SYSTEMS APPROACH TO BRIDGE STRUCTURE REPLACEMENT-PRIORITY PLANNING

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This paper presents a systems approach to the bridge structure replacement-priority planning. Structural condition and functional adequacy; safety; essentiality to traffic and other criteria for setting replacement priority are developed and evaluated. Budgetary, environmental, developmental, policy and other constraints on the replacement priority are identified and analyzed for their possible impact. A quantitative methodology is developed, based upon assignment of weights to the rated criteria and is illustrated step by step through a flow chart. Guidelines are provided to easily adapt use of this methodology to meet the needs of an individual area or policy, for a rational determination of long-range programming.

In recent years, the number of structurally deficient and functionally inadequate bridges has increased at an alarming rate. This increased number has made it imperative for agencies responsible for bridges to include bridge-replacement, in a major way, in their planning and programming process. A logical, consistent and comprehensive evaluation of an agency's bridge-replacement needs thus becomes necessary, not only to accomplish a rational and equitable distribution of limited public funds but also to ensure public safety. The systems approach, based upon use of factual data, can facilitate such a logical, consistent and comprehensive evaluation.

Systems Approach

The system for replacement-priority planning can be described as a step-by-step procedure following clearly defined guidelines to accomplish the priority planning process (see Fig. 1: Flow-chart). A comprehensive formulation of the priority planning process; characterizing various structural, functional, safety, traffic-related, economic and other aspects; is described by the following: Objectives, system inputs, criteria, constraints, evaluation and system output.

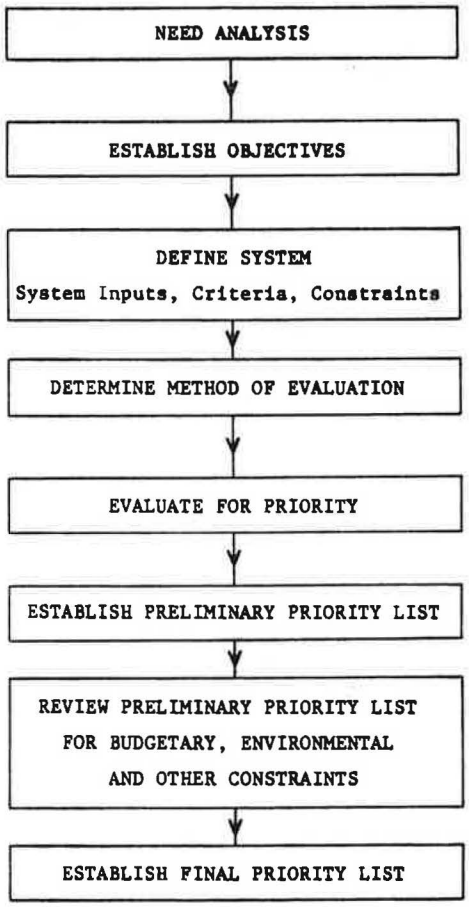

Figure 1. System flow chart for bridge replacement priority planning.

Table 1. Bridge replacement-priority rating.

Item	Number of Points: Individual Sub-category	Number of Points: Range for Category
I. Structural Condition and Functional Adequacy: (from Table 2):		0-40
a. Estimated Remaining Life	0-5	
b. Structural Condition Appraisal	0-15	
c. Deck Width	0-5	
d. Approaches and Alignment	0-5	
e. Overclearances	0-5	
f. Underclearances or Waterway Adequacy	0-5	
II. Safety: (from Table 3):		0-25
a. Safe Load Capacity	0-16	
b. Safety Appraisal (Frequency and Type of Accidents, % Correctible, User Complaints, Potential Hazards)	0-9	
III. Essentiality to Traffic: (from Table 4)		0-35
a. Traffic Demand (Present & Projected A.D.T., Peak Hour Traffic, Volume/Capacity ratio)	0-16	
b. Area Served (Planned or Projected Development)	0-8	
c. Alternate Route (Length @ Average speed...., Access to Metro-scale or similar facility, Link in Commercial and Industrial network of Out-state Significance)	0-8	
d. Road System	0-3	
RATING		0-100

Objectives

Objectives of this systems approach are to evaluate and rate the relative importance of all bridge structure replacement needs on the basis of clearly defined criteria and constraints, and arrive at a bridge-replacement priority list. The ultimate aim of this systems logic is to take into account all those aspects that truly influence the optimal or near optimal use of public funds.

