Development of a Utility Evaluation for Nondestructive Testing Equipment Used on Asphalt Concrete Pavements

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Nondestructive testing of pavements has become a cost-effective and invaluable aid in determining the actual condition of pavement sections in a highway network. Because the number of nondestructive testing devices in use grows each year, the choice of the best method involves a complex comparison of alternatives involving the test equipment itself, the resulting data, and the available methods of analyzing the data provided. All of these factors are considered in a systematic way by the application of utility theory. A hierarchical weighting system is developed using nonlinear utility curves. Each of the independent decision criteria is carefully defined. Weighting factors are developed using the Churchman-Ackoff technique. The analysis is performed with uncertainty obtained by using a beta probability distribution. The calculated results are expressed in terms of an expected value and a 95 percent confidence interval. Five generic nondestructive testing devices are evaluated for use on asphalt concrete pavements for both project-level design and network-level planning. The characteristics of these devices used in the calculations were deliberately revised so that none of them represent actual commercially available equipment. The generic devices are used to demonstrate the evaluation technique. The formulated utility analysis framework can be applied to real devices. Furthermore, the analysis can be extended to other situations by appropriate modification of the criteria, weights, or utility curves.

Nondestructive testing of pavements has become a cost-effective and invaluable aid in determining the actual condition of pavement sections in a highway network. However, the number of nondestructive testing devices that are in common use grows each year, and new devices are being developed. The choice of the best method to use involves a complex comparison of alternatives involving the test equipment itself, the available methods of analyzing the data provided, and a knowledge of the assumptions and limitations in the analysis. This paper provides guidelines and recommendations for the selection of nondestructive testing devices for use on asphalt concrete pavements.

The analysis of the usefulness of a device entails consideration of a variety of criteria. These criteria should include economic factors and operational characteristics as well as the quality of the resulting data. Because many of the factors that should be considered are noneconomic, they are thus difficult to compare. It is, however, important to consider all of the factors in a systematic way; this is done by the application of utility theory.

The formulation of the utility analysis decision framework included the following steps:

1. Identification and definition of important, independent attributes,
2. Assignment of weights of relative importance to attributes, and
3. Development of a utility curve for each attribute showing the relative desirability of values and the location of optimum values.

These steps required the input of personnel involved in the use of the testing devices. Once the decision framework is formulated, it can be used to objectively evaluate any nondestructive testing device. It can also be modified to evaluate other types of equipment.

DESCRIPTIONS OF NONDESTRUCTIVE TESTING EQUIPMENT

The nondestructive testing equipment used to collect data on existing pavements can be divided into four general categories:

1. Static deflection.
2. Steady state deflection.
3. Impulse load deflection.
4. Wave propagation.

Measurement systems that determine pavement response to slowly applied loads are generally termed static deflection systems. Loads are applied by slowly driving to or away from a measurement point with a loading vehicle, or they may be applied by reacting against a stationary loading frame. The measurement of static deflection under a slowly moving load to ascertain structural capacity must be done with care and attention to detail in order to achieve consistent results.

Steady state dynamic deflection measurement systems use a dynamic force generator and measure the deflection response of the pavement with inertial motion sensors. For pure sinusoidal motion at any fixed frequency, the output of such sensors is directly proportional to deflection. Thus, to measure deflection, it is only necessary to determine the calibration factor for the measurement frequency. The integrated output of a geophone is

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the most common type of motion sensor employed when deflections are measured over a range of frequencies. The calibration factor is constant in its flat response range, which generally begins at a frequency value that is about three or four times higher than the resonant frequency of the sensor.

Pavement deflection in response to dynamic loads at any specific driving frequency is approximately proportional to the amplitude of the load. The proportionality factor (dynamic stiffness) is not independent of driving frequency. At low driving frequencies the dynamic pavement stiffness approaches the value of the static (or elastic) pavement stiffness.

Essentially all impulse load testing methods deliver some type of transient force impulse to the pavement surface and measure its transient response. In principle, this method is rapid. Force impulses are normally generated by dropping a weight from a known height onto an impact plate that has been placed on the surface of the pavement. The pavement response is normally measured with inertial motion sensors.

