Maintenance Planning for Trunk Road Structures in England

Parag C. Das
Highways Agency, United Kingdom

INTRODUCTION

The Highways Agency is a government executive agency and is part of the Department of the Environment, Transport and the Regions (DETR). It is responsible for the management of the trunk road network in England, which includes 16,000 structures most of which are bridges. Although the number of structures is modest compared to the national stock of some 150,000 bridges, the trunk roads in England carry one third of all traffic and more than half of all lorry journeys; as such, the maintenance of the structures on the network is of considerable national importance. Furthermore, the procedures and standards set by the Agency in managing its roads and bridges are nationally important because other highway authorities in the country normally adopt these.

Many of the current procedures used by the Agency for the maintenance of its structures were set up some years ago. The current structures database NATS is about 13 years old and is in urgent need of revision, in particular to take on board new developments in bridge management methodology and of computational tools. This has necessitated a thorough review of the Agency's needs in this area.

The review started in the early 90's with a comprehensive examination of the state-of-the-art in respect of bridge management systems carried out by consultants (*1*). The examination included many overseas developed systems, notably PONTIS and BRIDGET from the USA and the BMS's developed by the central road authorities in Denmark and Finland. This was followed by a Highways Agency in-house review of the overall structures management methodologies, including inspection, assessment and other maintenance procedures. This internal review was founded on the extensive R&D work already under development through various Highways Agency projects.

During the reviews detailed liaison was necessary with UK and overseas government officials, system developers, bridge engineers and academics, who have all been extremely helpful throughout. It can truly be said that the proposed developments which are described in the rest of this paper are largely an outcome of international cooperation.

The purpose of this paper is to describe in broad outline the methodology currently being used by the Highways Agency for planning the maintenance needs of its structures and the software systems which are under development.

BASIC PRINCIPLES

The management of highway structures involves a large number of activities, which can be broadly grouped as:

Structures inventory information
Inspection
Assessment

Maintenance bids, prioritisation and allocation
Works data and outturn
Network structures condition monitoring
Planning and forecasting
Database.

A bridge management system is a computerised system which supports all these activities. The activities depend on each other for input and output of information and usually take place in sequence. The overall information system, in the form of a database, has to be involved at each stage.

Broadly speaking, the currently available bridge management systems record the condition ratings of the structures and their elements as obtained from the inspections and then determine the most cost-effective maintenance strategies based on the optimisation of the whole life costs of available options. In order to determine future needs, the systems also incorporate future deterioration models for various elements in respect of different maintenance regimes and environments.

The Highways Agency's proposed system is entitled Structures Management Information System (SMIS). The process of bidding for and prioritising of funds is independent of the information database and is being developed as a 'stand-alone' system entitled Bid Assessment and Prioritisation System (BAPS). The intention is that, unlike in the other current BMS's, the project level bids will be prepared through assessments and then input into BAPS rather than determined directly by a computerised process. The following are the main reasons behind this decision:

1. The bids have to take account of many local issues (network related or otherwise) which cannot be dealt with in an optimisation process.
2. Most bridge maintenance works (repair/strengthening/replacement) are not directly related to the condition states of the structures. Experience gained from the Highways Agency's bridge maintenance activities indicates that the major part of the work depends on the load carrying capacity (or structural adequacy) of the structures rather than on their conditions alone. Of course condition is taken into account in the assessments.
3. Any funding for bridge maintenance has to compete with multitudes of other urgent needs of society; hence the case for such funding has to be very strong. The justification that the maintenance work will cost more later if the work is not carried out now is not very convincing, firstly because society has a preference for short term benefits, and costs later, and secondly because any calculations involving the prediction of future circumstances and events are surrounded by uncertainties. On the other hand, possible traffic disruptions resulting from large-scale weight restrictions imposed on unsafe bridges is likely to be a more compelling reason for justifying funds. Assessment based bids will identify the bridges that are unsafe at any point in time as well as those that may become so in the foreseeable future.

The rest of SMIS will be a general database, the detailed specification for which is still being developed. BAPS is more advanced and is intended to form part of the new maintenance planning process which will be discussed in some detail in the rest of the paper.