System-inputs

An up to date and complete data-base (Tables 1, 2, 3 and 4) shall provide inputs for a rational replacement-priority planning. These system inputs, which utilize basic inventory and inspection data, are divided into the following sections:

Structural Condition and Functional Adequacy. Annual physical inspection reports by qualified staff provide information about estimated remaining life of the existing structure, condition of its superstructure (i.e., deck, stringers, etc.) and substructure (i.e., abutments, piers, and footings). Further, these reports indicate the type, extent, estimated costs of needed improvements, and replacement cost; as well as data for appraisal of deck-width, approaches, alignment, clearances and waterway adequacy.

Safety. The safe load carrying capacity (@ 0.75 of yield stress) and safety appraisal of the existing structure is given in this section. It provides information about frequency and type of accidents related to the structure, potential hazards, percentage of hazards and causes of accidents that are correctible, as well as user complaints.

Essentiality to Traffic. This section provides information about the present and projected Average Daily Traffic, Peak-hour traffic, and volume/capacity ratios. Further, it provides information about area served by the existing bridge, which is determined by using origin-destination studies (i.e., planned or projected development of the area and effect on its tax-base); alternate route (i.e., its length and impact on travel time or energy use); and the road-system (i.e., relative importance in overall transportation network).

Criteria

Criteria for developing a bridge replacement-priority list are factors or types of considerations that go into comparison of existing bridge structures. The first group of criteria relate to structural condition and functional adequacy of bridges. Estimated remaining life sets the time limit within which the bridge replacement is desired. Structural condition is compared on the basis of the ability of a structure to perform according to present acceptable standards. Comparison of deck-widths is based on the latest AASHTO (or equivalent) recommendations (1,2,3,5,6). Criteria for acceptable approaches and alignment relate to their effect on traffic flow and may influence early structure replacement. Overclearances, underclearances and waterway adequacy are judged against the current minimum AASHTO (or equivalent) recommendations (1,2,3,6). The second group of criteria relates to safety aspect of bridge structures. Criteria for safe load capacity are based upon legal vehicle loads. Safety of a structure is appraised on the basis of frequency and type of accidents as well as hazardous conditions and

their extent of correctibility. The third group of criteria pertains to essentiality to traffic. Structures are compared on the basis of their ability to meet traffic demand in terms of present and projected average daily (as well as peak-hour) traffic and traffic volume/capacity ratios. Planned or projected development of the area served by the bridge in terms of projected increase in its tax-base is used as a criteria for comparison. Alternate routes are compared on the basis of their lengths. Finally, the road systems are evaluated on the basis of their importance in the overall transportation network.

Table 2. Structural condition and functional adequacy.