The response of the pavement structure to transient loads is explained in the literature *(1, 2)*. Szendrei and Freeme *(3)* discuss the direct relationship in linear viscoelastic systems between impulse testing and steady state sinusoidal testing. Any impulsive force $f(t)$ that is a function of time can be represented through the inverse Fourier transform as a function of frequency *(4)*.

By far the major advantage in this testing approach is that the actual duration required for measurements is only a few seconds. One disadvantage is the problem of obtaining accurate response information in the low frequency range because of characteristic low output of inertial motion sensors in this range of frequencies. Also, to obtain reliable response information in the significant frequency range of the pavement requires force impulses that have a short duration. Such impulses are difficult to produce. Nevertheless, considerable pavement characterization information can be obtained when force impulses of longer duration are used.

Wave propagation techniques offer methods for the determination of the elastic properties of individual pavement layers and subgrades. There are two basic techniques for propagating waves through pavement structures: (1) steady state vibration tests, and (2) impulse tests. A good description of both steady state vibration tests and impulse tests is provided by Green and Hall *(5)*. The wave propagation method involves the measurement of the velocity and wavelength of the surface waves propagating away from the vibratory source placed on the surface. Generally, three types of waves are transmitted when a surface is subjected to a vibration source.

1. Compression *(P)* waves,
2. Shear *(S)* waves, and
3. Rayleigh *(R)* waves.

Rayleigh waves are dominant as about 67 percent of the energy is dissipated in Rayleigh waves. *P* and *S* waves attenuate rapidly. *R* waves are the principal type that are measured in wave propagation techniques.

Only limited use has been made of wave propagation techniques for pavement evaluation. Interpretation of wave velocity test results to obtain elastic constants of pavement layers is the greatest obstacle. Two approaches have been used, the dispersion curve method and an empirical method that associates the wave length with the depth of the layer below the surface where the wave energy travels. The dispersion curve method has been found successful in determining the moduli of the two layers closest to the surface *(6)*. The depth-of-wave travel empirical technique has been used successfully to determine the moduli of multiple layers below the surface *(7)*. Both methods require the signals reaching the sensors to be analyzed by using a Fourier transform to express the wave speed data as a function of frequency.

EVALUATION METHODOLOGY

The analysis of the usefulness of a nondestructive testing device entails consideration of a variety of criteria. Many of these factors are noneconomic, and are thus difficult to compare. It is, however, important to consider all of the factors in a systematic way; this can be achieved by the application of utility theory. Numerous texts on utility theory exist *(8–10)*, and the theory has been successfully used in the analysis of a number of extremely complex engineering problems. As an example, the optimum configuration for the supersonic transport was arrived at by use of utility theory *(11)*.

Basically, utility theory is a way to compare apples and oranges with bananas. Two important terms used in utility theory are value and utility. Value is defined as the worth or importance attached to an object or a service. Utility is defined as the power or efficiency of satisfying wants. A previously developed utility analysis program was modified to suit the needs of the project *(12)*. Provisions for alternative methods of weighting were incorporated.

Decision Criteria

The major attributes of the decision were first identified. The attributes are

1. Cost,
2. Operational characteristics,
3. Data quality,
4. Versatility,
5. Reliability and maintenance downtime, and
6. Time in service and degree of development.

These attributes were further divided into decision criteria that contribute to satisfying the objectives associated with the attributes. The resulting decision flowchart is shown in Figure 1. Each decision criterion had to be carefully defined so that objective values could be determined. The final definitions are given in Table 1.

In order for the utility evaluation to be valid, the criteria must be independent of one another. Any interdependence may sway the outcome by overlapping or repeating the consideration of a certain criterion or subcriterion. This factor was carefully considered when selecting the criteria and developing the definitions. It might appear that a better evaluation could be provided by adding more criteria or by further subdividing the criteria. However, if such actions are taken, independence must

