

PRECEPTS OF THE EVALUATION OF FACILITIES FOR HUMAN USE AND THE APPLICATION TO BRIDGE REPLACEMENT PRIORITIES

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Over the years, highway departments have inventoried and appraised their highway systems. One of the concepts that evolved is the sufficiency expressed as a percentage. This concept can be formalized as an inventory and appraisal process for general application. The concept has been applied intuitively to specific inventory needs such as the "Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges" and the sufficiency rating formula for bridges developed by the Federal Highway Administration. A generalized process which concisely defines terms required to develop precepts is presented. The methodology is a synthesis developed around the recognition that facilities subject to evaluation are directly or indirectly intended for human use. The process is then applied to a bridge replacement priority process through use of the sufficiency in an abridged example. Other uses are also discussed.

Precepts of the Evaluation of Facilities

The precepts of the evaluation of facilities for human use are a generalization of concepts narrowly applied only to highway facilities in the past. The concept of sufficiency or sufficiency rating which is the net results of the evaluation presented is not new. The context in which it has been traditionally used is the highway sufficiency rating used for planning purposes or more specifically ordering priorities or determining needs for upgrading highway facilities. The origin of the sufficiency concept is documented as early as 1946 and its use and the development of inventory data seem to be a somewhat arbitrary practice which relies on intuition.⁽⁹⁾ The precepts advance the concept of systematically developing evaluation goals, facility functions and the required inventory data to evaluate them. This ultimately involves establishing a glossary of terms to describe the evaluation process, generalizing and enhancing the evaluation process and presenting a systematic approach to the selection of strategic inventory data necessary to the evaluation process.

Emphasis should be placed on inventory data which is measured and not subject to judgement which may introduce bias.⁽³⁾ Subjective evaluations,

when included in the inventory data, should be in a uniform reporting approach to minimize bias in the site observations.

The need for this generalized approach became evident when the Federal Highway Administration developed a sufficiency formula around its bridge inventory data ⁽¹⁰⁾ which was required to be collected by the States and supplied to a national base it maintains. On occasion this inventory data has been questioned as to its value or need as inventory data. Justification for this data led to the review of the sufficiency formula to determine what was needed to evaluate a bridge. It logically follows that initial development of inventory data sets can be arrived at systematically and thereby justified through analysis of predetermined evaluation goals and facility functions.

The engineer is often called upon to investigate the feasibility of developed alternatives for capital outlay programs to maximize profits as well as optimize other benefits to his organization or client. The investigation of existing facilities which are directly or indirectly intended for human use can be accomplished by evaluating their sufficiency in the context of current standards of technology and practice. Several common precepts defined for the sufficiency evaluation presented herein are, in part, independent of a facility's specific function(s). The relative independence of function should be most valuable in a multi-discipline, team environment. Each team member can independently develop the function assessment in his specialty and together they must agree on the relative importance of each function. Another use of the sufficiency is the comparison of several similar facilities of different ages, states of repair and levels of usage. It provides a common denominator for input with other considerations in a retirement, maintenance, and replacement planning program.

Basic terminology is necessary to develop the sufficiency concepts. A glossary of terms follows to define the several terms which will be used herein:

Capacity - a data assessment standard representing a standard of capacity of the function to serve the elements in the environment of the facility.

Data Assessment Standards - a defined range of inventory data values defining levels of service.

Efficiency - the assessment of an inventory data

item which is used in a composite to evaluate the function assessment. An inventory data item can be an assessment requiring no further evaluation.

Element - the human element or a vehicle, machine or other device operated or utilized directly or indirectly by the human element for production purposes, comfort or other need. An element may also be defined as a function.

Essentiality - an evaluation of the inventory data with respect to its relative importance to the function and to the elements served by the function.

Facility - a distinct operational unit that may be independently evaluated relative to the elements it serves or affects in its environment.

Function - a service or product a facility provides or an effect it produces on one or more elements in its environment.

Function Assessment Standard - The evaluation of a function considering the vital and the nonvital data assessment results.

Inventory Data - information which is qualitatively descriptive of a function. Data best suited is that used in current practice to design or develop similar functions for new facilities and site observations, measurements, and evaluations.

Nonvital Data Assessment Standards - evaluation of inventory data items not relative to human health in terms of their essentiality to the function they describe and in terms of the efficiency expressed by the interactive effects of performance and capacity of the function.

Performance - a data assessment standard representing a standard of observed or measured service the function provides to the elements in the environment of the facility.

