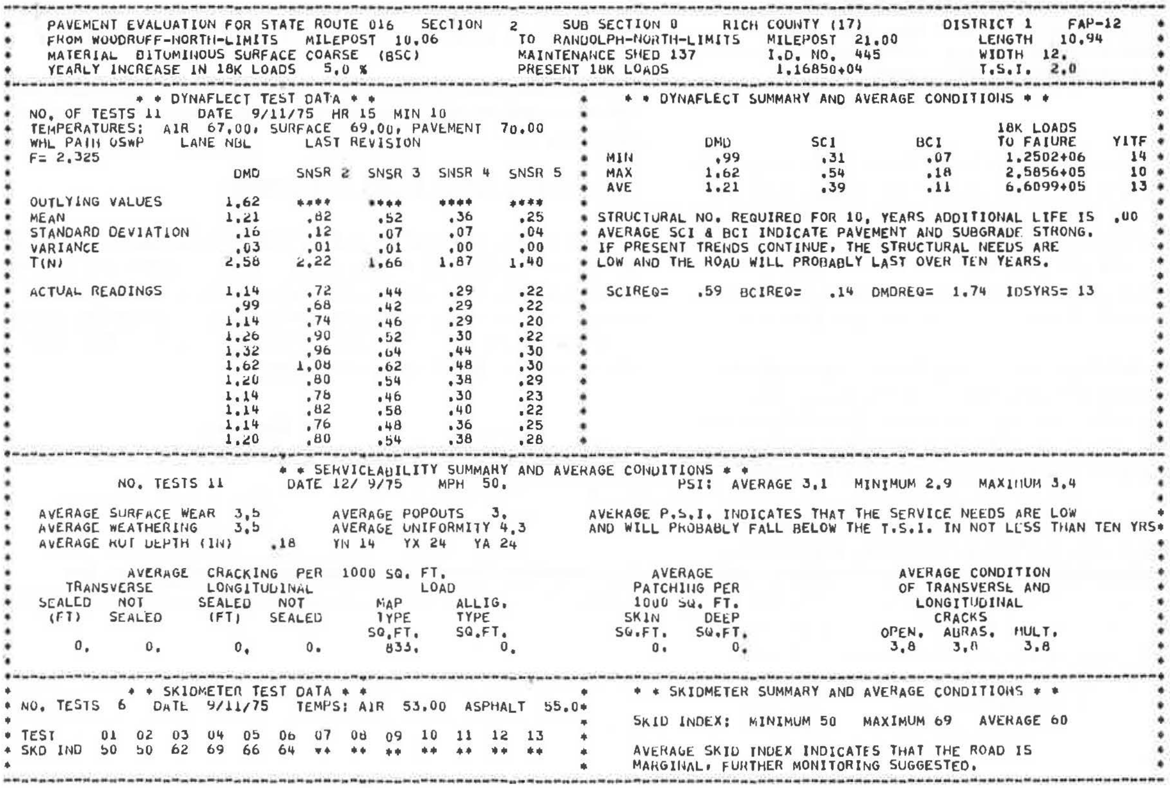
For planning and maintenance purposes, one must not only know the magnitude of the PSI at any particular time but also the relative change in PSI with time. If rideability declines rapidly, the pavement will most likely reach the terminal serviceability index (TSI) sooner (Figure 4A). The TSI is the value of serviceability of the pavement in need of rehabilitation before it deteriorates beyond repair by normal maintenance (4).

High-volume highways, such as Interstate highways, are assigned a TSI value of 2.5, and most low-volume highways are assigned a value of 2.0. The values are based on user costs, which include fuel consumption. Reports show that fuel consumption at a speed of 80.5 km/h (50 mph) increases by 50 percent when the vehicle is driven on badly broken patched asphalt compared to when the automobile is driven on smooth pavement (1).

Figure 5 shows the relation of TSI to average daily traffic (ADT). Functional class remains a controlling factor at low and medium traffic levels; minimum values are specified at 2.5 and 2.0 as before. At high traffic volumes, TSI is increased to ensure a higher level of service.

