Use of Deflections To Manage the Structural Maintenance Requirements at Network Level in England

John E. Oliver, *Highways Agency, England*

A major task for the manager of a maintenance program is to collate and present a robust case for funds to ensure that the network is maintained at an appropriate level. In England a project was conducted to collate and analyze deflection data collected, principally for project-level design, for the benefit of network-level planning. The total national highway network in Great Britain is some 11 000 km long, representing only 4 percent of total road length but carrying 30 percent of all traffic and 60 percent of heavy traffic. Deflection data usually are collected under contracts let by some 90 maintenance agents. Between 1985 and 1991 some 80 percent of the length of flexible roads was surveyed, some of it more than once, and the results analyzed. On the basis that the most cost-effective strategy for strengthening is to overlay the surface at the critical point, the network has been shown to be in suboptimal condition. The project collated deflection data and presented them in a consistent and easily understood format to illustrate requirements for restoring the network to its optimal condition. Condition data were also analyzed through a network model to investigate alternative strengthening strategies over the medium and longer terms. Collection and analysis of data in this way offers the opportunity to carry out valuable audits of the range of projects put forward—and not put forward—by agents. It therefore improves the management of maintenance at both network and project levels.

Major highways in developed and many developing countries constitute an enormous capital asset that requires correspondingly high investment to maintain its serviceability and load-carrying capacity. Understandably, bids from highway authorities to their national governments for the funds necessary to service and strengthen major roads must stand up to rigorous analysis if the required funds are to be secured.

At the same time as bids for network-level funding are being prepared, the highway authority must collect various condition data so that when funds become available it can make objective decisions on how and where they should be spent. It is logical and possibly cost-effective to investigate the potential for using the large amount of condition data collected routinely to support the bid for network-level funding.

This paper describes how the Highways Agency in England has used deflection data for project-level design to set out a robust case for funding to strengthen the motorway and all-purpose trunk road networks. Strengthening treatments that provide thicker structural overlays have been identified as offering optimum value for the money when carried out at the critical condition. The output from this analysis of deflection data, known as "The Residual Life Report," has shown clearly that the network is in suboptimal condition. The report also provides data from which a strong case can be made for a coordinated program of structural strengthening to restore the network to the desired condition.

Considerable effort has been devoted to presenting the output in a form that can be understood by the layman and politician, since it is the latter who must be convinced of the case for additional funding. A thoughtful mixture of simple graphics and concise text has illustrated the soundness of the work. Moreover, the case for adequate funds to achieve the optimal condition of the network has been recognized, so that even in the present difficult financial climate, provision for strengthening the national network has held up well, though understandably not as well as had been hoped.

The English Road Network

Responsibility for managing and maintaining the 274 000 km of public roads within England is delegated by Act of Parliament to 108 highway authorities. Within this total length of highway, the Department of Transport (DOT) is responsible for the national strategic network, that is, the motorway and all-purpose trunk road (APTR) networks, which total some 3000 and 8000 km, respectively. Even though this length of network only represents 4 percent of the country's total road mileage, it carries 30 percent of the total vehicle kilometers traveled annually and some 60 percent of heavy goods traffic. The remaining 70 percent of all traffic (and 40 percent of heavier traffic) is carried on the lower hierarchical levels of road, managed by local government highway authorities.

The day-to-day management of the motorway and APTR networks is carried out on a geographical basis by maintenance agents reporting through a regional office to a headquarters division in London. As of April 1, 1994, there were some 90 maintenance agents reporting through 9 regional offices. Of these agents, 84 were local government highway authorities and 6 were consulting engineering practices from the private sector. Within this organizational structure, the local government highway authority agents operate under a single agency agreement, which sets out in broad terms the duties delegated to them by DOT, the information flows required from them to DOT before work can be approved and funds allocated, and the fee scales. The consulting engineering practices operate under individual contracts covering the functions similar to but more specific than those contained within the single agency agreement, with the level of reimbursement governed by the tendered fee rates.