Relative Importance Factor - a relative importance to the human element is assigned to each function. The sum of the relative importance factors for all functions in the facility will equal unity.

Safety - a data assessment standard representing a standard of health and safety of the human element in contact with the function.

Serviceability - the function assessment based on the evaluation of its composite vital and nonvital data assessments.

Sufficiency Rating - the facility assessment based on the sum of the products of the serviceability of each function and its respective relative importance factor.

Utilization - a data assessment standard representing a standard of observed or measured service provided the human element served by the function.

Vital Data Assessment Standards - evaluation of inventory data items relative to human health in terms of their essentiality to the function they describe and in terms of the efficiency expressed by the interactive effects of utilization and safety on the human element.

First the facility must be clearly defined and so must its functions. A facility can be defined as a bridge or a segment of highway, an office unit or an office building, or a production unit or a production plant. A facility's functions can be divided into two somewhat related categories; the facility's objective(s) and its interaction with the human element. Facility objectives for example would be to convey automobile and truck traffic, provide office rental space or produce gasoline. Interaction of a facility with elements in its environment is inevitable. Environmental safety and comfort of the elements in contact with or affected by the facility and its contribution to their general welfare are the usual interactions to be sought to identify functions.

Once the several functions have been defined, an inventory data set is defined to adequately describe

each function in terms of vital and nonvital assessments. The best source of data for a function's assessment is the parameters currently used to design the same function for a new facility. Another source of data is a systematic process of on-site observations, measurements, and evaluations. An example of standardized reporting for on-site measurements, observations, and evaluations is the following condition ratings in a convenient numerical form which are particularly valuable for multi-facility evaluations:

- 9 New condition - no maintenance recommended
- 8 Good condition - no maintenance recommended
- 7 Fair condition - recommend maintenance on minor items
- 6 Fair condition - recommend maintenance on major items
- 5 Poor condition - recommend major rehabilitation
- 4 Poor condition - minimally adequate to operate with current use
- 3 Poor condition - inadequate to operate with current use - recommend restricted operation
- 2 Critical condition - inadequate to operate with current use - recommend minimum restricted operation
- 1 Critical condition - inadequate to operate with current use - recommend ceased operation until rehabilitated
- 0 Critical condition - inadequate to operate with current use - recommend ceased operation until replaced

Note: Condition Ratings 4, 3, and 2 will generally require the major rehabilitation recommended in Condition Rating 5, but prevailing conditions make the immediate concern, restricting operations, more important. If a facility or facility function is planned for another use, substitute the word "planned" for "current".

Each function identified will require evaluation of its importance relative to the importance of the other facility functions. The evaluation assigns a total importance of unity to the (n) facility functions. The relative importance (I_i) of each facility function will be identified by its assigned portion of unity as demonstrated in Equation 1.

$$\sum_{i=1}^n I_i = 1 \quad (1)$$

After the inventory data for a function has been selected, it is necessary to develop data assessment standards to evaluate the function described. It is convenient to divide the inventory data into two (2) distinct groups, vital and nonvital data. Vital data is descriptive of a function operation which directly affects element safety relative to utilization such as a structure's integrity versus the applied live load. Nonvital data is descriptive of a function operation in terms of performance relative to capacity and does not directly relate to element safety or utilization. Nonvital data might be considered those items associated with creature comforts such as heating, ventilation, and air conditioning and lighting. The data assessment standards are mathematical functions or data ranges which define standards of service.

Each function is assessed independently as a direct result of its associated inventory data assessments. The function assessment standards can be defined in common generic terms. The function may be appraised as being in either desirable, adequate, tolerable, or inoperative condition. A useful numerical evaluation for a facility function assessment

is in the form of appraisal ratings such as:

- 9 Better than desirable standards
- 8 Equal to desirable standards
- 7 Better than adequate standards
- 6 Equal to adequate standards
- 5 Tolerable conditions
- 4 Tolerable conditions - recommend rehabilitation
- 3 Intolerable conditions - recommend rehabilitation
- 2 Inoperative - recommend rehabilitation
- 1 Intolerable conditions - recommend replacement
- 0 Inoperative - recommend replacement

