NETCOM
THE TRL VISUAL CONDITION MODEL FOR ROAD NETWORKS

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(University of Birmingham)

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NETCOM

THE TRL VISUAL CONDITION MODEL FOR ROAD NETWORKS

ABSTRACT

The report describes the development of NETCOM, a road NETwork COndition Model, developed at the University of Birmingham under contract to the Transport Research Laboratory. NETCOM is a computer model developed for studying the effects of changes in road maintenance budget levels on the condition of a road network. NETCOM models the progression of defect distributions on a road network and predicts the network condition in future years based on specified maintenance standards and the budget profile. NETCOM is designed to assist road maintenance engineers and administrators in planning the medium to long term maintenance investment requirements for local and national road networks.

1 INTRODUCTION

1.1 Background

The road NETwork COndition Model (NETCOM) described in this report, is the result of three years of research conducted in two stages at the University of Birmingham under contract to the Transport Research Laboratory (TRL). The first stage comprised an investigation of the feasibility of developing a computer model which could be used to predict the performance of a road network under varying maintenance budget scenarios. This resulted in the specification of an interim Road Network Model based on indicators of road surface condition (i.e. visual pavement defects). The second stage of the research, discussed in this report, was principally a consolidation of the ideas developed in the first stage of the research into a prototype computer program - the TRL Visual Condition Model For Road Networks or more simply NETCOM.

1.2 Objectives of NETCOM

The objectives set out for NETCOM were as follows:

1. To provide a method of studying the effects of maintenance funding levels on the condition of a road network.
2. To predict the total maintenance budget requirements of a road network in future years and identify future peaks in the requirement for maintenance.
3. To study the effects of changes in maintenance treatment policies on budget requirements and road network condition.
4. To estimate costs incurred by road users and by maintenance authorities on a road network.
5. To provide an overview of the performance of a road network over a number of years.

A road network is taken to be a set of roads with similar construction and maintenance standards. Typical examples of road networks in the United Kingdom include the motorway network, the trunk road network, the classified and unclassified road networks in rural or urban areas. The model can be used to analyse the performance of any of the above road networks in a given geographical location (e.g. classified roads in Warwickshire). Consequently, it may be used by Government Departments or by Local Authorities to study the effects of funding or other maintenance policies on the condition of road networks under their control. It should be noted that the maintenance funding, referred to above, applies only to treatments which directly affect pavement condition. This therefore excludes activities such as drainage maintenance, snow clearance, road lighting and marking, etc.
2 DESCRIPTION OF NETCOM

2.1 Overview

The fundamental assumption made in NETCOM is that the condition of a network of roads can be modelled using frequency distributions of observed defect severities. All defects observed on a road pavement vary both in extent and severity throughout the network. If a condition survey is carried out to measure defect severities on a road network, the results can be presented in the form of frequency distributions of severity levels. An example of the distribution of severity levels for a selection of defects observed on the trunk road network in England and Wales in 1977 is illustrated in Figure 1. Table 1 shows the corresponding defect severities grouped into bands. In NETCOM, the first severity band for any defect is assumed to represent parts of the road network with little or no signs of the defect. For example in Table 1, severity band 1 for wheel track (WT) rutting represents the proportion of the network on which rutting is imperceptible (approximately 40%).

The defect distributions given in Table 1 and Figure 1 represent a network wide aggregation of road condition. Consequently, a typical source of data for NETCOM for roads in England and Wales are the results of annual National Road Maintenance Condition Surveys (NRMCS) (1). Throughout this report, NRMCS results (2) for certain years are used to illustrate the relationships built into NETCOM. For example, Figure 1 shows typical distributions of WT rutting, WT cracking, whole carriageway (WC) major and minor deterioration extracted from NRMCS results of 1977 for trunk roads by the Statistics Division of the Department of Transport. This permits estimates of the proportion of a road network with given defect severities to be directly obtained. For example it may be deduced from Table 1 that the proportion of the trunk road network in England and Wales with rut depths greater than or equal to 15 mm in 1977 was approximately 2.8%. If the 15 mm rut depth is taken to be an indication of critical pavement condition signalling the requirement for pavement strengthening, it may then be concluded that 2.8% of the trunk road network in 1977 required some form of strengthening (i.e. overlay or reconstruction).

It was decided at an early stage of the study that NETCOM would be designed to work with pavement condition indicators additional to those included in the NRMCS. Consequently, NETCOM is designed to work with any type of pavement defect or condition indicator, provided the incidence and severity of the pavement defect can be represented in the form of a frequency distribution. This will permit, for example, use of other defects expected to be monitored in the proposed Pavement Management System (PMS) for the United Kingdom.

