Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 38 (1982)

Artikel: Economic aspects in planning of bridge rehabilitation and repair

Autor: Gotfredsen, Hans-Henrik

DOI: https://doi.org/10.5169/seals-29526

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Economic Aspects in Planning of Bridge Rehabilitation and Repair

Aspects économiques et planification de la réparation des ponts

Wirtschaftliche Aspekte der Planung für die Sanierung und Instandstellung von Brücken

Hans-Henrik GOTFREDSEN
M.Sc.
Danish Ministry of Transport
Copenhagen, Denmark

H-H. Gotfredsen, born 1934, graduated in 1959 in civil and structural engineering at the Technical University of Denmark. After several years of employment with contractors and consultants mainly in the field of bridge building, H-H. Gotfredsen became head of the bridge division in the Danish Highway Directorate.

SUMMARY
The cost for the overall upkeep of bridges on the Danish National Highway System is expected to increase sharply in the coming decades. The paper endeavours to predict this increase and suggest policy models for the management of highway bridges under conditions of temporary insufficient available public means. When needed repairs and rehabilitations must be postponed due to lack of funds it becomes vital to make the best out of the available means as well as to keep the increase in risks under control. The development of advanced management information systems becomes thus a necessity.

RESUME
Le coût de l'entretien général des ponts du réseau danois des routes augmentera fortement dans les décennies à venir. Le présent document essaie de prédire cette croissance et propose des modèles de décision pour l'administration des ponts, tenant compte des limitations de crédit. Lorsque les réparations nécessaires sont reportées à plus tard, par suite de moyens financiers insuffisants, il devient indispensable d'utiliser les fonds disponibles au mieux et de contrôler les risques croissants. Un système évolué de gestion de l'information devient alors indispensable.

ZUSAMMENFASSUNG
Es wird angenommen, dass die Kosten für den allgemeinen Unterhalt von Brücken im dänischen Autobahnsystem in den kommenden Jahrzehnten stark ansteigen werden. Der vorliegende Bericht beruht auf einer Wachstumsvorhersage und schlägt Verfahrensmodelle für die Leitung von Autobahnbrücken unter der Bedingung vorübergehend ungenügender Finanzmittel vor. Wenn notwendige Sanierungen und Instandstellungen aufgrund nicht vorhandener finanzieller Mittel verschoben werden müssen, zeigt es sich als angebracht, aus den vorhandenen Mitteln das beste zu machen und die erhöhten Risiken unter Kontrolle zu halten. Die Entwicklung eines administrativen Informationssystems ist unerlässlich.

1. BACKGROUND FOR THE PRESENT BRIDGE SITUATION

In the last decades the Danish Highway Directorate has mainly been engaged with the construction of the Danish motorway system including a large number of bridges. These vast construction activities have been carried out at times under hectic circumstances with the aid of a major influx of personnel at all levels with limited experience in bridge building. The optimistic atmosphere of the previous decades fostered many new ideas, that were often adopted uncritically although not all of the accepted changes were of equal value.

Under the pressure of a strong public demand to establish the needed new road systems here and now, the governing idea during this construction period were to construct as much as possible with as little as possible without seriously considering the long term effects of such an approach. To-day the situation is revised. Public opinion has a very short memory. What yesterday was most desirous is to-day a disgusting intrusion upon a new set of environmental values.

In this adverse political climate we are facing the long term effects of previous years of construction booms with problems of unexpected early decays of modern bridge structures. Concrete structures and especially prestressed concrete structures pose the more serious technical challenges with demands of a thorough structural understanding combined with an extensive knowledge of materials technology especially of concrete, it´s deteriorating processes and the adverse conditions towards the overall durability of the bridges.

The economic consequences of the present situation is not fully appreciated or understood, but it is obvious that an increase of expenditures in the overall upkeep of bridges is to be expected.

It is, however, not quite so obvious that the expected increase of the costs will be met with the same degree of understanding by appropriation authorities as was the case during the hey-days of road construction of the sixties and seventies.