The pavements in each maintenance district are listed in order from the roughest to the smoothest on the basis of average PSI of that highway section (Table 1). This

Figure 1. Detailed data sheet.



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*---------------------------------------------------------------------------------------------------------------------------------------*
*    PAVEMENT EVALUATION FOR STATE ROUTE 016   SECTION   2     SUB SECTION 0     RICH COUNTY (17)          DISTRICT 1    FAP-12   *
*    FROM WOODRUFF-NORTH-LIMITS   MILEPOST  10.06          TO  RANDOLPH-NORTH-LIMITS   MILEPOST  21.00          LENGTH   10.94     *
*    MATERIAL  BITUMINOUS SURFACE COARSE  (BSC)            MAINTENANCE SHED 137         I.D. NO.  445            WIDTH  12.        *
*    YEARLY INCREASE IN 18K LOADS   5.0 %                  PRESENT 18K LOADS             1.16850+04              T.S.I.  2.0       *
*---------------------------------------------------------------------------------------------------------------------------------------*
*              * * DYNAFLECT TEST DATA * *                           *     * * DYNAFLECT SUMMARY AND AVERAGE CONDITIONS * *           *
*  NO. OF TESTS 11    DATE  9/11/75  HR 15  MIN 10                   *                                                                 *
*  TEMPERATURES:  AIR  67.00, SURFACE  69.00, PAVEMENT  70.00        *                                             18K LOADS           *
*  WHL PATH OSWP    LANE NBL       LAST REVISION                     *              DMD          SCI          BCI    TO FAIURE    YITF *
*  F= 2.325                                                          *  MIN          .99          .31          .07    1.2502+06      14 *
*                       DMD     SNSR 2  SNSR 3  SNSR 4  SNSR 5       *  MAX         1.62          .54          .18    2.5856+05      10 *
*                                                                    *  AVE         1.21          .39          .11    6.6099+05      13 *
*  OUTLYING VALUES      1.62    ****    ****    ****    ****         *                                                                 *
*  MEAN                 1.21     .82     .52     .36     .25         * STRUCTURAL NO. REQUIRED FOR 10. YEARS ADDITIONAL LIFE IS  .00   *
*  STANDARD DEVIATION    .16     .12     .07     .07     .04         * AVERAGE SCI & BCI INDICATE PAVEMENT AND SUBGRADE STRONG.        *
*  VARIANCE              .03     .01     .01     .00     .00         * IF PRESENT TRENDS CONTINUE, THE STRUCTURAL NEEDS ARE            *
*  T(N)                 2.58    2.22    1.66    1.87    1.40         * LOW AND THE ROAD WILL PROBABLY LAST OVER TEN YEARS.             *
*                                                                    *                                                                 *
*  ACTUAL READINGS      1.14     .72     .44     .29     .22         *  SCIREQ=   .59  BCIREQ=   .14  DMDREQ=  1.74  IDSYRS= 13         *
*                        .99     .68     .42     .29     .22         *                                                                 *
*                       1.14     .74     .46     .29     .20         *                                                                 *
*                       1.26     .90     .52     .30     .22         *                                                                 *
*                       1.32     .96     .64     .44     .30         *                                                                 *
*                       1.62    1.08     .62     .48     .30         *                                                                 *
*                       1.20     .80     .54     .38     .29         *                                                                 *
*                       1.14     .78     .46     .30     .23         *                                                                 *
*                       1.14     .82     .58     .40     .22         *                                                                 *
*                       1.14     .76     .48     .36     .25         *                                                                 *
*                       1.20     .80     .54     .38     .28         *                                                                 *
*---------------------------------------------------------------------------------------------------------------------------------------*
*                                      * * SERVICEABILITY SUMMARY AND AVERAGE CONDITIONS * *                                            *
*             NO. TESTS 11          DATE 12/ 9/75    MPH  50.                     PSI:  AVERAGE 3.1   MINIMUM 2.9   MAXIMUM 3.4         *
*                                                                                                                                       *
*   AVERAGE SURFACE WEAR  3.5          AVERAGE POPOUTS   3.           AVERAGE P.S.I. INDICATES THAT THE SERVICE NEEDS ARE LOW           *
*   AVERAGE WEATHERING    3.5          AVERAGE UNIFORMITY 4.3         AND WILL PROBABLY FALL BELOW THE T.S.I. IN NOT LESS THAN TEN YRS*
*   AVERAGE RUT DEPTH (IN)     .18     YN 14   YX 24   YA 24                                                                           *
*                                                                                                                                       *
*              AVERAGE  CRACKING  PER  1000 SQ. FT.                        AVERAGE                     AVERAGE CONDITION               *
*      TRANSVERSE        LONGITUDINAL            LOAD                    PATCHING PER                  OF TRANSVERSE AND               *
*   SEALED   NOT        SEALED    NOT           MAP       ALLIG.         1000 SQ. FT.                    LONGITUDINAL                  *
*    (FT)   SEALED       (FT)    SEALED         TYPE      TYPE          SKIN     DEEP                       CRACKS                     *
*                                               SQ.FT.    SQ.FT.       SQ.FT.   SQ.FT.                OPEN.  ABRAS.  MULT.             *
*      0.      0.          0.      0.           833.        0.           0.       0.                  3.8    3.8     3.8               *
*                                                                                                                                       *
*---------------------------------------------------------------------------------------------------------------------------------------*
*              * * SKIDOMETER TEST DATA * *                          *     * * SKIDOMETER SUMMARY AND AVERAGE CONDITIONS * *          *
* NO. TESTS  6   DATE  9/11/75   TEMPS: AIR  53.00  ASPHALT  55.0*                                                                     *
*                                                                    *     SKID INDEX:  MINIMUM 50   MAXIMUM 69   AVERAGE 60           *
* TEST     01  02  03  04  05  06  07  08  09  10  11  12  13        *                                                                 *
* SKD IND  50  50  62  69  66  64  **  **  **  **  **  **  **        *     AVERAGE SKID INDEX INDICATES THAT THE ROAD IS               *
*                                                                    *     MARGINAL, FURTHER MONITORING SUGGESTED.                     *
*---------------------------------------------------------------------------------------------------------------------------------------*
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Figure 2. Relationship between operating costs, running speed, and PSI.