	Rating
a. Estimated Remaining Life ("L" in years):	0-5 points
L > 20 years :	0 point
16 years ≤ L ≤ 20 years :	1 point
11 years ≤ L ≤ 15 years :	2 points
6 years ≤ L ≤ 10 years :	4 points
L ≤ 5 years :	5 points
b. Structural Condition Appraisal:	0-15 points
Good: Meets present requirements :	0 point
Fair: Needs minor improvements (@ costs 5% of replacement cost) to meet present requirements :	5 points
Fair to Poor: Does not meet present requirements, needs major improvements (@ costs 5% but 25% of replacement cost) to maintain in full service :	10 points
Poor: Does not meet present requirements, needs major improvements (@ costs 25% of replacement cost) to maintain in limited service :	15 points
c. Deck-width:	0-5 points
- Meets present desirable (i.e., better than AASHTO recommended or equivalent) requirements :	0 point
- Meets minimum (AASHTO recommended or equivalent) requirements :	1 point
- Does not meet minimum (AASHTO recommended or equivalent) requirements, but can be brought up to meet these requirements :	3 points
- Does not meet and cannot be rehabilitated to meet the minimum (AASHTO recommended or equivalent) requirements :	5 points
Note: Stable traffic flow with operating design speeds >65 kmh (40 mph): Desirable: 3.66 m.(12')/lane + 1.83 m. (6') distance from outside traffic lane edge to obstruction. Minimum: 3.66 m.(12')/lane + 0.61 m. (2') distance from outside traffic lane edge to obstruction. (not less than 9.75 m. (32 ft.) for 2 lane undivided roadway) Unstable traffic flow with operating speeds <65 kmh (40 mph): Desirable: 3.66 m.(12')/lane + 0.61 m. (2') distance from outside traffic lane edge. Minimum: 3.35 m.(11')/lane + 0.61 m. (2') distance from outside traffic lane edge to obstruction.	
Note: Sidewalk Widths: Desirable - 1.83 m.(6 ft.), Minimum - 1.22 m.(4 ft.)	
d. Approaches and Alignment:	0-5 points
- Do not adversely affect traffic flow :	0 point
- Slow down peak-hour traffic :	1 point
- Slow down traffic flow and affect Average Daily Traffic (ADT) :	3 points
- Slow down traffic flow, affect ADT and create traffic hazards which lead to accidents :	5 points
e. Overclearances (vertical and horizontal):	0-5 points
- Meet desirable (i.e., better than AASHTO minimum, or equivalent) requirements :	0 point
- Meet minimum (AASHTO or equivalent) requirements :	1 point
- Does not meet, but can be brought up to, minimum (AASHTO or equivalent) requirements :	3 points
- Do not and cannot be brought up to meet minimum (AASHTO or equivalent) requirements :	5 points
f. Underclearances (vertical and horizontal) or Waterway Adequacy:	0-5 points
- Meet desirable (i.e., better than AASHTO minimum underclearances or 100-year flood capacity plus 0.30 m.(1 ft.) freeboard) requirements :	0 point
- Meet minimum (AASHTO underclearances or 50-year flood capacity with 0.30 m.(1 ft.) freeboard) requirements :	1 point
- Do not meet, but can be brought up to above minimum requirements :	3 points
- Do not and cannot be brought up to meet above minimum requirements :	5 points

Table 3. Safety.

				Rating
a.	Safe Load Capacity (in W_L, gross weight):			0-16 points
	Closed to Traffic:		:	16 points
	Two Axle Vehicles	Three Axle Vehicles	Four or More Axle Vehicles	
	3 tons $\leq W_L <$ 8 tons	$W_L <$ 12 tons	$W_L <$ 12 tons	: 12 to 14 points
	8 tons $\leq W_L <$ 15 tons	12 tons $\leq W_L <$ 18 tons	12 tons $\leq W_L <$ 27 tons	: 8 to 11 points
	15 tons $\leq W_L <$ Legal	18 tons $\leq W_L <$ Legal	27 tons $\leq W_L <$ Legal	: 4 to 7 points
	Legal $\leq W_L$	Legal $\leq W_L$	Legal $\leq W_L$	: 0 to 3 points
b.	Safety Appraisal:			0-9 points
	- No recorded accidents/no obvious hazards noticed or reported			: 0 point
	- Accidents with minor vehicle damage reported/some hazards noticed and reported; hazards and causes completely correctible			: 2 points
	- Accidents with vehicle and structure damage, and bodily injury reported/ some hazards noticed and reported; hazards and causes completely correctible			: 4 points
	- Accidents with vehicle and structure damage, and bodily injury reported/ some hazards noticed and reported; hazards and causes partially (i.e., 50% or less) correctible			: 6 points
	- Accidents with vehicle and structure damage, and bodily injury reported/ some hazards noticed and reported; correction of hazards and causes economically not feasible, warrants replacement			: 9 points

1. AASHTO H-15 and H-20 Trucks[4].
2. AASHTO HS-15 and HS-20 Trucks[4].
3. AASHTO 3S2 and 3-3[4].
4. Use equivalent legal vehicle weights, if different.

Constraints

Various types of constraints or limitations generally control the bridge replacement priority planning process. The first group of constraints is of economic or financial type. Present and projected future available funds for a certain category of bridges can influence an early replacement of a lower rather than a higher priority bridge. A second group of constraints is environmental and local political factors, which have become prominent in recent years. Legitimate concerns of neighborhood groups can effectively prevent a bridge-replacement. The third group of constraints pertains to the consistency of the replacement priorities with local plans, civil defense needs and policies of the agency responsible for bridge replacement. Requirements of unusual length of construction periods that would unfavorably affect the economy of the area can influence priority. Finally, emergency situations, like accidents and failures as they develop can influence and change the replacement priorities. Experience has indicated that any of these constraints can move a bridge up or down on the replacement-priority list.