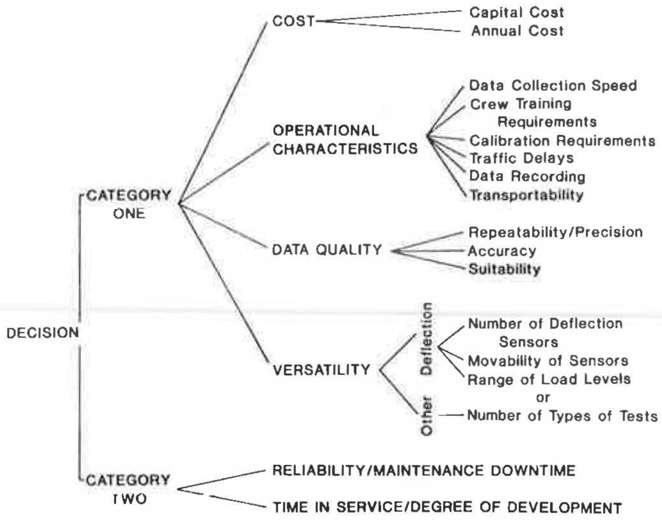

FIGURE 1 Flowchart of utility decision criteria.

be maintained. For example, a criterion for type of sensors could be added. Certainly, LVDTs and geophones are preferable to dial gauges. However, when the independence of such a criterion is examined, its validity is doubtful. The advantages of the better sensors are to a great extent included in the criteria for accuracy, reliability, repeatability and precision, data collection speed, and calibration requirements. Therefore, type of sensors would have to be defined and weighted in such a manner as to exclude such factors. Upon examination of this definition, it may well be found that such a factor is, in fact, already incorporated into the utility analysis and therefore unnecessary. Similarly, ease of operation could be considered. However, this criterion is almost totally incorporated into crew training requirements, data collection speed, and annual cost. In this manner, a wide variety of criteria were considered, defined, divided, and combined to result in the system given in Table 1. Totally independent criteria are not realistically possible, but the independence can be maximized by careful adherence to the definitions.

The attributes were divided into two major categories. Category 1 attributes are generally concerned with specific device characteristics, whereas Category 2 attributes involve reliability, time in service, and degree of development. Therefore, the utility of Category 1 reflects the potential of the devices; the combination of the two categories gives the current utility of the device to a user.

Weighting Factors

Next, weighting factors were developed for the decision criteria. The weighting factors provide a measure of the value of each criterion.

Several types of weighting factors are possible. Weights can be multipliers in an additive system, for example,

$$w_1A + w_2B + w_3C \qquad (1)$$

or weights can be exponents in a multiplicative system, as in

$$A^{w_1} B^{w_2} C^{w_3} \qquad (2)$$

A combination of hierarchical additive and multiplicative weighting methods was chosen for application to this problem. The attributes and criteria within Category 1 and within Category 2 were combined using the additive method. However, the total utility was determined by combining the utilities of Category 1 and 2 multiplicatively with exponential weights. This weighting was done because if a device has either a low Category 1 utility or a low Category 2 utility, its present use value is also low. The multiplicative scheme allows values to have a more noticeable impact. However, it was desirable to keep Category 1 characteristics separate and obtain the utility for Category 1 additively in order to provide some indication of the potentials of the devices at current cost levels.

Two separate sets of weights were developed to allow for the possibility that different devices could be optimal in different situations. The two situations considered were used for network-level analysis and planning and use for project-level analysis for design.

After the weighting system was decided upon, the weights had to be determined. The weights were determined using the Churchman-Ackoff point-allocation method as shown in Figure 2. The method was chosen because of its relative simplicity *(13)*. Furthermore, Schoemaker and Waid have experimentally examined multiple regression, analytic hierarchies, direct trade-offs, point allocations, and unit weighting, and have found that the point allocation method was more than adequate and, in fact, exhibited the narrowest distribution of correlations *(14)*. As previously explained, the method requires independence of the decision criteria.

Weights were determined independently by each of the following individuals who are familiar with the equipment:

1. Roger E. Smith, ERES, Inc., Champaign, Illinois;
2. Harold L. Von Quintus, Brent Rauhut Engineers, Inc., Austin, Texas;
3. Jim Hall of the Waterways Experiment Station, Vicksburg, Mississippi;
4. Robert L. Lytton of the Texas Transportation Institute, College Station, Texas; and
5. Freddy L. Roberts of the Highway Research Center, Auburn, Alabama.