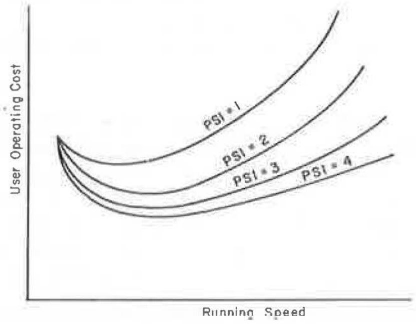


Figure 3. Relationship between accident occurrence, running speed, and PSI.

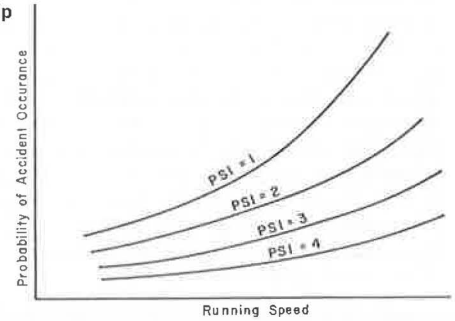


Figure 4. Pavement condition versus time.

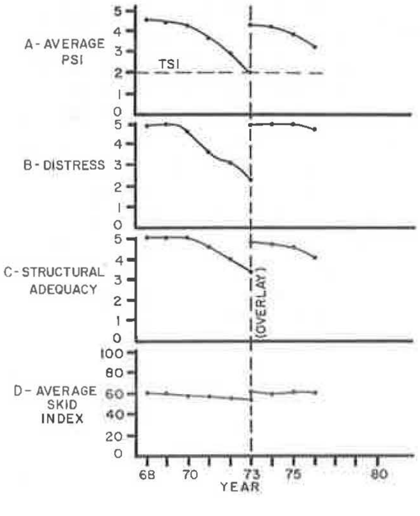
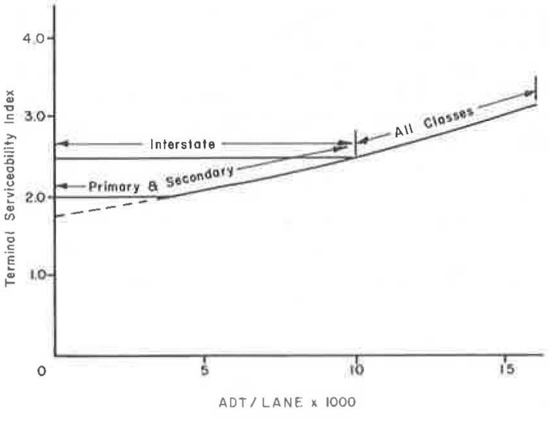