2. A PREDICTION OF FUTURE BRIDGE COSTS

2.1 Some Basic Economic Definitions.

Before making a prediction of costs it is necessary to clarify what kind of activities are covered by the various cost elements. The following definition has been made to serve the aim of the subsequent prediction and does not reflect any actual accounting system.

Future costs of bridges - excluding proper new constructions - are in the following subdivided into three elements:

- The costs to routine operations and maintenance.
  We deal here with the daily operations and the costs of them, that - apart from a suitable organization and a thorough planning - mainly is a function of the size of the total bridge volume and only to a lesser degree is influenced by the average age of the bridge volume.

- The costs of repairs.
  In this connection repairs are defined as the mending of existing structural elements such as surface treatment as painting or repair works on concrete but excluding all kinds of replacements.

- The costs of replacements.
  These costs can cover replacements of bridges as well as parts hereof. Some bridge elements are replaced relatively frequent such as bridge surfacing and waterproofing, parapets, joints and railings. Other elements are replaced considerably less frequent such as bridge decks, retaining walls, columns and foundations.

2.2 The Costs of Replacements.

The replacement costs of a bridge or a bridge element include the total costs of the replacements, i.e. the demolition plus the reconstruction plus arrangements for traffic deviation during the reconstruction but excluding all additional costs imposed upon the road users during the replacement of the bridge or bridge element.

The replacement costs will first appear when the lifespan of the bridge or the bridge element is terminated, which will happen either when the bridge or the bridge element is worn out or deteriorated to a degree that makes repairs economically unsound, or if the bridge has become functionally obsolete.

If we disregard the case of obsolete ability to function, then there is a close relationship between the total costs of repairs in a bridge´s lifetime and the time when a replacement is needed. Economically, repairs aim to postpone replacements until the time when a replacement is more profitable. It is therefore often technically possible - but hardly economically feasible - to avoid a threatening replacement by extensive repair works.

2.3 The Life Expectancy of Bridges

The following assumptions cover, strictly speeking, only bridges on the Danish national highway system. The assumptions are, however, supported by similar expectations for bridges on highway systems, e.g. in West Germany, Sweden and some parts of The United States.

As mentioned above various bridge elements deteriorate with different rates. We replace bridge surfacing and waterproofing considerably more frequent than structural elements in the superstructure. Parapets, joints, railings and other bridge elements have a relative short span of life. In the following the bridge volume is divided into 20% of the total replacement costs (corresponding to bridge surfacing, waterproofing, parapets, joints, railings etc.) with an average life expectancy of 20 years with a possible minimum of 5 years and possible maximum of 35 years. 20% of the total bridge volume has by these assumptions a mean life expectancy of 20 years with a standard deviation of 6 years. The remaining 80% of bridge volume is assumed to have an expected length of life of about 60 years with a possible minimum of 20 years and a possible maximum of 120 years. 80% of the total bridge volume has thus a mean life expectancy of 64 years and with a standard deviation of 20 years.

The above assumptions are indeed very rough and possibly too much so, but the assumptions are maintained for reasons of simplicity and clarity as well as of lack of a more informed basis of conjecture.

For those who find the assessed life expectancies surprisingly low, it should be noted that the climate in Denmark corresponds to an average winter period of 4-5 months with many often daily temperature changes around freezing point with high humidity, rain, snow and ice. These climatic conditions deteriorate especially concrete structures very rapidly and in addition to the climatic effects a large number of concrete bridges suffer from alkali-silica reactions that together with the use of de-icing salt acts as a "catalyst" in the deterioration processes.

ASSUMED LIFE EXPECTANCY OF ROAD BRIDGES

Pavement
Waterproofing
Rails
Bearings
Joints
etc.

20 % of the total replacement costs

Expected average = 20 years
Expected minimum = 5 years
Expected maximum = 35 years

Mean life expectancy = 20 years
Standard deviation = 6 years

Bridge decks
Columns
Foundations
Retaining Walls
etc.