Maintenance Expenditure

Current levels of annual expenditure by DOT in maintaining these networks is running at approximately £670 million, with £360 million spent on the rehabilitation of pavements, £150 million on the rehabilitation of structures, and £160 million on routine cyclical maintenance. As with any organization, public or private, that undertakes this level of annual expenditure, business activities must be monitored continually to ensure adequate value for expenditure and to strive for efficiency improvements by introducing new initiatives. Part of this process in England involves the Public Accounts Committee (PAC) of the House of Commons, which receives reports of studies undertaken by the National Audit Office (NAO). NAO is authorized by Parliament to investigate issues of value-for-money and propriety associated with programs and policies managed by government departments and agencies with expenditure authority.

In 1991 PAC received a report from NAO on the "Management of Road Maintenance." Following a committee hearing with senior DOT officials, a report was published that included the following two recommendations:

> We consider that the Department need to have better information on the condition of roads in order to deploy their funds most cost-effectively;
> We are concerned about past inadequacies of the Department's data on road condition, and note that the national structural survey of the condition of roads had to be abandoned because the data provided by their agents were incomplete and inconsistent. (House of Commons Committee of Public Accounts Third Report—Management of Road Maintenance, November 1991)

In the DOT's published response to these recommendations it stated:

> The Department shares the Committee's concern over past inadequacies and has instigated a programme to improve the monitoring and reporting of the condition of roads. The report by consultants on the structural condition of the network (The Residual Life Report) is the first example of this process. (Treasury Minute in Response to the PAC Report into Management and Road Maintenance)

Management of Maintenance

A highway network, especially a busy one, should be monitored regularly to assess its physical condition and change in condition. However, such monitoring is inherently dangerous for operators of survey equipment, and slow-speed survey methods inevitably cause disruption for road users. In practice, therefore, a hierarchical approach to condition surveys is required. High-speed and low-unit cost surveys that minimize disruption to traffic while maximizing the safety of the operation are undertaken most frequently as part of a first-pass program before subsequent detailed investigation using other survey methods. Routine surveys by slower-speed equipment must still be carried out to define the physical state of the network, but at less frequent intervals than previously. Slower-speed surveys are also now targeted, based on information from the first-pass surveys.

A high-speed first-pass survey is carried out using the High-Speed Road Monitor (HRM) (*1*), which utilizes laser technology. This defines the present functional condition of the network. Also, results from two HRM surveys (at intervals of 1 or 2 years) can be compared to identify sections of road where the condition is changing. More detailed surveys, such as deflection surveys and visual condition surveys—in England we use Computerized Highway Assessment, Ratings and Treatment (CHART)—can then be carried out to determine the reason for the change in condition as well as to define the residual life of the whole network from routine surveys. These more detailed surveys are normally repeated on a 3- to 5-year cycle. The texture results obtained from the HRM support the skid-resistance measurements obtained from network-wide surveys carried out on a 3-year cycle, using the Sideway-force Coefficient Routine Investigation Machine, SCRIM (*2*).

Deflection Surveys

Highway maintenance design methods that include prediction of the need for strengthening and estimates of the treatment thicknesses required are based on a structural evaluation of the existing pavement. The considerable and rapid variation in structural condition, or strength, that occurs along most flexible roads, particularly as they approach a critical condition and require strengthening, dictate that routine measurements of strength be taken at closely spaced intervals to allow strengthening proposals to reflect the variation. The additional need to survey large lengths of road each year effectively limits the possible measurements to those that can be taken on the road surface. In practice, therefore, the evaluation of the structural condition of flexible pavements is based on the measurement of the maximum displacement of the road surface generated by the application of a test load. These measurements can be obtained with a Pavement Deflection Data Logging Machine, PDDLM (*3*), which is the United Kingdom version of the Deflectograph.

The primary function of the PDDLM equipment is to measure, simultaneously in both wheelpaths, the maximum, transient deflection of the road surface produced by the passage of the loaded rear wheels along a road. The beam assembly, which measures deflection, is positioned beneath the vehicle chassis and between the two rigid axles. It is raised clear of the road when traveling between sites at normal operating speed. During operation, when the vehicle speed is constrained to 2.5 km/hr, it rests independently on the pavement surface.