Evaluation

The method of evaluation devised for arriving at priorities for bridge replacement are based upon a form of numerical evaluation of factors that influence bridge-replacement. Such rating procedures have been proved to be the most satisfactory, realistic and factual means of evaluating highway needs and programming improvements (7). The factors pertinent to bridge replacement are grouped into Structural Condition and Functional Adequacy, Safety and Essentiality to Traffic. Points are assigned to these groups in the order of their importance. Table-1 indicates assignment of these points.

In assigning points to factors in the first group, structural condition and estimated remaining life are given fifty percent of weight of the group. The structural condition appraisal is based upon maintenance-economics. Deck-width, approaches and alignment, overclearances, underclearances and waterway adequacy are weighed equally. Table-2 indicates assignment of these points. In the second group, Safety, about two-thirds of the weight in assigning points was given to the safe load carrying capacity, since it is the single most important factor in bridge replacement. Table-3 indicates assignment of points for this group. The traffic demand is considered the most important factor in the Essentiality to Traffic group and is assigned about fifty percent of the weight. Minor weight was given to the Road System while area served and alternate route were weighed equally. Table-4 indicates assignment of points for this group.

A preliminary list according replacement priority is the outcome of this stage of evaluation process. The preliminary list is then reviewed for budgetary, environmental and other constraints, discussed earlier. This review process will result in the final list of bridge replacement priority. The weights assigned in Table-1 can be changed to adapt to an individual agency's policies, such as policies to upgrade all bridge crossings to meet minimum legal requirements. Further, this system can be adapted to prepare separate replacement-priority lists for bridges on certain classified routes in order to utilize specific sources of funds.

Table 4. Essentiality to traffic.

	Rating
a. Traffic Demand:	0-16 points
Present Bridge:	
- Will satisfy projected (10-year) Average Daily Traffic (ADT) and peak-hour traffic, with no adverse effect on traffic flow	0 point
- Will satisfy projected (10-year) ADT and present peak-hour traffic, with no adverse effect on traffic flow	3 points
- Satisfies present peak-hour traffic and ADT, (Present peak-hour traffic volume/capacity = 1 or less)	7 points
- Satisfies present ADT, (Present ADT volume/capacity = 1 or less)	12 points
- Does not satisfy present ADT of the route and has adverse effect on traffic flow, (Route ADT volume/capacity>1)	16 points
b. Area Served:	0-8 points
- No appreciable area tax-base increase (< 10% of present tax base, in real values) projected in 10 years	0 point
- Moderate area tax-base increase (10% - 50% of present tax-base, in real values) projected in 10 years	4 points
- Considerable area tax-base increase (> 50% of present tax-base, in real values) projected in 10 years	8 points
c. Available Alternate Route:	0-8 points
- Alternate newer or better direct access to metro-scale or similar facility is available, and/or better alternate link(s) to commercial and industrial network of out-state significance is available. (Alternate route length < 1.6 km @ 32 kmh (1 mile @ 20 mph) average, or < 4 km @ 80 kmh (2.5 miles @ 50 mph) average or equivalent)	0 point
- Alternate access to metro-scale or similar facility is available, and/or alternate link to commercial and industrial network of out-state significance is available. (Alternate Route length < 8 km @ 32 kmh (5 miles @ 20 mph) average, or < 20 km @ 80 kmh (12.5 miles @ 50 mph) average or equivalent)	4 points
- No direct access to metro-scale or similar facility, and/or no alternate link to commercial and industrial network or out-state significance is available. (Alternate Route length < 8 km @ 32 kmh (5 miles @ 20 mph) average, or < 20 km @ 80 kmh (12.5 miles @ 50 mph) average or equivalent).	8 points
d. Road System:	0-3 points
- Non-municipal and non-county State-Aid Roads	1 point
- Municipal or County State-Aid Roads	2 points
- Interstate or State Highways and Federal Aid Urban Roads	3 points

System-Output

This consists of a preliminary and the final bridge replacement-priority list in decreasing order of final rating points. The agency responsible for bridge replacement can utilize this priority list in its planning and programming process.

Conclusion

This paper has presented a systems approach to the difficult bridge structure replacement-priority planning. The approach is comprehensive in that it goes beyond the structural sufficiency to include consideration of all relevant factors. The numerical rating system devised makes an objective evaluation possible. This system is simple, uses linear interpolation, and is easy to understand. Further, it is adaptable and its results are easy to communicate.

References

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