80 % of the total replacement costs

Expected average = 60 years
Expected minimum = 20 years
Expected maximum = 120 years

Mean life expectancy = 64 years
Standard deviation = 20 years

Figure 1

With a mean life expectancy for bridges of 64 years (half of the bridges are thus expected to be between 64 and 120 years) it is at the same time assumed that the functional demands upon the bridges, such as the load carrying capacity, the width and the clearence will not need to be changed significantly in a corresponding long period. This assumption should be compared with the fact that in Denmark the allowable high of vehicles has been changed from 3.6 mtrs to 4.0 mtrs within the last 5 years and that the codified traffic load (for exceptionally heavy vehicles) has been doubled within the last 20 years.

2.4 Future Bridge Costs on the Danish National Highway System

Figure 2 shows the total bridge volume on the Danish national highway system distributed according to the decades in which the bridges were built or is planned to be build, and measured not in the yearly construction costs but in yearly added replacement costs. The profile of the total bridge volume corresponds with similar profiles of other national highway networks (give and take a decade) and shows the relatively high construction intensity during the depression before the second world war, almost no construction during the war and the decade following the war, where upon the construction of bridges increased strongly during the building of national motorways that in the case of Denmark is expected to be completed inside the present decade.

BRIDGES ON THE DANISH NATIONAL HIGHWAY SYSTEM

Yearly investments measured as replacement costs in mio. of Danish kroner

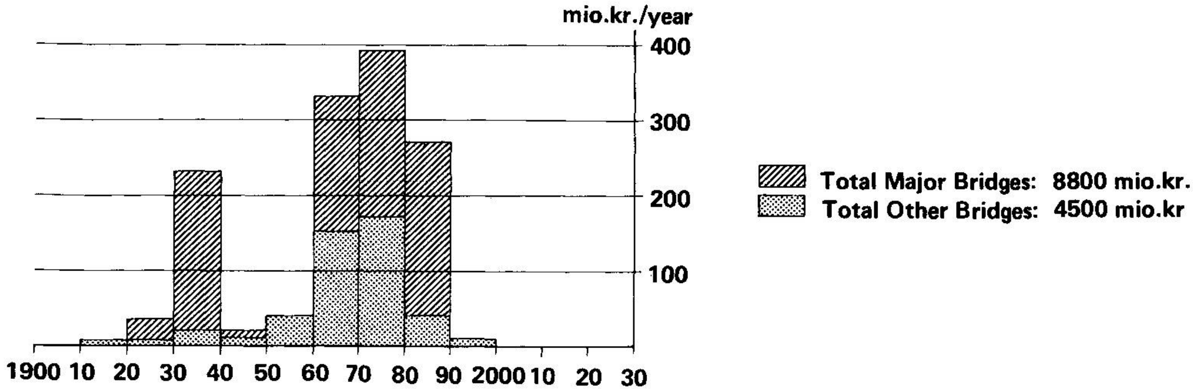

Figure 2.

These activities cause the above mentioned costs to operation, maintenance, repairs and replacements. Do we project the above mentioned assumptions regarding the costs of replacements into the shown activity of construction then we get the future yearly costs of replacements as shown in figure 3. As expected we are facing sharply increasing costs for replacements and almost half of these costs will be commanded by the relatively short-lived 20% of the bridge volume consisting of surfacing, waterproofing, railings, joints, bearings, etc.