The downward movement of the road surface produced by the approach of the rear wheel assemblies is monitored by a pivoted deflection beam. A displacement transducer, located near but ahead of the beam fulcrum, converts the beam's downward movement into an electrical signal. Deflections are measured and recorded for routine purposes at intervals of about 3.8 m in both wheelpaths.

The equipment can monitor 12 to 20 lane-km per day, producing 3,000 to 5,000 individual measurements in each wheelpath. Machines of this sort currently monitor about 18 000 lane-km of the United Kingdom road network each year.

Design of Strengthening

The deflection measurements provide the major input to the United Kingdom structural maintenance design system for flexible pavements (*4,5*). The survey and design procedures are integral requirements to be included in the submission of bids to obtain funds for structural maintenance of national roads. The method uses the PDDLM deflection measurements to characterize the structural condition of a pavement. The output from the PDDLM is used to (*a*) predict the residual life of an existing pavement and (*b*) estimate the thickness of overlay required to extend the life of a pavement for a specified period (expressed in terms of standard axles).

The design method is based on correlations of measured deflection and pavement performance from a large number of full-scale road experiments. The method has undergone a process of continuous development and validation by the United Kingdom's Transport Research Laboratory (TRL) over 20 years.

Residual life as defined by the design method relates to the onset of critical conditions in a road pavement. The critical condition is defined as the point in the life of a pavement at which the rate of deterioration becomes less predictable, and where deterioration accelerates, leading over a period of several years to a failure condition. During the period of acceleration to failure, the existing strength in a pavement may diminish rapidly, and the cost of maintenance implemented beyond the critical condition can be expected to increase. In the short term, a road will remain serviceable to vehicular traffic beyond its critical condition, providing that patching and other palliative measures, such as surface inlay techniques, are implemented. These measures become increasingly costly to carry out and inflict ever-increasing disruption on the road user.

Survey Coverage

The analysis reported in this paper includes the deflectograph results from the most recent survey recorded on about 3900 slow-lane km of the motorway network and on about 9500 km of APTR network. All sections tested by the deflectograph from 1985 to 1991 for which sufficient information is available to enable them to be located accurately are included.

The overall results from about 76 percent of the total network in England, excluding known lengths of rigid and elevated sections, have also been included in this study: about 91 percent of the total for motorways and 71 percent of the total for trunk roads.

The analysis procedures reported are updated annually, with each successive year's survey results added. In addition, since 1992, the method of analysis and reporting has been extended to the next lower category of road, principal roads; in 1992 the results for approximately 25 000 lane-km were included. This is expected to increase to about 60 000 lane-km by the end of 1995.

Deflection Analysis

The residual life has been determined for 100-m-long sections of road on the basis of the 85th percentile deflection level. The 85th percentile level has been calculated from the combined wheelpath individual deflection values. The 85th percentile deflection levels have been converted into equivalent residual-life values, defined in years, using construction and traffic-load data supplied by the maintenance agents.

For the purpose of analysis and presentation, residual lives have been corrected to the reporting year (1992 in the case of this paper) and grouped into the residual life bands (in years) given in Table 1.

For effective map-based presentation of the residual life along the network, the residual life has also been calculated for section lengths in excess of the basic 100 m. Where alternative section lengths have been adopted, the residual life has, in all cases, been based on the 85th percentile level of combined wheelpath individual deflections.

The deflection results used in the analysis have been collected from cyclic surveys carried out over 6 years. The calculated residual lives cannot automatically take account of maintenance work undertaken during the 6-year period, unless a subsequent survey has been undertaken on the maintained lengths. Without modification, the residual lives calculated would therefore present a very pessimistic view of the state of the network. To correct for this effect, the calculated residual lives have been modified where subsequent maintenance work has been undertaken by updating the calculated values to an assumed 20-year design life (the norm in England) from the date of maintenance. Details of the location of strengthening and the deflection files are supplied by maintenance agents and edited over the appropriate lengths to take account of these construction updates.