The appraisal ratings are directly applicable to establishing data assessment standards because of the direct contribution of the data assessment to the function assessment. The efficiency of the vital and nonvital data, (V_{ij}) and (E_{ij}) respectively, is the percent effectiveness of the function operation the data describes. The efficiency can be numerically related to the appraisal ratings if they are used. Each item of data must also be evaluated for its essentiality to its related function. The essentiality (K_{ij}) is the proportion of unity assigned each of the (m) items of data demonstrated by Equation 2.

$$\sum_{j=1}^m K_{ij} = 1, i = 1, 2, 3, \dots, n \quad (2)$$

The serviceability (S_i) of a facility function is computed by summing the products of the efficiency and essentiality of its related data. The serviceability is the percent effectiveness of the function as determined by its assessment results demonstrated in Equation 3.

$$S_i = \sum_{j=1}^m (E_{ij} + V_{ij}) K_{ij}, i = 1, 2, 3, \dots, n \quad (3)$$

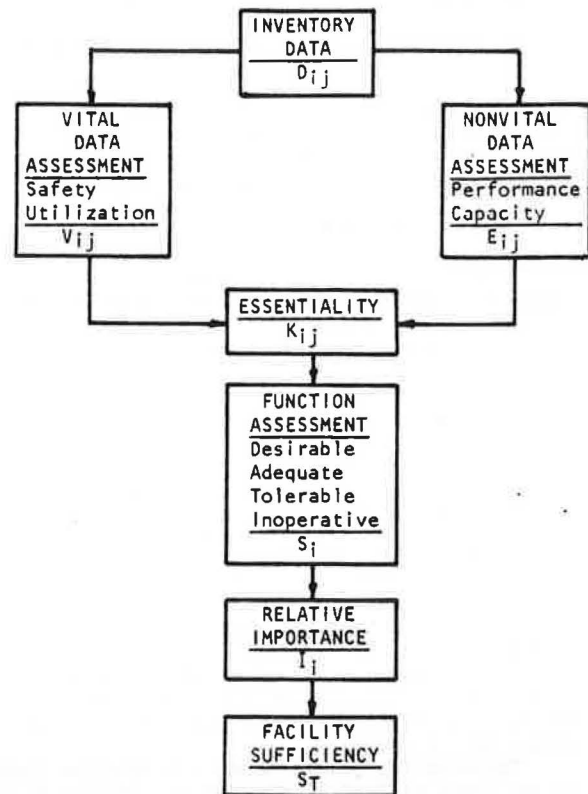
where (E_{ij}) or (V_{ij}) is zero when it is a vital or nonvital data assessment respectively.

The sufficiency rating (S_T) for the total facility is computed by summing the products of the serviceability and the relative importance of the facility function as demonstrated by Equation 4. The sufficiency rating is then a composite of the serviceability modified by the relative importance of each function resulting in a percent sufficiency for the facility.

$$S_T = \sum_{i=1}^n S_i I_i \quad (4)$$

In retrospect the process for evaluation of facilities for human use as presented provides a guideline which will aid the engineer or other specialists in communicating complex technological evaluations. This is accomplished by reducing the evaluation results into layman's terms such that the input and output can be easily comprehended by all parties involved. Facilitating effective input into the evaluation process and reducing its results to layman's terms makes it attractive as a communication tool. An equally important feature is that the evaluation implementation process leads to a strategic selection of inventory data (D_{ij}) which best describe and thereby evaluate a facility. The facility function serviceability provides easy access to the magnitude of functional problems affecting the sufficiency evaluation. The complete evaluation process is demonstrated by the flow chart in Figure 1.

Figure 1. Sufficiency evaluation flow chart.



Bridge Replacement Priorities

The facility for human use shall be defined as a highway bridge. The facility functions normally provided for through the design process for bridges are structural and geometric. Structurally the bridge design provides the required strength to routinely accommodate legal weight vehicles and the reserve strength to accommodate occasional overweight vehicles. Geometrically the bridge design provides for a high probability of success in negotiating the bridge site for the motorist. Geometrics account for the psychological and physical limitations of the driver and also for the performance, dimensions, speed, and volume of the vehicle expected to use the facility.

Another function which the highway bridge design must provide for, is adequacy of opening or underclearances for the facility or geographic barrier bridged over. The underclearances for underpassing highways, railways, or navigable waterways and the adequacy of opening for drainage through the bridge site must be included in the assessments when applicable. The regional significance of the bridge is also a facility function to be assessed. Regional significance is measured by the regional importance of the route the bridge is on, the detour distance which would be necessary to by-pass the bridge if it were lost from service and the volume or traffic served by the bridge.