Figure 5. TSI versus ADT per lane.



condition listing gives a preliminary indication of which pavements most need attention but not the best method for rehabilitation and can be used to establish the existing needs with respect to rideability for each district. The total lane kilometers of pavement below a specific level of service can be obtained and related to the cost needed to maintain or restore those areas by reference to the appropriate detailed data sheets. Also by comparing listings from previous years, one can predict failures and estimate future needs.

A similar listing based on the minimum PSI reading within each highway section is also provided in the program. This list reflects short rough areas requiring maintenance such as patches, bridge decks, and utility construction sites. This list is required because a short rough stretch could be left unidentified if the average PSI value on that pavement is adequate.

A third serviceability listing identifies sections that have reached the TSI specified for these sections. The sections that have dropped below TSI by the greatest amount appear first on the list. Before the pavement is programmed for rehabilitation however, consideration must be given to things such as costs due to maintenance delays, impacts on the present and future economics of the area, and changes in traffic configurations on adjoining facilities.

PAVEMENT DISTRESS RATING

In the routine evaluation of distress, 11 pavement parameters are reviewed; the 7 parameters that are given a rating on a scale from 0 to 5, where 5 is a condition showing no distress, are opening, abrasion, multiplicity of cracks, wear, weathering, popouts, and uniformity of surface. The other 4 parameters, given an approximate value per 1000 square units of pavement, are transverse cracking, longitudinal cracking, map cracking, and patching. Definitions of the conditions for each rating used in Utah are given in a previous report (4). This evaluation should be done only by trained personnel so that consistency throughout the state can be maintained. Each number on the rating scale should be well defined, and the evaluator should be familiar with each pavement condition.

Pavement distress does not necessarily indicate a rough condition that would be noticeable to materials. For example, a cracked pavement may provide a smooth ride for a period of time. However, a cracked surface allows moisture to reach the subgrade; a loss in matrix and erosion around the cracks may then occur and eventually lead to complete failure. Rutting can occur without creating a rough situation under certain driving conditions but can cause difficulty when drivers change lanes. Also, rutting can cause hydroplaning when pavement is wet and will eventually lead to strain cracking along the wheel path. The Maintenance Division must not only correct deteriorated pavements but also recognize which pavements most need attention to prevent extensive deterioration and greater costs.

STRUCTURAL ADEQUACY

The structure of a pavement being considered for rehabilitation must be analyzed for ability to support traffic loads. The Dynaflect is used to predict the remaining years to failure based on measured traffic loading on the highway and projected yearly increase. A listing is then made of the pavements in each district in the order in which they will probably fail structurally. Sections can be selected from this list for increases in structural adequacy. The maintenance engineer may request a secondary analysis, which also would incorporate use of the Dynaflect, to obtain a more extensive testing of weak areas. If an overlay is selected as the mode of upgrading the structure, the deflection data can be used to design the thickness of the overlay. A thicker overlay may be placed on the deteriorated areas, and some areas may even be left untouched rather than overlay the entire section with one thickness (5). Skipping nondeteriorated areas could greatly reduce the cost of a rehabilitation.