Reporting Style

With the work being targeted as much at a nontechnical audience as at a technical one, the presentation of the results was of major importance. Results are presented separately by motorways and APTRs and, for each of these groups, further classified at the national, regional, and agent level. Four basic forms for presenting results have been adopted on the basis of the six residual life bands defined in Table 1:

1. Pie charts showing percentage of 100-m-section residual lives for each 100-m section within each of the life bands (Figures 1 and 2);
2. Color-coded maps showing the location of lengths of road falling within each of the life bands;
3. Tables, such as the example of Table 1, summarizing the pie charts; and
4. Moving cursor plots.

Typical pie charts for the conditions in 1992 are shown in Figure 1 for motorways and APTRs. The figure shows the distribution of residual life in segments representing the percentage in four separate 5-year bands plus the percentages that are past critical and have a residual life greater than 19 years.

Figure 2 shows the distribution of residual life on sections of the road immediately prior to strengthening; the distributions show that very large proportions of the lengths receiving maintenance have short residual lives, demonstrating good targeting of maintenance treatments.

Figure 3 shows the distribution of residual life on strengthened pavements. The relatively high proportion of short lives shown in this figure points to the need for more detailed studies. Procedures for updating traffic files and for referencing deflection surveys may partially account for these results.

The English motorway network is relatively modern, as shown in Figure 4, but because of very high increases in traffic loading in the last 10 to 15 years, much of the network has been or will need to be strengthened in the next few years.

Color-coded maps are developed against plain backgrounds at the national and regional level and against a relief background at agent level (1:50,000 scale). These could not be reproduced satisfactorily for this paper.

The distribution of residual life at network level on the motorway and trunk road networks is given in an alternative style in Table 1. Despite improvements in survey coverage, the general condition has remained broadly similar over the study period. However, the survey trend of slowly deteriorating condition recorded between 1989 and 1991 was arrested in 1992, and results for 1993 confirm a small improvement.

What has been termed a moving cursor presentation has been produced for the motorway and trunk road networks. This presentation involves the display of 85th percentile values of 100-m sections graphically with a 4-km moving average superimposed (nominal maximum length

TABLE 1 Comparison of Changes in Condition

Motorway Network

Residual Life Band	1992	1991	1990	1989
<0	16.13	16.57	15.45	14.37
0-4	23.55	23.40	22.64	21.31
5-9	18.14	19.05	19.37	17.73
10-14	10.06	10.59	11.16	11.45
15-19	16.76	14.65	13.92	6.84
>19	15.36	15.74	17.47	28.30
Total Length (km)	4299	4265	4265	4408
Coverage (%)	91	91	83	69

Trunk Road Network

Residual Life Band	1992	1991	1990	1989
<0	14.66	15.48	13.86	12.75
0-4	12.91	12.92	12.94	11.33
5-9	12.83	12.17	12.68	11.84
10-14	10.31	10.26	10.50	9.99
15-19	13.13	11.31	9.73	8.14
>19	36.16	37.86	40.28	45.45
Total Length (km)	13421	13951	13796	13863
Coverage (%)	71	71	67	55

for maintenance schemes). Moving cursors show previous moving averages so that consistency of prediction can be confirmed on a routine basis. The plots also present information on the age of the carriageway and details of traffic loading. Again, these plots could not be reproduced with sufficient clarity for this paper.

UNIFORMITY OF RESULTS

Routine deflection surveys have been tested to assess the uniformity with which the design method predicts the residual life both at network and at project levels. The uniformity study was based on an analysis of more than 1500 km of carriageway where repeat independent deflection surveys separated by between 1 and 5 years had been completed during the period between 1985 and 1991. The residual life of 100-m-long sections was used in the study. An analysis of the distribution of differences in the residual lives predicted by the most recent and earlier survey showed that, at the network level, the predictions from the two populations differed by only 1 to 2 years. For sections of the network with residual lives predicted by the most recent survey to be between 0 and 5 years (i.e., approaching the time for maintenance), the error in predictions at the network level reduces to 1 to 1.3 years. At the project level, 70 percent of all paired residual life predictions for 100-m-long sections from a second survey on the same section of carriageway are shown to be within ±3 years of the prediction made by an earlier survey.