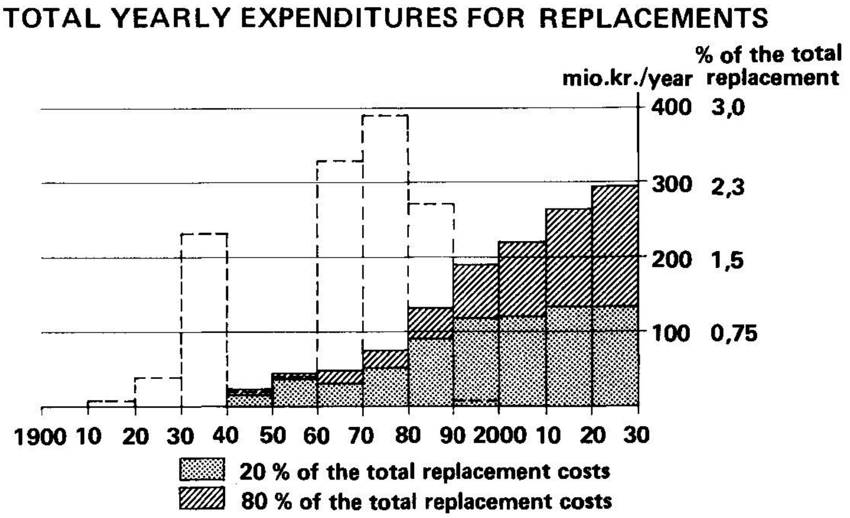

Figure 3.

To the replacement costs we must add the costs to operation, maintenance and repairs. The costs to operation and maintenance, which relate to daily activities, is regarded as practically independent of the age of the bridges. It is assumed that the yearly costs hereto is about 0.5% of the replacement costs of the actual bridge volume. The costs to repairs are of cause dependent on the age of the bridges. It is assumed that the average costs to repairs are of the same order as the costs to operation and maintenance, i.e. about 0.5% of the total replacement costs of the actual bridge volume but these costs vary from zero to about 1% during the life time of the bridge. With these assumptions we get a cost profile as shown in figure 4 for operation, maintenance and repairs.

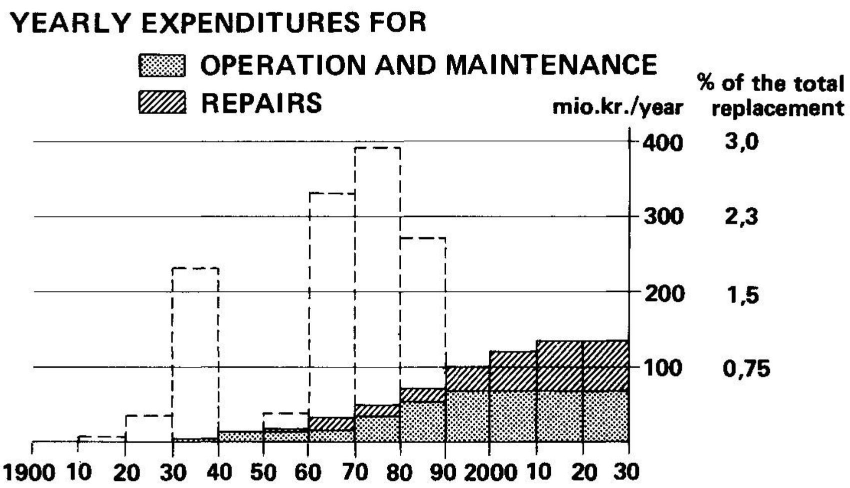

Figure 4.

When all the costs add together we get the fearsome picture as shown in figure 5. It is seen that in the eighties we must use almost twice as much as in the seventies, and in the nineties almost 2.5 times as much as in the seventies as yearly costs to the overall upkeep of the bridges. If we move 50 years ahead of present time we will, with the assumptions made, reach a level of about 3% of the total replacement costs as yearly expenditures for operation, maintenance, repair and renewals of the bridge volume before the cost increases start to level of.