Each individual was asked to fill out a form, using the Churchman-Ackoff method. Weights were then normalized so that the weights in each division totaled one. The five normalized weights for each criterion were then analyzed to determine the mean and standard deviation. Using this information, the final weights were determined in a group session. These final weights are given in Table 2.

Utility Curves

Utility curves show the function of efficiency of each criterion in satisfying the corresponding want. They enable us to mea-

TABLE 1 DEFINITIONS OF DECISION CRITERIA

Criterion	Definition
CATEGORY ONE:	
Capital Cost	Determination of capital costs shall include consideration of the following components: 1. Initial Cost -- The cost to purchase the equipment and accessories. 2. Salvage Value -- The expected salvage value of the NDT equipment and accessories at the end of its service life. 3. Equipment Life -- The expected life anticipated for the NDT equipment and its accessories.
Annual Data Collection Cost	Determination of annual data collection cost shall include consideration of the following components: 1. Maintenance Cost -- Average annual maintenance costs over the life of the equipment, including both parts and labor. 2. Crew Costs -- The costs of the crew required to operate the equipment for one day of testing (an eight-hour day).
Data Collection Speed	The total time required to test a pavement station from the time the tow vehicle stops until it starts again after the measurement is completed. This time includes set-up, testing, data collection, and reloading.
Crew Training Requirements	Personnel training includes actual time operating the equipment as well as reviewing the operations manual provided by the manufacturer. It should include familiarization with equipment operation, trouble-shooting, data interpretation for verification, and calibration procedures. Requirements should be expressed as the total number of man-hours of training required for an entire crew.
Calibration Requirements	The estimated number of hours of calibration required per week of use.
Traffic Delays	This factor is a measure of the inconvenience to other road users. It is dependent upon the travel speed of the testing vehicle and upon the space occupied by the required equipment. It will be evaluated on a continuous scale from 0 to 1: 0 = No traffic delays. 0.5 = Complete obstruction of a single lane. 1 = Complete obstruction of two lanes.
Data Recording	A measurement of the degree of automation and the ease of data acquisition, storage, and retrieval. It will be evaluated on a continuous scale from 0 to 1. 0 = No automation; all data must be hand recorded. 0.5 = Data is recorded automatically, but does not include test section or other relevant information. 1 = Equipment must be transported over distances by a specially equipped additional vehicle.
Repeatability/ Precision	The expected coefficient of variation of a measurement repeated at a single location.
Accuracy	The expected error of the measured quantities. For deflection-type devices, this should incorporate the accuracy of both load measurements and deflection measurements.

TABLE 1 continued

Criterion	Definition
Suitability	Are the pavement responses measured the same as would occur when a 9-kip moving wheel load is applied? It will be evaluated on a scale from 0 to 1: 0 = No. 0.4 = Procedure to convert to 9-kip moving wheel load requires use of assumed material properties of the layers. 0.7 = Accurate procedure available for conversion from the applied load to a 9-kip moving wheel load. 1 = Yes.
For deflection-type devices:	
Number of Deflection Sensors	The actual number of deflection sensors used for each test.
Movability of Sensors	Are the sensors movable, for the evaluation of load transfer, etc.? It will be evaluated on a continuous scale from 0 to 1: 0 = No. 0.5 = Yes. Requires sensors to be moved manually. 1 = Yes. Sensors can be moved automatically.
Range of Load	The range of load levels that the deflection-measuring equipment can exert on the pavement. The rating will be on a continuous scale from 0 to 1 as follows: 0.0 = No load. 0.2 = One light load level. 0.4 = One heavy load level. 0.6 = A range of loads from light to medium. 0.8 = A range of loads from medium to heavy. 1.0 = A range of loads from light to heavy. The light loads shall be 0-4000 lb.; medium loads, 4000-10,000 lb.; and the heavy loads, 10,000-24,000 lb. or more.
For other NDT devices:	
Versatility	Versatility shall be defined as the number of types of measurements that can be made by a single device.
CATEGORY TWO:	
Reliability/ Maintenance Downtime	The estimated time, in number of days per year, that the equipment will be out of service due to equipment failures, malfunctions, etc. This includes waiting time required to obtain necessary parts and service.
Time in Service/ Degree of Development	It will be evaluated on a continuous scale from 0 to 1: 0 = Equipment is in developmental stages and has not been field tested for pavement studies, and equipment or software is not yet developed for production testing. 0.5 = Equipment has been developed and field tested on a limited basis but is not in production or available commercially. Some software has been finalized. 1 = Equipment and software is in fully-developed use, accepted nationwide, available commercially, and in use for production testing.