MODELING OF FUTURE NEEDS

A subsidiary aspect of the commission was to undertake a comparison with a TRL research model of a budget

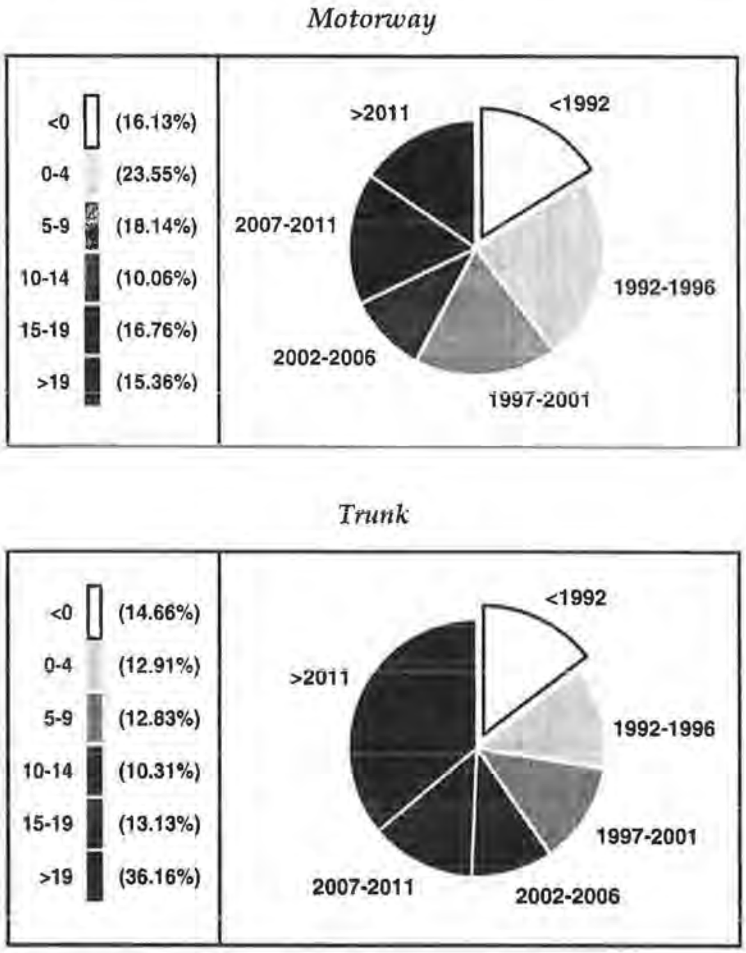

FIGURE 1 Residual life of the network corrected to 1992, including data from 1985 through 1991.

profile analysis for the motorway network. The main objectives of the budget exercise were to investigate (*a*) the structural maintenance budget options over a 30-year period, based on real schemes, and (*b*) the location of candidate schemes over the study period.

Several assumptions and rules have been applied to the model for this comparison:

1. There is no variation in treatment costs with time.
2. Treatment costs are based on three lanes plus hard shoulder carriageways (the normal cross-section standard for motorways).
3. No traffic delay costs are included in the analysis.
4. The maximum overlay is 250 mm and the minimum overlay is 50 mm with possible overlays in steps of 25 mm between these limits.
5. No treatments other than reconstruction or overlays are applied in the analysis, and these treatments restore the scheme lengths to a residual life of 20 years.
6. Residual lives greater than 30 years will form one band of the residual life distribution, as will residual lives less than zero.
7. Reconstruction is only permitted at residual life = -7 years.
8. Overlay is only permitted at residual life = 0.
9. The maximum permissible scheme length is 8 km and the minimum permissible scheme length is normally 1 km.
10. No buffer zone restriction is placed on gaps between schemes in any one year.

THE MODELING PROCESS

The modeling for budget analysis is based on 10-m length, 85th percentile deflections from the network residual life files.