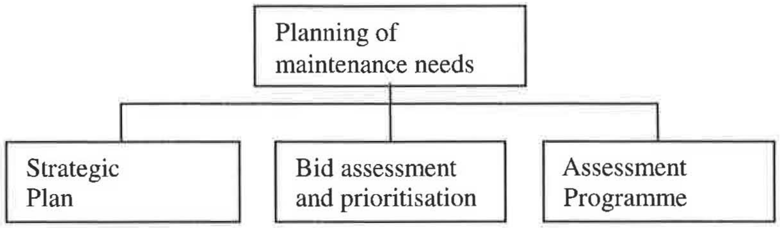


Figure 1: Maintenance planning process.

MAINTENANCE PLANNING

The maintenance planning process involves three steps as shown in Figure 1.

The first step in the process is to produce a strategic plan which would provide the future expenditure profiles for different types of maintenance work covering a number of years representing an ideal mix of work, in terms of both logistics and funding.

The second component, the annual list of maintenance bids, is made up of the bids determined for individual structures or structural elements by the maintaining engineers. Each bid consists of options of maintenance strategies determined on an individual basis, and the work items are input as work profiles for a 30-year period. The prioritisation of the bids for the purpose of allocation is then carried out by finding the best whole life cost option for each structure.

The third component, the assessment programme, ensures that the at risk structures are assessed at the right time so that the annual bids add up to the strategic plan expenditure items.

The following are more detailed descriptions of the maintenance planning process. It is assumed for the following procedure that all elements of a structure, whether it is a bridge deck or a bearing, will have a critical performance level (assessment level), normally related to safety considerations. If the performance of the element falls below this level (i.e., it is sub-standard) it has to be replaced or strengthened as soon as practicable. Such work is considered as "essential" or "rehabilitation" work. If the current performance is above this level, and yet some work is deemed to be justifiable on grounds of economy, such work is considered as "preventative."

STRATEGIC PLAN

A strategic plan was prepared by the Highways Agency in 1997 to determine its bridge maintenance needs for the future. For this purpose, the overall method was developed in-house by the Agency, the details of typical maintenance activities and costs were provided by Messrs G Maunsell Ltd and the background computation was carried out by the Transport Research Laboratory. The following describes the significant stages of this exercise.

The first year's strategic plan was based on an approximate methodology with the intention that different parts of the method will be improved upon in subsequent years. The costs were therefore grouped together into two items—preventative and rehabilitation.

The maintenance work items and their typical costs were based on examination of past records of work done for the Highways Agency's bridges. The following is a breakdown of the work types:

- Preventative work

  -Steelwork painting
  -Expansion joints
  -Waterproofing
  -Silane impregnation
  -Cathodic protection
  -Minor concrete repair, etc.

- Rehabilitation work

  -Major concrete repair
  -Deck/pier replacement
  -Posttensioned rehabilitation
  -Parapet upgrading
  -Bearing replacement, etc.

It should be noted that in addition to the above two types of work, routine maintenance of the Highways Agency's bridges is also carried out on a regular basis. This includes the following items:

- Routine maintenance

  -Inspections of different categories
  -Clearing drains, expansion joints and bearings
  -Minor repairs of paintwork
  -Minor concrete repairs
  -Cleaning graffiti, etc.

Routine maintenance is expected to continue at the current level for the foreseeable future and hence is not considered in this paper.

The next step was to divide the bridges into a number of distinct types such as concrete, concrete/steel composite etc., and to obtain, from the inventory database, the numbers of bridges of these types with their years of construction. This will provide information of the form shown in Figure 2. The different types were assumed to have different rehabilitation rates, with and without preventative maintenance, as shown in Figure 3. Figure 3 also shows the expected cycles of preventative maintenance. The triangular profiles in Figure 3 are an approximation based on expert opinion from bridge engineers. These are now being examined for future use with the help of maintenance records, and also using probabilistic analysis, in much greater detail.