With the facility functions for a highway bridge thus defined, it is now necessary to determine what inventory data sets would be most suited to evaluate each of them. The functions were identified from the design process. Most of the inventory data can also be selected from the design process.

The design strategy is to determine the structural and geometric standards which are desirable for a planned bridge. Consideration is given to the

planned and actual significance of the highway and bridge as a transportation link. This provides the standards of highway traffic expected in terms of speed, volume, size, and weight. The bridge is fitted to its site for the required underclearances and other site requirements while meeting the necessary geometric and structural standards for highway traffic.

The evaluation strategy is to assess the structural and geometric capabilities of an existing bridge using assessment standards compared with the actual traffic characteristics and also assess the underclearance needs with respect to those provided. The difference between design and evaluation is simply the difference between prescription and appraisal respectively.

Facility Function Considerations

Structural Evaluation. The AASHTO Standard Specifications for Highway Bridges (11) provides for hypothetical trucks and lane loads in terms of the designations H20-44 and HS20-44 for example. These design loads simulate actual traffic loads for structurally proportioning bridges in the design process. The AASHTO Manual for Maintenance Inspection of Bridges (8) provides for the evaluation of bridge components by specifying stress carrying capacity in terms of the "inventory" load producing the design stress and the "operating" load producing an infrequently allowed stress such as that for a permitted overweight vehicle. The "operating" load stress is allowed on a more frequent basis provided that the rate of surveillance is greater than that for structurally adequate bridges.

The inverse of the design process is applied. The structural capacity of a component is computed and the dead load stress effects are applied. The resulting stress available for live load is consumed by an H, HS or other vehicle configuration with axle weights in the same proportion as provided for in the specifications. A direct comparison between current design load and the evaluated load is then possible. A common denominator is provided for by this method comparing the results and the evaluation processes for bridges.

Geometric Evaluation. The geometric evaluation of a bridge and its site is concerned primarily with those parameters which affect the ability of a vehicle and its driver to successfully traverse them. Under clearances will be taken as a geometric evaluation based on the specific needs of the underpassing functions. These parameters can be obtained from field measurements or from original plans when available.

The stopping sight distance as defined in A Policy on Geometric Design of Rural Highways (2) is the distance at which a vehicle driver can detect an object of a given size in the roadway. This distance is associated with vehicle speed and the time required for the driver to react and physically stop the vehicle before passing the object. A direct evaluation between the measured stopping sight distance and the speed limit is possible.

The approach roadway width compared to the clear roadway width of the bridge deck is another significant parameter affecting safety. There is a direct correlation between the two and the traffic accident rate. The most serious of these conditions is when the bridge roadway width is narrower than the width of the approach roadway. The accident rate dramatically increases for this condition. (7) Some other geometric considerations which require evaluation are the number of highway lanes provided by the structure, presence of one-way or two-way traffic and vertical clearance provided by through structures with elements over

the roadway. The under clearance requirement is evaluated from the specific underpassing function need.

Condition Rating. The structural and geometric information can be obtained from direct field measurements and sampling or from plans and specifications when available. Another form of evaluation which plays a significant part in the overall evaluation is the condition rating. It represents a relatively subjective view based on field observations of individuals trained and experienced in such observations.

The condition rating is an analysis of observed site conditions and resulting recommendations which may stipulate corrective actions to improve or repair observed deficiencies. The condition rating as previously presented in a standardized format is suitable for multiple facility evaluation where hundreds or even thousands of facilities are to be compared to established repair and/or replacement priorities. This approach lends itself well to numerical evaluation. It is also helpful to divide the site and the bridge into components or inspection items and rate each one by a performance criteria as an aid to making the condition rating judgement. These ratings will be of great value in determining specific maintenance needs and repair priorities for large multiple facility systems. Performance ratings may take the following form:

- 9 The item is in new condition with no repairs necessary.
- 8 The item is in good condition with no repairs necessary.
- 7 The item is in good condition, but is in need of minor repairs.
- 6 The item is performing the function for which it was intended, but is in need of minor repairs.
- 5 The item is still performing the function for which it was intended at a minimum level, but is in need of minor repairs.
- 4 The item is still performing the function for which it was intended at a minimum level, but is in need of major repairs.
- 3 The item is still performing the function for which it was intended at a minimum level, but is in need of replacement.
- 2 The item is not performing the function for which it was intended and is in need of minor repairs.
- 1 The item is not performing the function for which it was intended and is in need of major repairs.
- 0 The item is not performing the function for which it was intended and is in need of replacement.