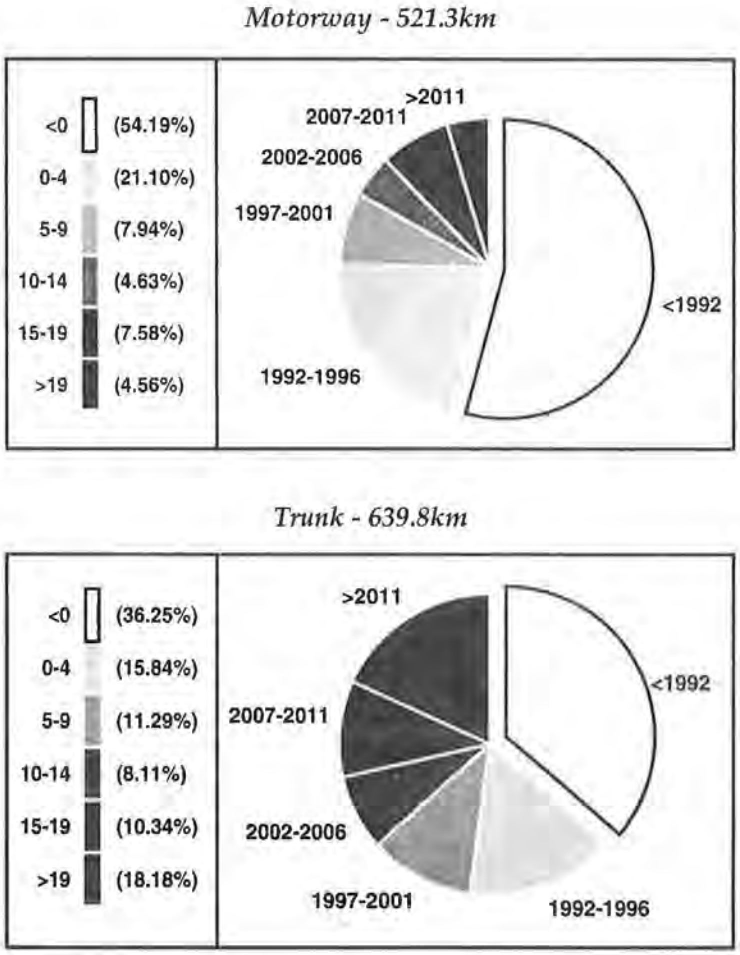

FIGURE 2 Residual life of renewal sections before any work was undertaken.

The results of the deflection surveys are trended forward in time to define residual life and overlay requirement for each 10-m length. An interactive statistical analysis of the residual life data is then used to create "schemes" representing lengths of carriageway that are statistically homogeneous in terms of condition. The year in which maintenance is required is defined for each scheme, and the maintenance policy, rules, and assumptions are applied across the whole motorway network over the 30-year budget period. Strengthening requirements for each scheme are then defined with its location. Two forms of output are produced from the budget analysis:

1. Costings, both discounted and undiscounted, to maintain the network over the study period can be presented in diagrammatic form.
2. Map-based presentation can show, for the 10-year period 1992 to 2002 an array of information: the location of schemes, the year they should be implemented, and a broad indication of treatment requirements (e.g., at regional level).

Future Developments

The analysis described uses full referenced network data held on a relational data base. It is possible therefore for traffic delay costs and other condition indicators such as the results from HRM and SCRIM surveys to be added to the analysis, and for full optimization to be undertaken against either cost-benefit analysis or condition of the network. At a much simpler level, more realistic rules on maintenance scheme lengths and gaps between scheme could be implemented to make the automatic scheme definition module even more realistic. The system in its present state could be used to evaluate alternative maintenance intervention policies, for instance, adding thin overlays after 10 years of a 20-year design life, to compare net present values.