The next step was to multiply the numbers of bridges built in any year with the assumed rates of rehabilitation to produce the numbers that will require rehabilitation in

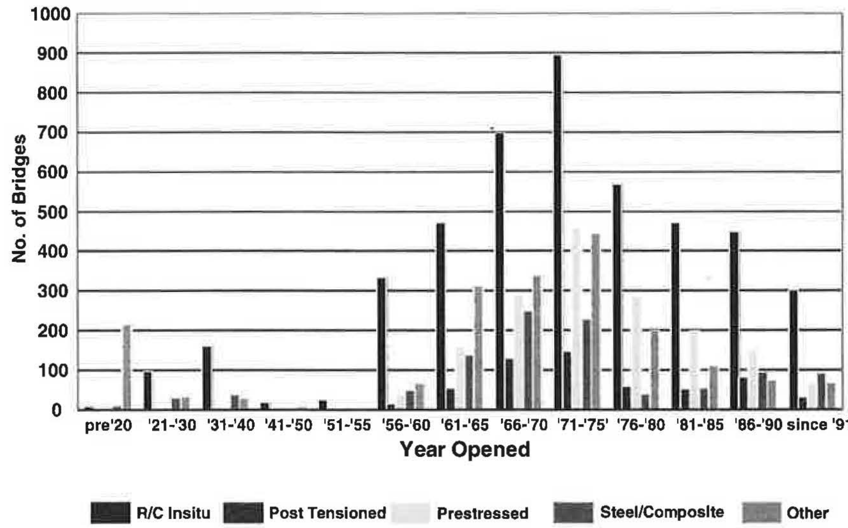


Figure 2: The Highways Agency's bridge stock by years of construction.

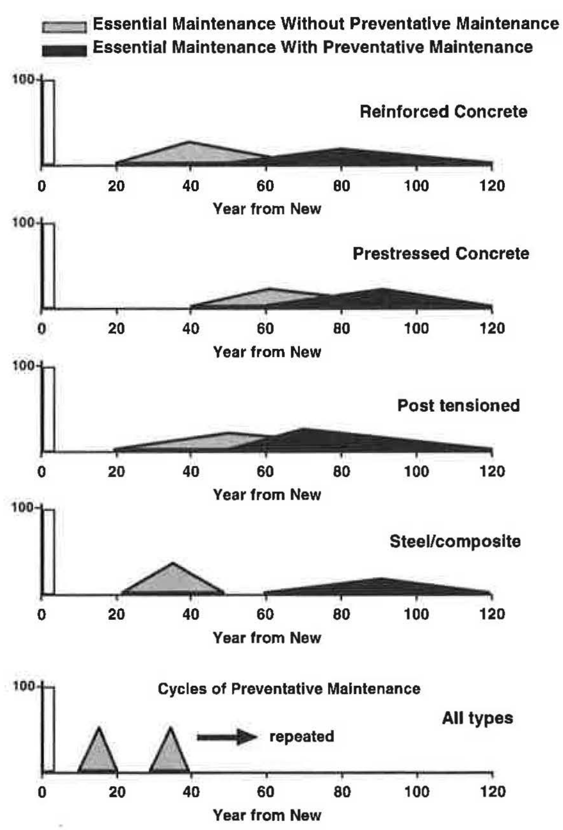


Figure 3: Rehabilitation rates and maintenance cycles for different bridge types.

the future years. For example, 200 reinforced concrete in-situ bridges were built in the year 1973. Numbers were also determined that would undergo preventative maintenance in any particular year, and it was found that these numbers could be averaged to be 7% of the total for all bridge types.

From the top diagram of Figure 3, it can be seen that 100% of the reinforced concrete bridges will need rehabilitation without preventative maintenance between the years 20 to 70 from construction, an average rate of 2% per year, with a peak of 4% at the 40th year from construction. Therefore, a total of 8 such bridges may need rehabilitation in the year 1973 + 40 = 2013. This can be seen in the in-situ line in Figure 4. The same procedure has been used for all of the four bridge types resulting in Figure 4 and Figure 5.

Numbers were also determined that would undergo preventative maintenance in any particular year, and it was found that these numbers could be averaged to be 7% of the total for all bridge types.

It was assumed that preventative maintenance covered items such as steelwork painting, replacement of expansion joints and waterproofing, silane impregnation, minor concrete repair, cathodic protection, etc. Rehabilitation work was assumed to cover concrete repair, deck or pier replacement, column strengthening, rehabilitation of post tensioned bridges, etc. Both types of work were costed using available cost data.