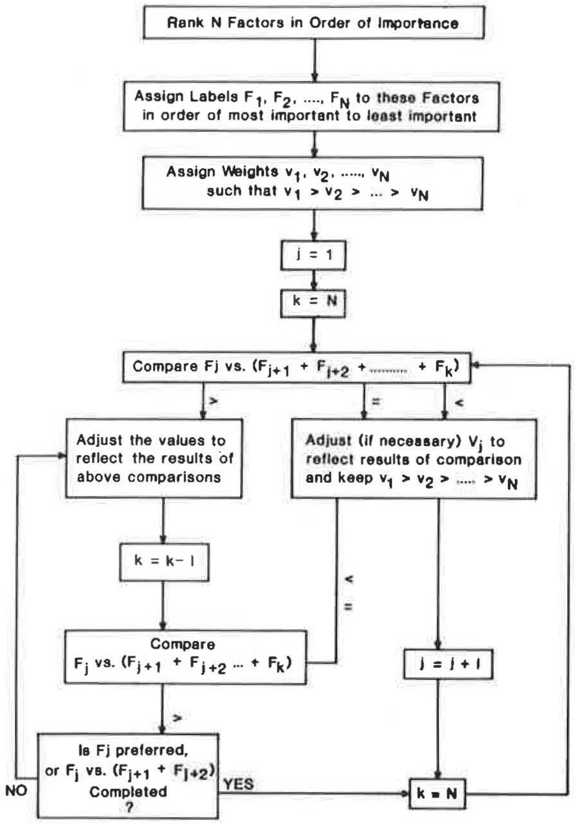

FIGURE 2 Graphical illustration of the Churchman-Ackoff Method to determine the weights of the factors.

TABLE 2 WEIGHTING FACTORS

Factor	Project-Level Relative Weight	Network Level Relative Weight
Category One	1.00	1.00
Category Two	0.50	0.50
Cost	0.19	0.23
Operational Characteristics	0.22	0.34
Data Quality	0.35	0.28
Versatility	0.23	0.15
Reliability/Maintenance Downtime	0.48	0.60
Time in Service/Degree of Development	0.52	0.40
Capital Cost	0.52	0.43
Annual Cost	0.48	0.57
Data Collection Speed	0.22	0.23
Crew Training Requirements	0.14	0.10
Calibration Requirements	0.15	0.14
Traffic Delays	0.20	0.19
Data Recording	0.19	0.20
Transportability	0.09	0.13
Repeatability/Precision	0.28	0.38
Accuracy	0.41	0.30
Suitability	0.31	0.32
Number of Deflection Sensors	0.30	0.43
Movability of Sensors	0.30	0.27
Range of Load Levels	0.40	0.30

sure the utility for a given level of an attribute. A utility function *u(x)* represents the utilities of a group of decision makers for various values of an attribute. Utility curves may assume a variety of shapes. In this project, both linear and nonlinear utility functions were used. The utility values range from 0 to 1, with 0 being of no value and 1 satisfying the want perfectly. The shapes of the utility curves indicate preferences. Curves that are convex upward are representative of personal preferences of those people who are willing to take a chance. This risk proneness is due to an expectation that the method, if successful, will more than justify the expenditure of additional amounts of the independent decision variable plotted along the abscissa. Curves that are concave upward represent risk aversiveness in personal preferences, indicating a less than optimistic expectation of a successful outcome. Straight-line curves represent a set of personal preferences that is convinced of neither an optimistic nor pessimistic outcome. Actual curves may be any combination of these shapes *(8, 12, 15)*.

One set of utility curves was used for both project-level and network-level analyses. Each of the five expert participants constructed a set of utility curves, drawing one curve for each decision criterion. Points on these curves were averaged, the curve shapes were examined, and a tentative set of combined curves were drawn. These curves were later refined in a group session. Example curves shown in Figure 3 were fitted with an exponential equation of the form

$$u = a + bx^c \qquad (3)$$

where

u = utility,
x = decision variable, and
a, b, c = constants computed to fit the points.