Use of Results at Network Level

The information contained within the annual reports from the consultants on the structural condition of the mo-

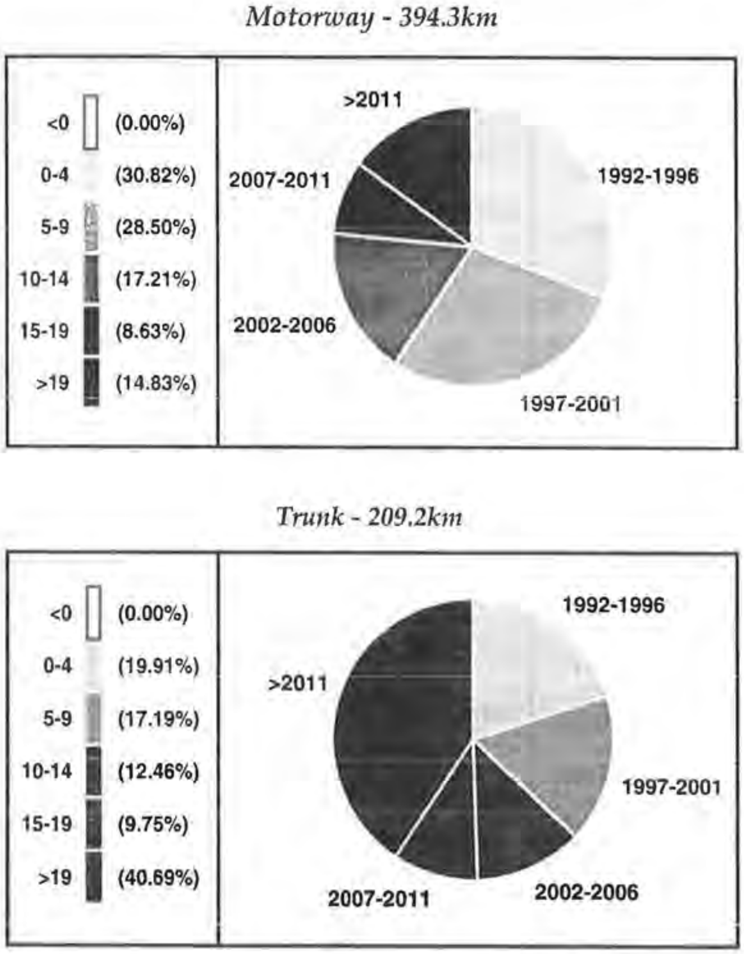

FIGURE 3 **Performance of renewal sections.**

torway and APTR networks, as given in Table 1, has helped the agency to respond to the recommendations of PAC, listed earlier in this paper. In addition it provided the department with robust information to program a national package of maintenance works.

Having assembled this information, the agency is now in a position to develop a stronger case, based on value for money, for funds to achieve these targets on a needs-led basis. The case has continued to be convincing and has helped to secure additional funds.

Use of Results at Project Level

The color-coded maps and moving cursor plots have enabled the department at both regional and national levels to adopt a more hands-on style. This has been the first time that comprehensive information on the entire network has been made available to these parts of the organization. In the past agents were only required to put forward structural information on lengths of the network they had identified as being in need of treatment. This extra information has enabled the department to be more proactive in identifying schemes that should be put forward by agents, and it is anticipated that this will improve the targeting of maintenance schemes, as shown in Figure 2, and possibly reduce the time required to eliminate the backlog.

Confidence in the department's use of the deflection design system in targeting schemes has been enhanced following the delivery of the uniformity report. The results of this study show that the design system, which includes collection and measurement of deflection and associated data as well as the performance models themselves, makes consistent predictions of residual life and that the maintenance schemes identified are located in a reproducible manner.