The next stage was to determine the appropriate maintenance strategy for each bridge type, i.e., whether preventative maintenance was justifiable in terms of the future

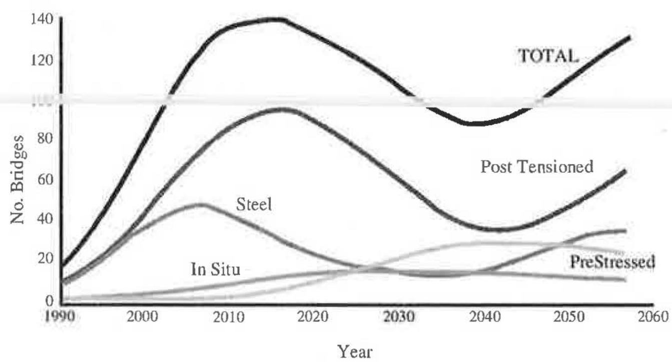


Figure 4: Predicted numbers of bridges requiring rehabilitation without preventative work.

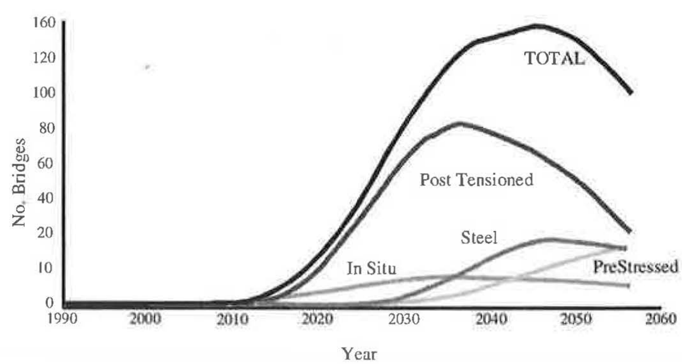
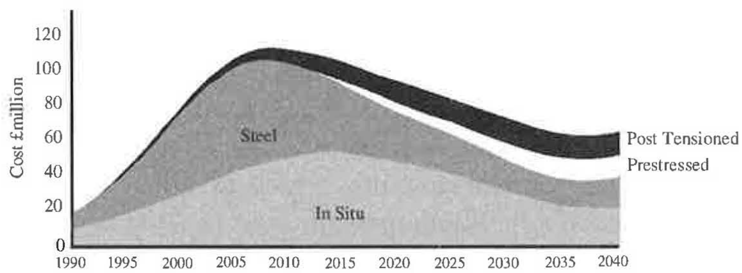


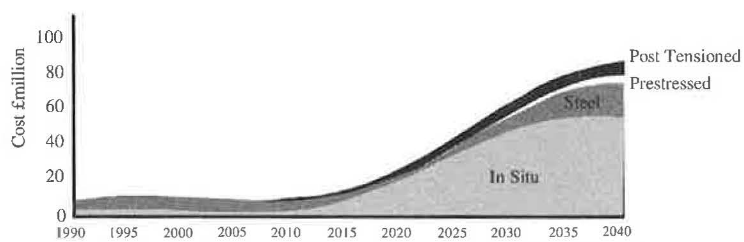
Figure 5: Predicted numbers of bridges requiring rehabilitation after preventative work.

needs of the bridge-stock. For this, the estimated numbers of bridges requiring rehabilitation and preventative maintenance in each future year were multiplied with the average unit costs of rehabilitation and preventative work in order to produce the total maintenance cost profiles for the future years. These are shown in Figure 6.

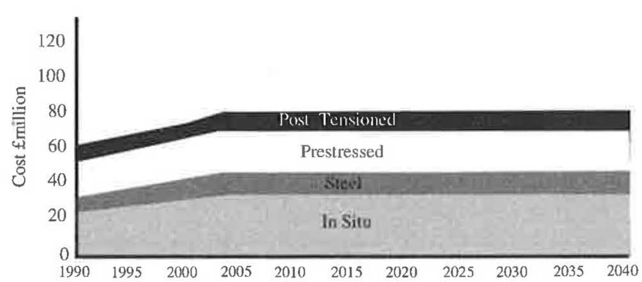
Figure 6(a) shows the rehabilitation costs when no preventative work is carried out. It shows that in such circumstances, the rehabilitation of steel bridges (second area from bottom), will be the biggest cost item in the near future, followed by the rehabilitation of in-situ reinforced concrete bridges. Figure 6(b) shows that most of this rehabilitation work will be postponed beyond 2025 if preventative actions are taken. Figure 6(c) shows that the cost of preventative actions is fairly constant, with high costs for in-situ concrete and pre-stressed concrete bridges. The cost of preventative work, i.e., painting, for steel bridges is relatively small.