Regional Significance Evaluation. The regional significance of a bridge can be accounted for through the functional classification of the route the bridge is on and the net by-pass detour length. The net by-pass detour length is the extra distance which would be required to route the through traffic on a comparable facility which could accommodate the volume and character of the traffic currently using the bridge. These parameters should be used to independently evaluate regional significance of the bridge. The regional significance is incorporated into the selection of several data assessment standards such as volume of traffic to select the appropriate data assessment standards for the roadway width or number of lanes provided by the bridge. Regional significance is therefore not entirely an independent function.

Why have an independently evaluated regional significance? The subtle effect of regional significance

Table 1. Inventory data and related functions.

Structural Function	Geometric Function	Regional Significance Function
Inventory rating	Stopping sight distance	Average daily traffic
Operating rating	Bridge roadway width	Net by-pass length
Condition rating	Approach roadway width	Functional classification
	Vertical clearance over roadway	
	Underclearances	
	Condition ratings	

cannot be controlled or measured by its effects on the data assessment standards. By providing a separate function, the effect can be controlled and recognized in the total evaluation.

Inventory Data. The inventory data established thus far for the evaluation of a highway bridge facility is summarized in Table 1. There will be obvious questions raised about the choice of inventory data. As an example, some would question why the accident records are not included in the data as geometric inventory data. The answer is that the accident rate at a given bridge site would have a high correlation with geometric problems already described and therefore it would not be independent data. Also, raw accident data does not provide the cause of a series of recurring accidents unless uniform reporting procedures of traffic accidents are sufficient enough that review of the individual reports can determine the cause.

The functions chosen were arbitrary. Another approach would have been to combine some of the functions into "provide safe transit through bridge site". This would include all the inventory data items under structural and geometric functions except underclearances. Any valid choice of function and complete analysis should lead to an appropriate and valid inventory data set. A limitation of selecting an all encompassing function is the lost opportunity to review the results at the more detailed function definitions. An example of further expanding the functions would be to separate underclearance, bridge geometry, and approach geometry as separate functions.

Relative Importance of Functions

The obvious need for structural integrity should require that the structural function receive a substantial part of the relative importance. The safety aspects involved in the potential for collapse are onerous relative to structurally deficient bridges. However, it should not be overlooked that nine out of ten highway deaths associated with bridges are those related to geometric deficiencies.⁽¹²⁾ The regional significance of a bridge should also play a role in determining priorities.

The goals of a replacement program should be reviewed in determining the relative importance assigned to the various functions. If the goal is to replace structurally deficient bridges, regardless of other operational characteristics or regional significance, the choice of relative importance factors is trivial. The relative importance would be unity for the structural function and zero for all others. If the goal is to replace structurally deficient bridges of regional importance, the regional importance function would share some relative importance with the structural function for example 0.2 and 0.8 for the regional

importance and structural functions respectively.

The factors which affect the need for replacement are considered for each defined function in proportion to its contribution to the goals of the program when selecting the relative importance value. Values representing the goals of three replacement programs are shown in Table 2. Policy I gives the structural function the prime consideration with slight modification by the geometric and regional significance functions. Policy II gives a strong significance to the geometric and regional importance functions coupled with the structural function. This may be more in line with the real needs for consideration of highway bridge replacements. Policy III places heavy emphasis on the regional importance function especially in the view that items in its inventory data set will be used in setting data assessment standards for other functions. The benefits that may be derived from a replacement program based on Policy II compared with Policy I is a greater reduction in fatal traffic accidents associated with the replaced bridges at a slightly higher risk of collapse from those structures not replaced as soon with Policy II as they would have been with Policy I. The benefits associated with Policy III might be improved capacity of bridges on principal arterials at the sacrifice of higher risk of collapse of structures on secondary roads which would have been replaced sooner by Policies I or II. However, the exposure to the dangers of collapse may actually be reduced for the total motoring population by Policy III. It is possible that there may be significantly more traffic and therefore more exposure to collapse of bridges on the principal arterials which would remain by following Policies I and II. For the purpose of this example, Policy III will be used.

Table 2. Relative importance assignments to functions.