For comparison, the structural adequacy prediction was modified to a 0 to 5 rating similar to those used in the PSI and distress analyses. This system should be more compatible with the rest of the pavement rehabilitation model. In cases where a years-to-failure criterion is desired, the following can be used:

Structural Rating	Years to Failure	Structural Rating	Years to Failure
5.0	>10	2.5	3
4.5	8 to 10	2.0	2
4.0	6 to 7	1.5	1
3.5	5	1.0	0
3.0	4		

In the past, failure predictions based on structural adequacy have been misused; Dynaflect data cannot be used absolutely to predict the failure of a pavement. The analysis can only indicate structural failure based on the load-carrying capacity of the pavement structure. The modes of failure of a highway are interrelated. The presence of any one of the three basic failure modes (roughness, distress, or structural) usually precedes the appearance of the remaining two. Theoretically, years to failure based on a structural analysis should result in a decrease by 1 year each successive year; for example, at 10 years 1 year, at 9 years another year, and so forth, to 10 years and failure. In reality, however, we often observe predictions such as 10 years to failure the first year, 5 years the next year, and 2 years the next year. This apparent accelerated failure can be due to increased traffic loading, a rough condition, or distress weakening of the pavement structure. The observation of any single year's prediction can be misinterpreted, misused, and inevitably mistrusted. Therefore, adopting the 0 to 5 rating system of structural failure prediction rather than years to failure seems reasonable. The basic theory, however, remains sound. A reasonable indication can be obtained of how well the structure is supporting the present traffic loadings and how long the structure will perform adequately under projected traffic loadings if pavement distress or other factors do not accelerate failure.

SKID RESISTANCE

The Mu-meter is used to evaluate pavement surfaces for slipperiness. This device estimates surface skid resistance by pivoting the testing wheels to an angle with the line of movement at 64.4 km/h (40 mph) and measuring the resulting side force generated. The skid indexes range from 0 to 100; any surface that measures below 35 is considered to be in a hazardous condition. Lengths of 402 m (0.25 mile) are tested every 3.22 km (2 miles) within each section (plus any areas that appear to be slippery). Two listings of highway sections are needed to properly select highway sections for skid improvements. The average skid values of each section are listed in order from most slippery to least slippery to isolate sections that need surface rehabilitation. Minimum skid reading within each section is also listed to indicate smaller areas that need attention such as patches, nonuniform construction, or bleeding areas.

OVERALL PRIORITY RANKING

When reviewed individually, these lists can be helpful in establishing priorities as to which pavements are in need of maintenance, what type of failure is present, and to some extent how far the problem has progressed. However, to obtain an indication of the overall condition and to gain insight as to the most efficient form of rehabilitation to pursue, one must analyze the listings collectively as well as individually.

The interrelation between the general failure modes is important in determining the type and time of a rehabilitation effort because one form of deterioration leads to another. The degree to which deterioration progresses indicates when and how extensive the maintenance strategy must be to ensure proper service. Figure 6 is a diagram of the development of pavement failure. Because skid problems are surface problems and only slightly related to other modes of failure, they are not included in the flow chart. In new highway construction the intent is to obtain a pavement system that is structurally sound, has no initial pavement distress, and has a smooth riding surface. Pavement deterioration can occur if one of these requirements is not fully met in construction, if some unexpected problem occurs while the pavement is in service, or as the natural pavement aging processes take place. When

Table 1. Pavement sections ranked by average PSI.

Number	State Route	Length (km)	Beginning Terminus	Ending Terminus	Index
1	E02	13.52	Saltair	SLC Airport	1.9
2	106	0.56	Junction Utah-131	4th N. Bountiful	2.3
3	171	2.82	Redwood Road	Junction Utah-I15	2.7
4	201	1.27	Junction I-15	Junction Utah-271	2.7
5	186	1.61	East end US-40	2500 West	2.9
6	171	8.53	Junction Utah-111	4000 West	3.0
7	E02	5.79	Coalville	Echo Dam	3.0
8	270	1.21	East end I-15	1st W. Railroad	3.0
9	201	3.27	Redwood Road	Junction I-15	3.1
10	071	1.61	Draper West	11 400 South	3.1

Note: 1 km = 0.6 mile.

Figure 6. Development of pavement failure.