These utility functions *u(x)* were used for the integration in the utility analysis program.

Consideration of Uncertainty

Many of the nondestructive testing devices considered are still in a developmental stage. Furthermore, even if detailed knowledge of a particular technique were known, the actual values of the criteria could vary significantly, depending upon the specific use and user. In order to be confident of the decisions made in this condition of uncertainty, the decision criteria were described as a distribution of values instead of as a single value. Each decision criterion was assumed to have a beta probability density function. At some value of a decision criterion x, the beta probability density is

$$f(x) = [\Gamma(\alpha - \beta) x^{\alpha-1} (1 - x)^{\beta-1}] / [\Gamma(\alpha)\, \Gamma(\beta)] \qquad (4)$$

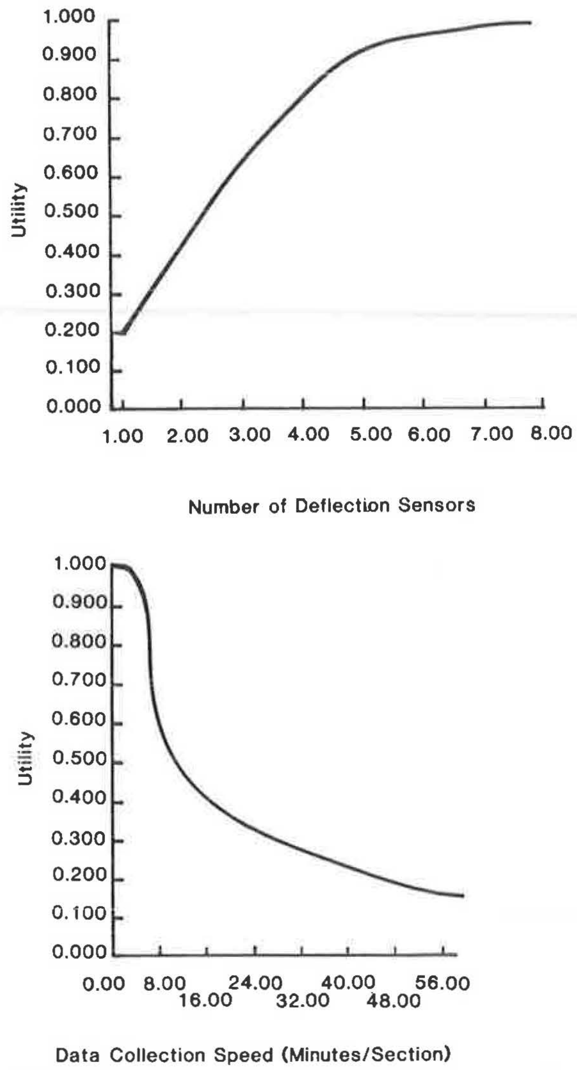

FIGURE 3 Two of the utility curves developed for the decision analysis.

where $\Gamma(\alpha)$, $\Gamma(\beta)$ are gamma functions of α and β, respectively, and α, β are distribution parameters that can be determined if the mean and standard deviation of the variable x are known.

The beta distribution is convenient for determining the mean and standard deviation if estimates of optimistic, most probable, and pessimistic values of the decision variable are known. The mean is given by

$$\bar{x} = (o + 4m + p)/6 \qquad (5)$$

where o, m, p are optimistic, most probable, and pessimistic values of x. The variance of a beta distribution is given by (9):

$$\sigma_x^2 = (p - o)^2/6 \qquad (6)$$

The distribution parameters α and β are

$$\alpha = \mu\,[\mu(1 - \mu)/\sigma_x^2 - 1] \qquad (7)$$

$$\beta = (1 - \mu)\,[\mu(1 - \mu)/\sigma_x^2 - 1] \qquad (8)$$

With these values of α and β known, it is possible to calculate $f(x)$ for any value of x.