(a) Rehabilitation cost without preventative work



(b) Rehabilitation cost with preventative work



(c) Cost of preventative work

Figure 6: Profiles of future maintenance costs.

From the three diagrams in Figure 6 it can be seen that, for the steel bridges, the cost of rehabilitation when preventative work is carried out together with the cost of the preventative work itself is much smaller than the cost of rehabilitation when no preventative work is undertaken, at least for the next 30 years or so. This does not appear to be the case for the other three types of bridges. If all the costs were discounted to present value, it is therefore likely that for types other than steel composite, the cost of rehabilitation with preventative maintenance would be greater than the cost of rehabilitation without preventative work. Hence for the rest of the calculations, preventative work was considered to be justifiable only for steel composite bridges in terms of periodic repainting, i.e., the cost for steel bridges was taken as the sum of the relevant (second from the bottom) areas of (b) and (c), whereas for the other types (a) was used. This is a surprising finding from this exercise, and has been taken as an interim conclusion for the purpose of the review and is at present being examined in more detail.

Based on the above assumptions, the future maintenance cost profiles for the Agency's bridges were calculated in terms of both essential (i.e., rehabilitation) and preventative work that may arise from possible future condition deterioration of the present bridge stock. As explained earlier, rehabilitation will be necessary when a structure becomes sub-standard, i.e., inadequate in terms of the assessment loading, and preventative work is the work done on structures which are not yet sub-standard. In addition to this cost, the cost of rehabilitating the present backlog of sub-standard bridges, already identified in the current bridge rehabilitation programme, was also included in the final profiles (see Figure 7).

PROJECT LEVEL BIDS

The strategic plan is intended to provide an overview of maintenance needs and in itself will not be sufficient for allocating funds, which requires the assessment of project level (i.e., structure related) bids.

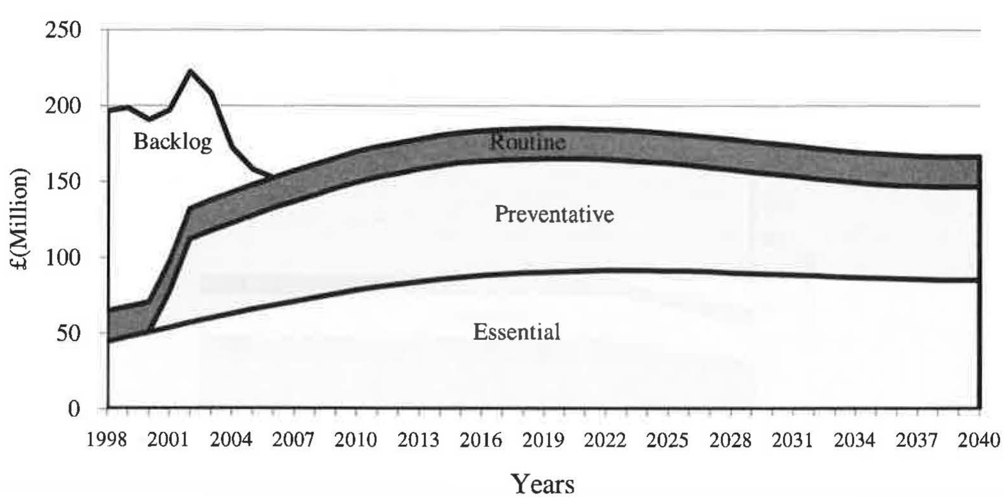


Figure 7: Maintenance expenditure profile.

The project level bids are based on whole life assessments (*2*), the process being as shown in Figure 8, where the current safety level is compared with the critical level (minimum acceptable level) appropriate for the element concerned to determine if the work is 'essential (rehabilitation)' or 'preventative.'

The performance of the element is then projected into the future using a number of alternative maintenance strategies. For example Figure 8 shows that the safety (structural capacity) level of Bridge 2 at present is below the acceptable minimum level. Hence it must be strengthened/replaced, or otherwise has to be weight-restricted until that is done. Bridge 1 is on the other hand at present structurally adequate, but offers a number of options. For instance, it can be (a) fully strengthened, (b) partially strengthened to maintain its current level of structural capacity, or (c) left to be replaced in the near future.