Function	Policy I	Policy II	Policy III
Structural	.60	.50	.50
Geometric	.30	.40	.30
Regional significance	.10	.10	.20

Serviceability of a Function

The serviceability of each function may be derived from a direct relationship established between the previously presented appraisal ratings which are a numerical approach to the function assessment. The serviceability is associated with a percent effectiveness a function has, based on its assessment. The serviceability could be arbitrarily assigned as

Table 3. Assigned serviceability percentages for appraisal rating values.

Appraisal Rating	Serviceability Percentage	Appraisal Rating	Serviceability Percentage
9	100	4	84
8	100	3	64
7	100	2	36
6	100	1	0
5	96	0	0

Table 4. Structural appraisal limits.

ADT ^a	Desirable	Adequate	Tolerable	Inoperative	Rating
Over 1,500 ^b	HS20	HS20	HS15	-	Inventory
	-	-	HS20	HS2	Operating
750-1,500	HS20	HS15	-	-	Inventory
	-	HS20	HS20	HS2	Operating
Less than 750	HS15	-	-	-	Inventory
	HS20	HS20	HS20	HS2	Operating
-	9,8	7,6	5,4	1,0	Condition ^c

^aADT is not applicable with condition ratings.

^bAll principal arterials.

^cCondition Ratings of 3 and 2 are in the intolerable range.

demonstrated in Table 3.

The boundary conditions selected are the appraisal ratings 9, 8, 7, and 6 will have a serviceability of 100 percent and the appraisal ratings 1 and 0 will have a serviceability of 0 percent. The remaining task is to select a reasonable declining scale between 6 and 1 based on the relative need for replacement of the facility stated in appraisal ratings 5 through 2. An estimate of these values is represented by a second degree parabolic function with zero slope at the appraisal rating of 6 as a third boundary condition.

The serviceability is ordinarily determined directly from the inventory data assessment using the efficiency and essentiality. This is a particularly valuable alternative when several data assessments are involved for a function. In this alternative, the efficiency will be determined in the same way as described here for serviceability.

Data Assessment Standards

The data assessment standards convert the inventory data into an efficiency through mathematical functions or ranges of data. The efficiency is described in terms of appraisals which are either desirable, adequate, tolerable or inoperative. For highway facilities, there is a wealth of information available for assessing some of the inventory data. (1,2,4,5,6,7,8,11)

Structural Function Inventory Data. The structural evaluation is accomplished by developing a table of inventory and operating loads and condition ratings which are characterized as one of the four stated appraisals describing the function. Table 4 is a policy for the efficiency evaluation of the data for the structural function.

Though Table 4 is presented using all HS type loads, it can be converted for other load types. The condi-

tion rating used in the evaluation would be the lowest of those associated with the bridge structure exclusively. The efficiency of the structural rating and the condition rating are expressed with the same values used for serviceability and the essentiality is expressed as .75 and .25 of their efficiencies respectively.

Geometric Function Inventory Data. The geometric function for this example is divided into two functions to provide more detailed significance at the function level. These functions will be bridge geometry with an assigned relative importance of .20 and approach geometry and underclearances with an assigned relative importance of .10.

The stopping sight distance limited by the approaches to the bridge ends and limited by the bridge itself is applied in part to the appraisal ratings of the approach geometry and the bridge geometry respectively. The data assessment standards for evaluating the desirable criteria for the stopping sight distance (SSD) are common to both applications and a policy is demonstrated in Table 5. The adequate criteria is represented by the posted speed limit or advisory speed for the location equated to its corresponding wet pavement stopping sight distance. The tolerable criteria is represented by the posted speed limit or advisory speed for the location equated to its corresponding dry pavement stopping sight distance. The condition ratings for the bridge roadway and the approach roadway are included in the assessment with the same appraisal limits demonstrated in Table 4. The inoperative criteria is not considered applicable to geometric function assessments.

The bridge roadway evaluation policy demonstrated in Table 6 and Table 7 is a component of the bridge geometry function evaluation which will also include the stopping sight distance, condition rating and the vertical clearance. The essentiality of the inventory data are expressed by allocating .50 of the lowest

Table 5. Desirable criteria for Stopping Sight Distance

Functional Classification	Average Daily Traffic	Speed (Km/h)	Wet Pavement SSD(m)
Principal arterial	Over 3,000	110	210
Principal arterial	3,000 or less	95	150
Minor arterial	750 or less	70	95
Other	400 or less	65	80

Note: 1 Km/h = 0.62 mph; 1 m = 3.28 feet.

Table 6. Desirable criteria for bridge roadway width.