The expected value of the utility of x is given by the integral

$$E(u_x) = \int_{x_{\min}}^{x_{\max}} f(x)\,u(x)\,dx = \mu_u \qquad (9)$$

and the variance of the utility of x is

$$\mathrm{var}(u_x) = \int_{x_{\min}}^{x_{\max}} f(x)\,u^2(x)\,dx - \mu_u^2 \qquad (10)$$

Simpson's rule is used in the computer program to numerically evaluate the two integrations in Equations 9 and 10. The reason for calculating variances as well as expected values of the utilities is to provide the option of comparing the nondestructive testing devices at various degrees of certainty.

If the utility distribution is assumed to be normal, a confidence interval (L, U) for u is given by

$$\left.\begin{matrix} L \\ U \end{matrix}\right\} \; E(u) \mp Z_{(1+\gamma)/2}\,[\mathrm{var}(u)]^{0.5} \qquad (11)$$

where $Z_{(1+\gamma)/2}$ is the $100(1 + \gamma)/2$ fractile of the standard normal distribution. To compute the 95 percent confidence interval, $(1 + \gamma)/2 = 0.975$ and $Z = 1.96$.

EVALUATIONS OF NONDESTRUCTIVE TESTING DEVICES

For purposes of demonstrating the use of the utility analysis, five generic devices were evaluated. The characteristics of these devices are given in Table 3. These characteristics have been set deliberately so as not to represent actual devices; therefore, the resulting rankings as obtained here do not necessarily represent realistic comparisons between the various types of devices.

The utility analysis program was run for each of the generic devices. The resulting total utilities, one being optimal, are given in Table 4. The expected value of utility is shown for each device; the range given represents the 95 percent confidence interval.

The decision process as presented reflects the viewpoints of the panel of experts involved. However, the decision process for other groups may vary. For example, one significant change might occur if an organization already owned one or more NDT devices. The decision analysis for purchasing additional devices would probably still be similar to that presented here; perhaps compatibility of data and software would require consideration. However, such an organization might also wish to examine the net utility of replacing the devices already in use. The primary difference would be in the evaluation of capital cost; the capital cost would be zero for the device or devices already owned, thus improving their utility relative to the device being considered for purchase. Crew training requirements might also be taken as zero. With capital cost and crew training requirements equal to zero for each of the devices, the utility analyses were repeated. The resulting total and Category 1 utilities are presented for project-level and network-level use in Table 5. The utilities from Table 5 for a device already owned can be compared to those in Table 4 for other devices. For example, the total utilities for a previously purchased static

TABLE 3 CHARACTERISTICS OF GENERIC DEVICES

		Static Deflection			Steady-State Vibration I			Steady-State Vibration II			Impulse Device			Wave Propagation		
Characteristic	Unit	Low	Most Probable	High	Low	Most Probable	High	Low	Most Probable	High	Low	Most Probable	High	Low	Most Probable	High
Capital Cost	Dollars	1,000	2,000	3,000	40,000	45,000	50,000	20,000	25,000	30,000	55,000	60,000	70,000	50,000	75,000	100,000
Annual Cost	Dollars/yr	40,000	45,000	55,000	40,000	45,000	50,000	40,000	45,000	55,000	40,000	45,000	50,000	45,000	50,000	55,000
Data Collection Speed	Minutes/ Station	5	10	15	0.75	1.30	2.75	1.88	2.75	11.00	0.75	1.30	2.75	15	35	55
Crew Training Requirements	Man-hours	1	4	6	21	42	70	16	40	80	40	60	95	60	80	100
Calibration Requirements	Hours/week	.25	.50	2	2	4	6	2	4	6	4	6	9	3	5	7
Traffic Delays	---	0.4	0.6	1.0	0.36	0.56	0.66	0.36	0.47	0.66	0.36	0.47	0.66	0.6	0.8	1.0
Data Recordings	---	0.0	0.1	0.2	0.33	0.55	0.77	0.50	0.85	1.0	1	1	1	1	1	1
Transportability	---	0.0	0.25	0.50	0.67	0.70	0.75	0.5	0.5	0.5	0.5	0.5	0.5	0	0	0
Repeatability/ Precision	---	0.3	0.05	0.10	0.005	0.01	0.02	0.005	0.01	0.02	0.005	0.01	0.02	0.005	0.01	0.02
Accuracy	Percent	4	11	20	4.5	8.6	13.2	4	11	20	3.6	7.0	10.6	5	10	15
Suitability	---	0.0	0.3	0.6	0.43	0.57	0.70	0.6	0.7	0.8	1	1	1	0.3	0.4	0.5
No. of Deflection Sensors	Sensors	1	1	1	5	5	5	3	3	3	3	5	7	4	4	4
Movability of Sensors	---	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.7	0.5	0.5	0.5
Range of Load Levels	---	0.4	0.4	0.4	0.2	0.2	0.2	0.6	0.6	0.6	1	1	1	0.1	0.1	0.1
Reliability/Maintenance Downtime	Days/year	0	3	5	5	7	15	5	7	15	7	10	18	14	18	27
Time in Service/ Degree of Development	---	0.90	0.95	1.0	1	1	1	1	1	1	0.6	0.7	0.8	0.1	0.1	0.1