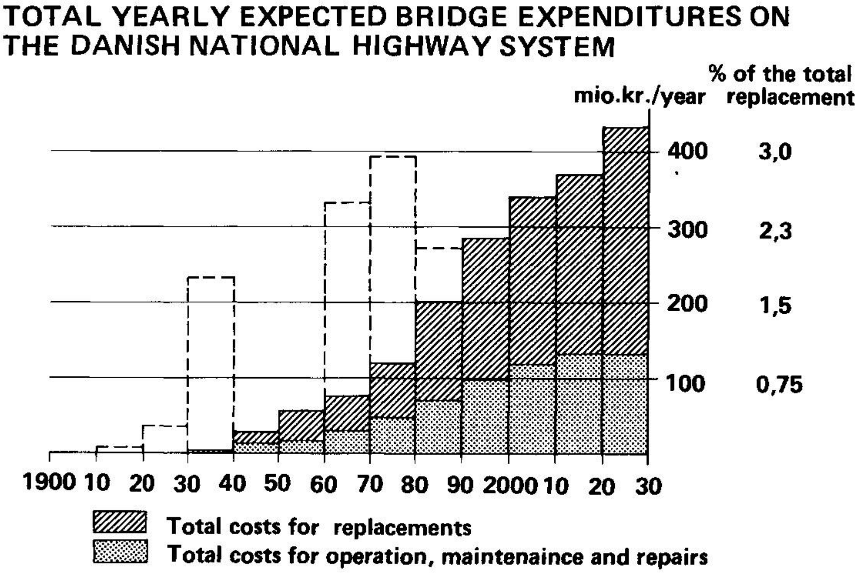

Figure 5.

Firstly, it is important to underline that the above shown prediction is a first rough attempt to make a forecast of the future costs of bridges and that considerable uncertainties are attached to the calculations which we hopefully by a more intensive planning effort can minimize and this must of cause be done. It is doubtful, however, whether such an increased planning effort will lead to considerable changes in the pattern and the order of magnitude of costs that we see here. It is on the other hand obvious that the cost increases as shown are quite unacceptable and that serious efforts are needed to limit and reduce the increases.

The fundamental problem is the durability of the bridge structures or rather the lack hereof. As shown in figure 5 it is especially the renewals, the replacements, that will draw heavyly upon our limited resources and to a large degree this is caused by the limited durability of the concrete structures. The bridges that have been built can only with difficulty been given a higher degree of durability, but the bridges that are going to build, whether it be replacements or actual new constructions, must be constructed with a fundamentally better durability. This demands a collective effort on all levels not in the least within research and development, and the argument to increase resources to such an effort lies evidently in the above shown increases in bridge expenditures which otherwise are to be expected.

3. COUNTERACTIVE MEASURES AGAINST INCREASE IN BRIDGE EXPENDITURES

Ultimately only increased durability of the bridge structures as a whole can make an impact upon the increase in expenditures. It is, however, important not to focus on the durability problems alone. Sudden increases in the functional demands such as demands for increased load carrying capacity, increased road width or clearance can make efforts in the field of durability meaningless, if the bridges have not been constructed with reasonable foresight with regard to future traffic demands. In this context it should be noted that the road networks serve an increasing part of the overall need for transport and that alternative transport possibilities from railways and shipping, when exceptionally heavy indivisible loads must be moved, become increasingly more questionable, because industry often disregard these forms of transport in their overall planning, where factors such as easily accessible, well educated labour, various environmental regulations, possibilities of expansions etc., overrules the diminishing advantages of access to railway and shipping facilities.

Even the most optimistic highway administration cannot expect immediate positive response from appropriation authorities in meeting the increasing bridge expenditures and bridge authorities may therefore - hopefully only temporarily - operate with insufficient funds.

This situation raise two principal questions:

- What are the consequences of the limited appropriations?
- How can we counteract or control such consequences?

3.1 Consequences by Limited Funding

It is possible for quite a long time to stave off the need for bridge maintenance without creating any serious problems for the traffic or road users. The fact that there is no immediate response when appropriations for bridge expenditures are cut can tempt political authorities in their some times desperate pursue for cut-backs in the public household.

The New York State Department of Transportation made a report in 1980 that most vividly described the consequences of limited appropriations in it´s report "The Deterioration of New York State Highways Structures". The report analyses on the basis of 5 years of bridge inspection data, the change in the rating of the bridges in the State of New York and makes a projection of what is to be expected if appropriation authorities remain as tightfisted as they are or have been. The report concludes that the current rate of decay appears to be five times the historical rate and may increase still futher. The report also project that by the year 2010 the deterioration on New York structures will be essentially completed, when 95% will be rated deficient and more than 50% will posted for reduced load.