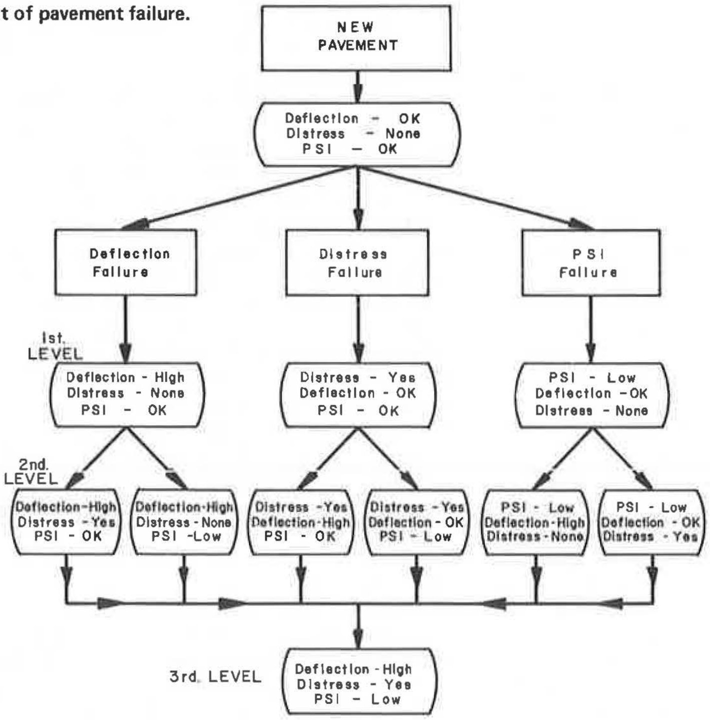


Table 2. Pavement sections ranked by final index number.

Number	State Route	Length (km)	Beginning Terminus	Ending Terminus	Final Index	Structure	Distress	PSI	Avg Skid
1	106	0.56	Junction Utah-131	4th N. Bountiful	2.4	4.0	1.0	2.3	70
2	E02	13.52	Saltair	SLC Airport	2.4	1.0	4.2	1.9	58
3	201	1.27	Junction I-15	Junction Utah-271	2.4	1.0	3.6	2.7	63
4	186	1.61	East end US-40	2500 West	2.5	4.0	1.0	2.9	35
5	201	3.27	Redwood Road	Junction I-15	2.6	1.0	3.8	3.1	51
6	071	1.61	Draper West	11 400 South	2.7	5.0	1.0	3.1	29
7	270	1.21	East end I-15	1st W. Railroad	2.8	1.0	5.0	3.0	33
8	171	2.82	Redwood Road	Junction Utah-I15	2.9	4.0	3.0	2.7	49
9	E02	5.79	Coalville	Echo Dam	3.0	3.0	3.7	3.0	43
10	171	8.53	Junction Utah-111	4000 West	3.2	5.0	3.3	3.0	56

Note: 1 km = 0.6 mile.