Functional Classification	Average Daily Traffic	Roadway Width (meters)
Principal arterials	Over 12,000	15.2 ^a
	12,000-3,000	11.6 ^a
	Less than 3,000	12.2
Minor arterials	1,500-751	12.2
	750-400	8.5
	Less than 400	8.5

Note: 1 meter = 3.28 feet

^aTwin structures are required.

Table 7. Adequate and tolerable criteria for bridge roadway width.

Average Daily Traffic	Adequate Roadway Width (meters)	Tolerable Roadway Width ^a (meters)
Over 1,500	11.0	9.1
1,500-751	9.8	7.3
750-401	8.5	6.7
400-250	8.5	6.7
Less than 250	7.9	6.1

Note: 1 meter = 3.28 feet

^aRoadway width shall not be less than the approach roadway width.

efficiency value between the roadway width or vertical clearance and .25 of the efficiency of the stopping sight distance and condition rating each.

The vertical clearance evaluation through a bridge structure is not as complex in application. For example; a vertical clearance policy of 4.9 meters can be taken as the desirable criterion, 4.6 meters as the adequate criterion and 4.3 meters as the tolerable criterion.

The underclearance and approach geometry are also components of the bridge geometry function. The approach geometry is evaluated as previously shown by the least stopping sight distance from the bridge ends and the condition rating. The essentiality of these inventory data items are expressed as .60 and .20 of their respective efficiencies.

The underclearance evaluation can not be assessed in a uniform manner. The vertical and horizontal underclearances and other dimensional requirements will be dependent on the unique services under the bridge or the hydrological characteristics of a stream. This evaluation must be done independently for each bridge. An essentiality of .20 is assigned to this inventory data assessment.

Regional Significance Function Inventory Data.

The regional significance evaluation is a measure of the impact of the increased costs to transportation if the bridge were suddenly lost from service. Additional data is collected to compare the cost of the replacement structure to the increased cost of transportation. The increased cost for transportation is due to the detour distance added per vehicle over the time required to restore bridge service. The approximate replacement cost and time required before bridge service could be restored can be estimated from the physical size of the existing bridge. The cost per mile for operation of the average vehicle can also be estimated.

An appraisal rating for regional importance would have no significant meaning. A mathematical function (Equation 5) is developed which directly computes the function's serviceability. The regional significance of a bridge can be thought of as independent of its condition. In this instance it is the regional significance of the bridge relative to its current adequacy which is of interest. This will require that the regional significance appraisal be performed last such that the results of the remaining function serviceabilities can be used.

$$S = \left[1 - F \frac{C_t}{C_b} \left(\sin \pi \left(\frac{20 + S_T}{80} \right) + 1 \right)^{1/a} \right] 100 \quad (5)$$

The variables in this equation are the regional significance function serviceability (S), the functional classification factor (F), the total increase in transportation cost (C_t), the bridge replacement cost or a base cost (C_b), the sufficiency if the regional significance function serviceability were 100 percent (S_T), and an arbitrary constant (a). The arbitrary constant (see figure 2.) is taken as 2 and the functional classification factor is taken as 1.00 for principal arterials, 0.95 for minor arterials and 0.90 for other roads. The value of (F C_t/C_b) should not exceed unity. The total increase in transportation cost is the product of the average daily traffic, the estimated time required to restore the bridge to service in days, the net bypass detour length and the cost per unit length traveled per vehicle.

Sufficiency of a Facility

As previously presented, the sufficiency of a facility is a percentage determined from multiplying the serviceabilities by the relative importance and summing the resulting products. Depending upon the goals of the replacement programs as previously discussed the bridge with the lowest sufficiency percentage should have the highest replacement priority. In order to calibrate the algorithm to obtain the desired goals of a replacement program, substitute several different sets of relative importance values and review the priority sequence of bridges obtained. Continue this process until the desired results are obtained. It should be realized that the desired results are obtained only in a general sense because there are no absolutes in the comparison of deficient bridges requiring replacement.(9)

Ordering priorities

The established goals represent benefits expected from a facility. They provide the scale to measure the sufficiency or a percent of the benefit provided by a facility. The benefit of replacing or repairing a facility can be directly measured by the percent

increase in a facility's sufficiency once an action is complete.(3) With the inclusion of the cost of the action in the inventory data, the cost-benefit ratio can be compared and priorities can be reassessed to maximize benefits at the least cost.

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Figure 2. Effect of the arbitrary constant (a) on the regional significance function serviceability (Equation 5).