deflection device are 0.553 and 0.575 for project level and network level, respectively. In both cases, there are still three devices with higher total utilities, including capital cost. Although the utility for the static deflection device is improved, the owner might still wish to consider the purchase of one of the higher-ranking devices.

SUMMARY AND CONCLUSIONS

A utility analysis framework has been formulated for the evaluation of nondestructive testing devices on asphalt concrete pavements. This analysis enables a variety of factors, both economic and noneconomic, to be considered in an objective,

TABLE 4 UTILITIES OF GENERIC NONDESTRUCTIVE TESTING DEVICES

Device		Project-Level Use		Network-Level Use	
		Category One	Total	Category One	Total
Static Deflection	Expected Value	.565	.552	.587	.573
	95% Confidence Interval	.513-.617	.500-603	.547-.627	.533-.614
Steady-State Vibration I	Expected Value	.701	.664	.704	.657
	95% Confidence Interval	.672-.730	.627-.701	.683-.726	.619-.695
Steady-State Vibration II	Expected Value	.717	.679	.723	.675
	95% Confidence Interval	.670-.764	.627-.731	.690-.757	.630-.720
Impulse Device	Expected Value	.810	.668	.776	.638
	95% Confidence Interval	.790-831	.626-.710	.760-792	.593-.684
Wave Propagation	Expected Value	.605	.325	.615	.349
	95% Confidence Interval	.570-.639	.292-.358	.589-.647	.312-.385

TABLE 5 UTILITIES OF GENERIC NONDESTRUCTIVE TESTING DEVICES ALREADY OWNED

Device		Project-Level Use		Network-Level Use	
		Category One	Total	Category One	Total
Static Deflection	Expected Value	.567	.553	.589	.575
	95% Confidence Interval	.515-.619	.502-605	.549-.630	.535-.616
Steady-State Vibration I	Expected Value	.718	.680	.722	.674
	95% Confidence Interval	.689-.747	.642-.717	.700-.743	.635-.712
Steady-State Vibration II	Expected Value	.729	.690	.736	.687
	95% Confidence Interval	.682-.776	.639-.742	.603-.770	.641-.733
Impulse Device	Expected Value	.833	.687	.799	.658
	95% Confidence Interval	.812-853	.644-.730	.783-815	.611-.704
Wave Propagation	Expected Value	.636	.342	.647	.367
	95% Confidence Interval	.603-.669	.308-.376	.624-.671	.329-.405

consistent manner. The analysis is concerned with the selection of a device for either project-level design or network-level planning by highway and transportation officials. The analytical framework consists of a hierarchical weighting method with nonlinear utility curves and consideration of uncertainty.

This analysis can be easily modified to suit other specific needs. For example, if a device is to be selected for use in a research study monitoring pavement performance, the requirements would probably differ in some ways. The availability of technical support from the manufacturer might become a significant criterion. Perhaps accuracy would be more important. Factors can be added and weights changed without altering the overall framework. However, when these changes are made, the independence and relative overall importance of the criteria must be reevaluated.

An objective, extendable, and repeatable decision analysis method has been developed for selecting nondestructive pavement analysis devices. This utility analysis should prove useful to highway and transportation agencies or firms contemplating the purchase of a nondestructive testing device for use on asphalt concrete pavements. Officials and consultants are able to see objective and comprehensive comparisons of a much wider variety of devices than any one agency could compare by trial use. The method should be applied to the actual characteristics of real devices.

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