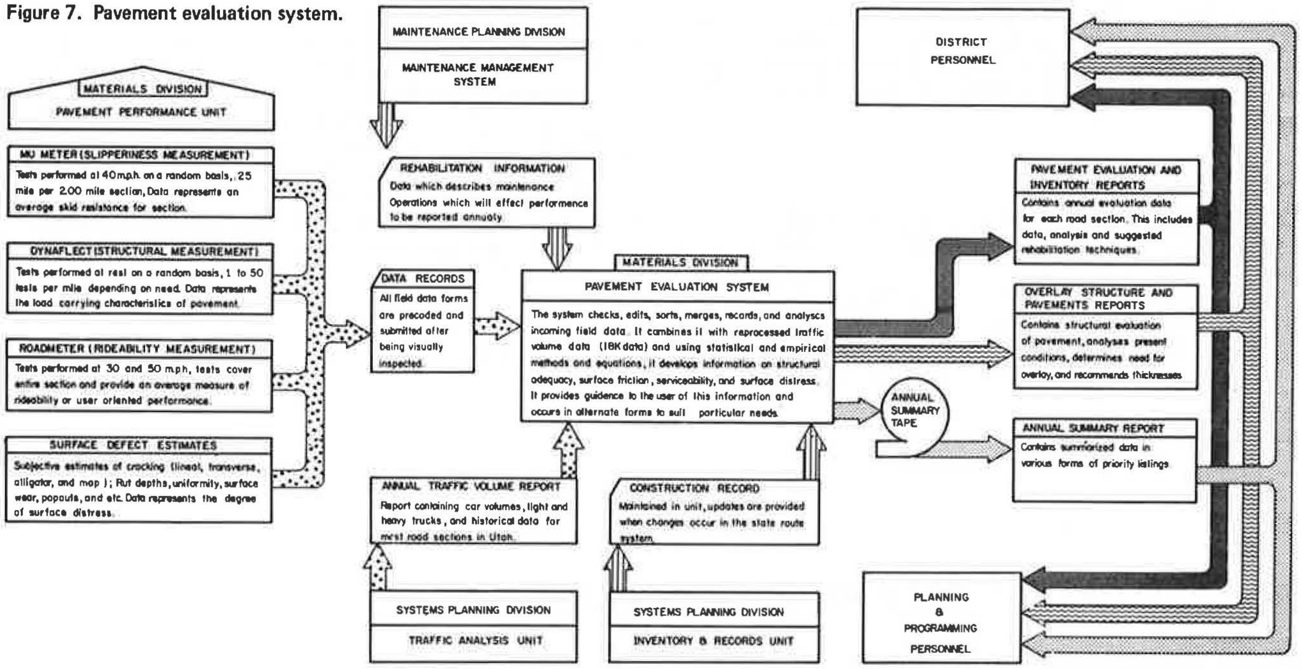


Figure 7. Pavement evaluation system.

one of these modes of failure appears the pavement has reached first-level deterioration. If not corrected, the deficiency can lead directly to further problems, or the pavement could continue to age naturally, until the appearance of a second mode of failure. The pavement is then at the second level of deterioration. Inevitably the pavement system reaches the third level of deterioration if no rehabilitation effort is made at the appearance of any of the three modes of failure.

Each year data are added to a graph containing data from previous years. General trends are illustrated and made easily comparable for the four main failure modes (Figure 4).

The most efficient level for rehabilitation of a pavement depends on traffic demands placed on the system, which include ADT, 80-kN (18-kip) loads, functional class, and running speed. These parameters were used to list overall maintenance priorities. For highways with high ADT, the system weights the PSI proportionately to account for user costs. Structural adequacy of pavement is given extra attention where there is much truck traffic. An overall 0 to 5 rating that considers these variables is thus obtained for each pavement.

A final summary table (Table 2) gives the value of each of the four failure modes for each specific section of highway. This listing enables the reviewer to observe the section's relative condition and aids in choosing a rehabilitation strategy. For example, pavement 1 is structurally sound and has good skid resistance, but rates poorly in the distress and PSI columns. Although a more detailed analysis and field evaluations would be necessary before a final decision on rehabilitation could be made, some form of stress-relieving interlayer with overlay seems to be a consideration. This could minimize reflective cracking and create a smooth riding surface. Because the structure appears to be adequate, possibly enough material is in place. Therefore, recycling may be considered; however, bringing in the necessary machinery for such a short section may not be possible.

Pavement 2 is deficient in structural adequacy and PSI but has little distress and fair skid resistance. Further Dynaflect testing should be requested, and an overlay should be designed to support the traffic loading; thus, the PSI measurement of the section would be upgraded. Action should be taken before heavy distress occurs.

Reviewing the lists indicates direction for further analysis of various rehabilitation strategies. A flow chart of the entire evaluation system is presented in Figure 7 (6). The pavement condition evaluation conducted annually by the Materials and Research Section is limited to number of kilometers of highway that can be tested. To realize the greatest benefit from this program, we must make a careful selection of which pavements to test. The following are used as criteria for establishing testing priorities for any given year:

1. Control sections tested every year to ensure consistency in data,
2. Pavements with indexes below 3.0 on any failure mode listing for the previous year,
3. Sections requested for testing by district personnel, and
4. Pavements that have not been tested for 3 years.