In connection with a change in the traffic code in Denmark where the allowable total weight of vehicles was increased to 44 ts and the allowable axle load was increased to 10 ts we made an inventory of the load carrying capacity of existing road bridges. We managed to classify 6203 bridges out of a total registered number of bridges of 8234. Of the classified bridges, 4895 bridges, or 79% could carry the new traffic demands, the remaining part or 21% failed to do so in a varying degree. For instance will 10% or 628 bridges only be able to sustain an axle load of 5 ts and a total weight of vehicle of 8 ts. Only an insignificant number of the weaker bridges have been posted. Experience have shown that posting for limited allowable load does not prevent overloading so there is potential risks of bridge collapses regardless of traffic signs. Up till now no such collapses have occured which might be due the fact that the weaker bridges are situated on minor roads where heavy vehicles rarely travel. An other factor might be that the change in the traffic code does not momentarily change the size and construction of heavy vehicles, although it is expected that in a few years time this change will be completed.

3.2 Priorities under Restricted Funding.

With restricted funds evaluation of priorities becomes a key in establishing control of the consequences. The main purpose for highway authorities is obviously to maintain the road system intact for the road users, so major or more trafficked roads will evidently take precedence over minor or less trafficked roads when allocating funds for the overall upkeep. Large or major bridges are the most costly elements in a road system and they are often especially sensitive to neglect of maintenance so such structures will command a higher priority than ordinary bridges.

A tool in such a priority system would be a discounting technique as described in the 1981 report: "bridge maintenance" from a road research group under the Organisation for Economic Co-operation and Development (OECD). In this report it is suggested that a future cost, $C_{T=t}$, is expressed by its present equivalent, $C_{T=0}$:

$$C_{T=0} = e^{-r \times t} \cdot C_{T=t} \quad \text{(continuously}$$

or (or)

$$C_{T=0} = (1 + r)^{-n} \cdot C_{T=t} \quad \text{discretely)}$$

where t is a given time span, n the equivalent number of time periods, and r is the time preference rate or discount rate. The term "interest rate" is here intentionally avoided as interest rate may only be a subconcept to the discount rate.

Figure 6 shows the effect on future costs of using the concept of discounting. The abscissa gives the number of years ahead of present time when a future cost shall be carried (defrayed), and the ordinate axis gives its present value in percentage of the future cost. The relationship is shown for various discounting rates 1 %, 2 %, 3 % and up to 15 %. It is assumed that we operate at the same cost level, i.e. no inflation and the discount rate does therefore not contain the rate of inflation.

By discounting the future costs of operations, maintenance, repairs and replacements it is theoretically possible to adapt limited funds to a poorly maintained bridge stock with backlogged repairs by ajusting the discount rate, i.e. increasing the rate. The reason for this is - as mentioned above - the existing possibility of staving off bridge repair needs without causing serious problems - for a period at least. By increasing the discount rate the present value of all future costs are reduced and thus the the consequences of a low level of maintenance are viewed through the wrong end of the telescope. The question of whether such a decision is recommendable or not is ultimately a political matter. There might simply not be enough funds available - perhaps only for a limited period - and the show must go on.