For each strategy option, and for each maintenance action in the strategy, the year of the action, various costs including planning, supervision and traffic management costs and, in addition, the traffic delay costs if the work is not carried out are submitted as bids. For instance in Figure 8, if the strengthening is not carried out for Bridge 2, it will have to be weight-restricted, which will result in traffic disruption. In the UK there is a standard method using a computer program QUADRO 3 (*3*) for calculating traffic delay costs at restrictions on specific parts of the trunk roads.

The project level bids are entered by the maintaining agent for a 30-year period, entering the following items at the year in which the action is planned or predicted to occur occur:

- Work type,
- Work category,
- Work cost,
- Traffic management cost,
- Supervision/design cost, and
- Road user delay cost, etc.

Up to 4 options are entered for each structure or element bid. The data entered are shown schematically in Figure 9.

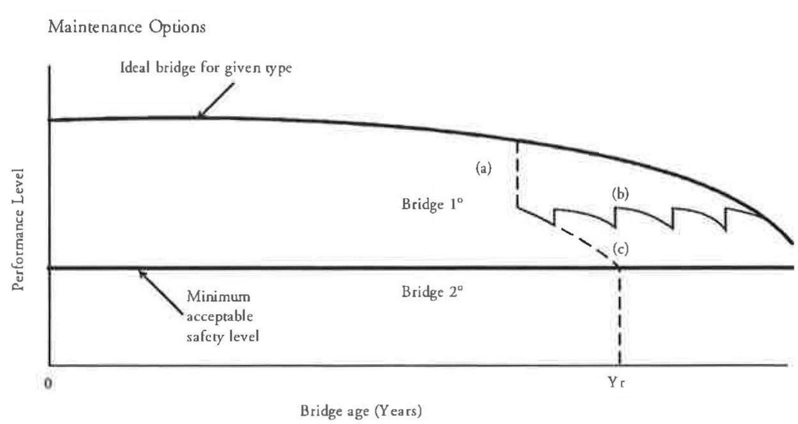


Figure 8: Whole life assessment of bridges and components.

Element or structure	Maintenance option	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	● ● ●
1	1			●	●			●		
	2	●	●	●	●	●	●	●		
	3					●				
	4			●						●
2	1	●								
	2					●				
	3			●			●			●
	4			●		●				
3	1	●	●	●	●	●	●	●	●	●
	2				●					
	3					●				
	4	●	●							●
●										

Figure 9: Maintenance bid profiles.

PRIORITISATION

Once the maintenance bids from all the agents are received the network level prioritisation can be carried out by prioritising first by the nature of the work, i.e., contractually or otherwise committed, essential and preventative etc., and then by work categories which are to be chosen by the authority (e.g., pier strengthening, parapet replacement, protection against scour, etc.). Following this, the cost profiles are discounted to present value (PV) and the maintenance option with the lowest PV is selected for each structure or element. This process is shown in Figure 10.

Finally, all the selected bid items are totalled up to check against the strategic plan estimates. This is because the cheapest option for a scheme may not be the best option in terms of the strategic considerations of the whole stock. For instance if the cheapest options for the whole stock totalled to say 20 bridges for rehabilitation in a particular year, and the strategic plan indicates that 60 bridges are to be rehabilitated, the discrepancy needs to be investigated. In such cases there is a possibility that an unacceptable backlog of rehabilitation work may build up in the future, and hence, the project level bids may need to be adjusted to include some options which may not be the cheapest project options in order to bring some of the postponed rehabilitation work forward.

The final prioritised list should show, for instance, from the bottom of the list, decreasing funding level and increasing traffic delay cost for not providing the full funding (see Figure 11). Those involved in considering the options for different funding levels should then be able to draw a line at a given level and get an indication of the extent of traffic disruption that is likely to take place from weight restrictions, etc. which would be necessary for maintaining safety if the full bid is not funded. It should be noted that the traffic delay cost is only used here to indicate the likely level of traffic disruption.