CONCLUSIONS

The goal of pavement evaluation and rehabilitation is to minimize cost of constructing, maintaining, and operating on any given highway and still maintain level of safe service. To minimize user costs and prevent total loss of a pavement, a minimum value of the serviceability index should be specified where rehabilitation is indicated. This TSI, as defined in this report, is dependent on ADT as well as functional class.

The priority listings developed in this report give serviceability, distress, structural adequacy, and skid resistance of each pavement tested. These lists can be used in the development of highway rehabilitation strategies, programs for pavement testing schedules, and maintenance budgets to be submitted to legislative bodies.

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is responsible for the facts and the accuracy of the data. The contents do not necessarily reflect the official views or policy of the U.S. Department of Transportation. The report does not constitute a standard, specification, or regulation.

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Prediction of Rigid-Pavement Performance From Cumulative Deflection History

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Data from the AASHO Road Test were used to investigate a functional relationship between the cumulative deflections sustained by a rigid pavement and a quantitative measure of the corresponding condition of the pavement. Cumulative deflections were estimated from periodic Benkelman beam deflections. Deflections had been measured at approximate 2-week intervals during the road test, and we assumed in the analysis that such deflections were representative of those that would have been measured had Benkelman beam deflections been measured continually. The present serviceability index (PSI) was used as a quantitative measure of pavement condition. Because of wide variation in response to loading of similarly constructed test sections and even between replicate test sections, no definitive relationship could be established that could predict PSI as a function of cumulative deflection. However, when data from test sections having the same slab thickness were averaged, a PSI-cumulative deflection relationship could be described by two straight lines intersecting at a threshold cumulative deflection. For cumulative deflections less than the threshold, an increase in cumulative deflection produced small changes in PSI; for cumulative deflection larger than the threshold, relatively small increases in cumulative deflection produced large changes in PSI. The level of the threshold cumulative deflection increased with increasing slab thickness.

Most methods of rigid pavement design for airfields and highways are based on considerations of load-induced stresses in elastic slabs. Repeated application of loads that induce stresses well below the modulus of rupture of a given material can cause the material to fail. This phenomenon, fatigue failure, is attributed to the fact that materials are not ideal homogeneous solids (1). Portland cement concrete (PCC) exhibits this behavior. Pavement distress due to fatigue may become more important in the future as aircraft and highway loads increase and exceed those contemplated by designers because the number of load repetitions that produce fatigue distress decreases as the load-induced stress increases.

Curves depicting the fatigue phenomenon usually have stress or strain on the ordinate versus cycles of load on a logarithmic abscissa. Such relationships are difficult for the pavement engineer to apply to in-service rigid pavements because measuring in situ stresses or strains is difficult and time consuming. Deflection measurements are made much more easily; the Air Force has a vehicle-mounted, optical-deflection measuring system under development that will be able to measure and compile deflections accurately with little or no interruption to traffic. Thus a correlation of deflections with a rigid-pavement performance index, which includes fatigue effects, would provide a valuable tool to the pavement engineer.

BACKGROUND INFORMATION

Fatigue of concrete has been investigated in terms of stress by several investigators (2, 3, 4). Nordby (4) reviewed research findings involving the fatigue of PCC and noted that most of the research performed on both plain concrete specimens and those with reinforcement similar to that of highway pavements was motivated by the fact that many failures of concrete pavements by cracking were due to repeated applications of stress. Fatigue research on plain concrete beams indicates (4) that plain concrete may not possess a fatigue limit within 10 million cycles of load, that inadequately aged and cured concrete is less resistant to fatigue than well-aged, well-cured concrete, and that as the induced stress is decreased the fatigue strength is increased substantially.

There is substantial agreement among fatigue investigators that, for reinforced concrete specimens (4), (a) most failures of reinforced beams were due to failure of the reinforcing steel that was accompanied by severe cracking in the concrete and stress concentrations associated with these cracks and (b) beams accumulated residual deflections over many cycles of load but recovered somewhat during rest periods, indicating, at