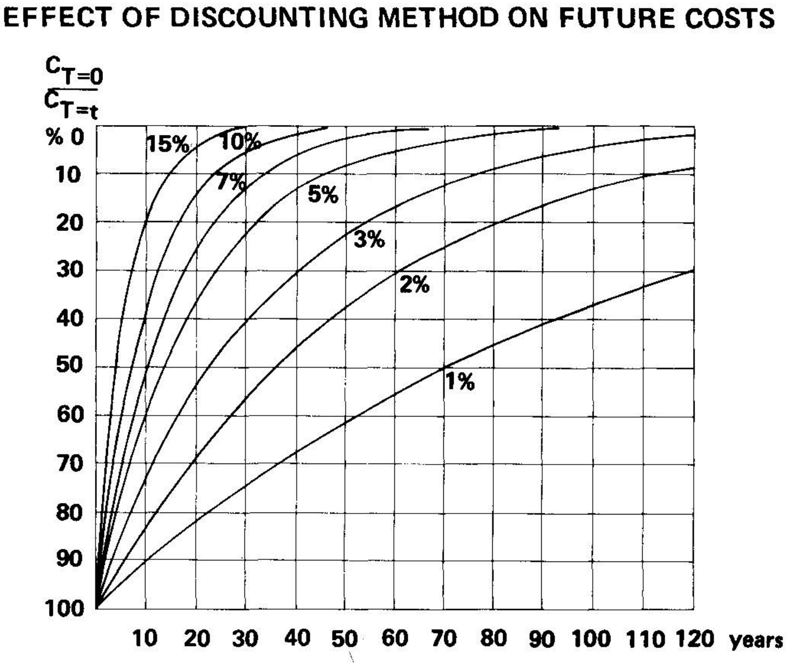

Figure 6.

In a priority system the overall discount rate is a function of available funds and accumulated needs. A low overall discount rate (1-3%) corresponds to a well maintained bridge stock with no serious backlogged repairs or replacement needs, whereas a poorly maintained bridge volume with several needs for repair and replacements and in a situation with very limited funds to meet these demands will correspond to a very high (7-15%) overall discount rate.

The overall discount rate sets the general level for the price of money. The next step is the priorities. With the overall discount rate as a "mean value" bridges on more important roads are given a low discount rate where bridges on more humble roads are given a high discount rate. A similar procedure can be introduced for major bridges against ordinary ones.

4. MANAGEMENT SYSTEMS

In the first case with sufficient funds and a well maintained bridge stock the management hereof poses few problems and only limited risks that in general do not call for more than ordinary care and diligence. The latter case, however, with a poorly maintained bridge stock, is a challenge for the best bridge management.

Information in its broadest sense is the first demand. A bridge authority does not manage inspection, maintenance, repairs, etc., but manages rather information from inspection, maintenance, repairs, etc., and the quality of the management is not likely to exceed the quality of the information received.

Bridge inspection reports from superficial, principal and special inspections form together with reports from executed repairs and the general bridge data the backbone of the information available to management. When all this is added together from just a few thousand bridges the amount of information becomes unmanageable unless steps are taken to automate the digestion of it. EDP-based databanks for general bridge data as well as from inspection reports, etc., is an obvious answer to this problem and several such databanks have been introduced. The aim for the EDP-based databanks has been easy and fast accessibility to available information and a need for analysing the large amount of collected experience from bridge inspection reports. The next generation of databanks will aspire to become sophisticated management tools containing also economic information such as repair costs defrayed against damages inspected. A further step could be the introduction of a priority system as outlined above combined with analyses of the consequences of registered damages, decays or reduced load carrying capacities with the aim of establishing a basis for management decisions of what should be done: nothing - temporary repair - full rehabilitation - and relevant solutions in between.

Such a management tool could prove to be an essentially complete risk information system where risks of collapses, deficiencies of any kind and their economic consequences as well as the level the serviceability of the road network will serve to make the most out of the available means.

Regardless of how elaborate such a risk information system may become, the increasing decay of the highway structures will continue with an increasing accumulation of backlogged repairs and replacement needs when the available funds are insufficient. The bridge information system should contain capabilities that will assist the overall planning efforts, whereby political appropriation authorities will be able to make informed decisions as to whether an accelerating decay of highway structures should be arrested by influx of funds or whether the present state of affairs is acceptable when considering the needs of competing public enteprises.

Such capabilities can be created from the data bases already established by registering the total costs of all backlogged needs combined with possibilities of regressions and forecasts of the development of these total costs under varying influx of funds into the bridge maintenance system.

In the previously mentioned report "The Deterioration of New York Highway Structures" attemps along these lines have been made. The backlogged repairs in N.Y. are estimated to amount to $ 4 billion in the year 2010 if the current rate of expenditures is maintained.