The results from the budget analysis study agreed closely with the analysis undertaken by TRL using its own

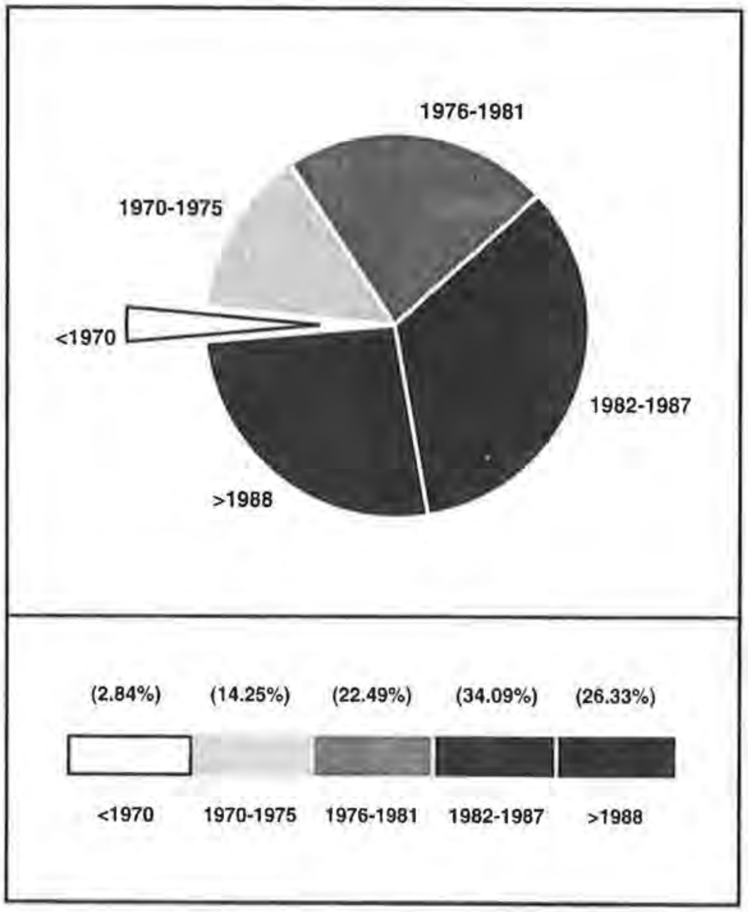

FIGURE 4 Distribution of age of motorways.

model and in broad terms with the current budget profile identified by DOT. The scheme locations, their extent, and the estimate of overlay treatment thickness generated automatically in the study were compared by the regional offices with those generated by the agents using more traditional manual techniques of data analysis. They concluded that there was sufficient agreement between the two to enable the automatically generated program to be used as one of the source documents in formulating an indicative national program of schemes over a 5-year period.

CONCLUSION

This project has shown the condition of the national network. The work has cost only about 0.1 percent of the cost of carriageway maintenance and, because it uses the data collected by agents for project-level design, offers the opportunity for checks on the consistency between the two exercises. Work will continue to improve the quality and reliability of the Residual Life Report, but it has already proved to be a very effective tool for determining network-level requirements from project-level data.

REFERENCES

1. Cooper, D.R.C. *The TRL High-Speed Road Monitor: Assessing the Serviceability of Roads, Bridges and Airfields.* Transport Research Laboratory Report RR11. Department of the Environment, Department of Transport, Crowthorne, United Kingdom, 1985.
2. Hoskin, J.R., and G.C. Woodford. Measurement of Skid Resistance, Part 1. *Guide to the Use of SCRIM.* TRL Report SR642. Department of the Environment, Department of Transport, Crowthorne, United Kingdom, 1976.
3. Kennedy, C.K., and J.L. Gardiner. The British Pavement Deflection Data Logging Machine and Its Operation. *Proc., International Symposium on Bearing Capacity of Roads and Airfields*, Norwegian Institute of Technology, Trondheim, Norway, 1982.
4. Kennedy, C.K., and N.W. Lister. *Prediction of Pavement Performance and the Design of Overlays.* TRL

Report LR833. Department of the Environment, Department of Transport, Crowthorne, United Kingdom, 1978.

5. Lister, N.W., C.K. Kennedy, and B.W. Ferne. The TRL Method for Planning and Design of Overlays. *Proc., 5th International Conference on Structural Design of Asphalt Pavements*, Vol. 1, University of Michigan, Ann Arbor, 1982.

This paper is presented with the permission of the Director of Network Management and Maintenance. The views expressed by the author are not necessarily those of the Highways Agency or Department of Transport.