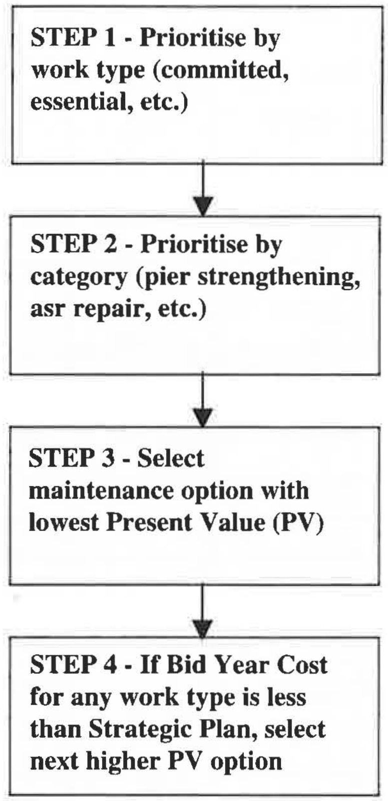


Figure 10: Bid prioritisation process.

ASSESSMENT PROGRAMME

The strategic plan indicates the desirable amount of expenditure (hence the volume) for the three types of maintenance work for any particular year. With the bidding and bid assessment system (BAPS) the work items are input as work profiles for a 30-year period. The prioritisation of the bids for the purpose of allocation is then carried out by finding the best whole life cost option for each structure, subject to complying with the strategic plan objectives.

The work programme is a programme of inspection and assessments recommended to those preparing annual bids, so that all the at risk structures are covered in a systematic manner in a given period of time. This is intended to ensure that the annual bids add up to the strategic plan expenditure for different work types, and that maintaining agents (MA) input the bids for a particular year in respect of the types of work. If no other planning is carried out, it is very likely that the right amount and type of bids will not be forthcoming year by year. For instance, if the right bridges are not assessed in a particular year, the next year's bids may miss some sub-standard bridges which would justify essential work that year. These critical bridges will then be identified in a later year, resulting in large backlogs of work.

It is therefore essential that a plan is produced which comprises programmes for inspection and assessments of bridges that could potentially be sub-standard at different periods. Similarly, there should also be a recommended policy for preventative strategies.

Work Type	Category No.	Structure/ element	Bid year cost	Cumulative bid year cost	Traffic delay cost	Cumulative traffic delay cost
Committed	1	***	***		***	
	5	***	***		***	
	15	***	***		***	
	33	***	***		***	
Routine	All		***		***	
Essential	3	***	***		***	
	12	***	***		***	
	17	***	***		***	
	23	***	***		***	
	50	***	***		***	
Preventative	2	***	***		***	
	16	***	***		***	
	28	***	***		***	
	41	***	***		***	
	42	***	***		***	

Figure 11: Prioritised bid list.

The purpose is to ensure that all the sub-standard elements are identified as they become sub-standard, and that the appropriate type and amount of preventative work are carried out. The maintaining agent is then given bidding instructions every year based on this plan.

CONCLUSIONS

This paper describes the principles and basic steps of a new bridge maintenance planning procedure being developed by the Highways Agency. It has the following innovative features:

1. It combines the strategic needs of the network with the maintenance needs of individual structures.
2. It takes into account whole life costing, risks and options of maintenance bids. The risk of not choosing a particular maintenance option is considered in terms of resulting traffic disruption or future premature rehabilitation.
3. It makes assessment an integral part of the bidding process.
4. All engineering decisions are left to the engineer and the network manager rather than automatically provided by the computer.
5. It takes account of deterioration related maintenance as well as those arising from other needs, such as design deficiency. This is because the maintenance needs are

determined by whether a structural element is sub-standard or not in terms of its structural adequacy and not determined from its condition rating alone.

In conclusion, it is hoped that the proposed procedure will make a useful contribution towards maintaining bridge stocks in a safe, economic and sustainable manner.

ACKNOWLEDGMENTS

This paper is being published with the kind permission of Mr. Lawrie Haynes, the Chief Executive of the Highways Agency. The author is also very grateful to Mr. J. Wallbank of Messrs G Maunsell Limited, Professor P. Vassie of Transport Research Laboratory and Mr. P. Tailor of the Highways Agency, for their valuable suggestions for the strategic plan procedure and for providing the results used in the example.

REFERENCES

1. Highpoint Rendel and others. *Bridge Management System.* Unpublished Project Report to the Highways Agency, London, 1994.
2. "Whole life performance assessment of highway structures." Departmental Standard, Highways Agency, UK (Draft).
3. *The QUADRO Manual.* Vol. 14, Section 1. Design Manual for Roads and Bridges. HMSO, London.