<table>
<thead>
<tr>
<th>Severity Band</th>
<th>WT Rutting Severity Proportion (%)</th>
<th>WT Cracking Severity Proportion (%)</th>
<th>WC Major Severity Proportion (%)</th>
<th>WC Minor Severity Proportion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1-4</td>
<td>1-9</td>
<td>1-9</td>
<td>1-9</td>
</tr>
<tr>
<td>3</td>
<td>5-9</td>
<td>10-19</td>
<td>10-19</td>
<td>10-19</td>
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<tr>
<td>4</td>
<td>10-14</td>
<td>20-29</td>
<td>20-29</td>
<td>20-29</td>
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<tr>
<td>5</td>
<td>15-19</td>
<td>30-39</td>
<td>30-39</td>
<td>30-39</td>
</tr>
<tr>
<td>6</td>
<td>&gt;=20</td>
<td>&gt;=40</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1: Observed defect severity distributions on trunk roads in 1977
2.2 Fundamental Assumptions

The procedures adopted in NETCOM to model road network performance assume the following:

1. The condition of a road network can be adequately represented in the form of statistical distributions of defect severities.
2. The observed deterioration trend for a road network remains stable over a period of time equal to the analysis period and takes account of observed traffic growth rates. Thus the deterioration trend observed from past years can be used to predict the condition of a road network over a defined analysis period.
3. The maintenance budgets specified to NETCOM are spent entirely on maintenance treatments which directly affect pavement condition.

2.3 Outline of NETCOM

NETCOM predicts the annual change in pavement condition by calculating the effect of maintenance treatments on defect severity levels and then ageing the resulting distributions to predict the severity levels in the following year. Ideally, a road network should be defined in terms of stretches of roads with the same pavement structure and traffic loading, and should be within the same geographical region. The object of this is to analyse roads which exhibit similar performance. The processing involved in the model is then broken down into a calculation of the annual progression of defect severities followed by a simulation of the effects of maintenance treatments applied in each year. This iterative process is summarised in the steps below and described in more detail in section 3.

1. Initialise NETCOM by specifying physical characteristics of the road network (e.g. length, width), annual maintenance budgets, maintenance standards and defect severity distributions for the first year of analysis from results of road network condition surveys.
2. Compute the percentage of the road network requiring maintenance from defect severity distributions and specified maintenance intervention levels taking into account the proportion of the network which is to receive structural maintenance as given by the Residual Life model (see section 3.2).
3. Compute the percentage of the road network which will receive treatment under the specified maintenance budget limits and maintenance intervention levels.
4. Compute the interaction between multiple defects occurring on the same stretch of road and predict the effects of maintenance treatments triggered by one defect on the severity distributions of other defects.
5. Predict the condition of the road network in the following year using defined defect progression relationships.

In step 1, the condition of the road network is initialised at the beginning of the analysis period using defect distributions obtained from surveys of road network condition, for example, from NRMCS results. Steps 2 to 5 are then repeated for each year in the specified analysis period as illustrated in Figure 2. Within these, the percentages of the road network requiring each type of maintenance treatment are calculated according to specified maintenance intervention levels. For example, some local authorities in England and Wales may apply strengthening treatments when pavements attain a rut depth of 15mm. From Table 1, this would include the 2.8% of the network in severity bands 5 and 6 with WT rutting greater than or equal to 15mm. If however, the total expenditure requirement for maintenance exceeds the annual maintenance budget, it becomes necessary to limit the amount of maintenance work carried out to that possible under the given budget. The percentage of the network receiving treatment in any given year is therefore determined from the computed maintenance requirement, but is limited to the maximum percentage which can be treated under the specified budget. The severity distributions of all defects on the network are then calculated for the following year taking into account the joint occurrence of defects on the stretches of road receiving treatment.
3 NETCOM SIMULATION PROCESS

NETCOM comprises a number of simulation modules which perform specific tasks designed to reflect commonly accepted practice in road maintenance. These include the specification of maintenance budgets and intervention levels, the calculation of maintenance requirements, simulation of the effects of maintenance treatments on road network condition, and modelling pavement deterioration based on observed distributions of defect progression.

3.1 Specification of maintenance standards

In NETCOM, a maintenance standard defines the intervention levels at which various treatments are to be applied. Table 2 shows an example of a maintenance standard in which reconstruction will be applied when wheel track cracking reaches 40% of the carriageway or when wheel track rutting is equal to or greater than 20 mm. Reconstruction will also be applied when whole carriageway major deterioration reaches 40%. The table also shows that overlays are to be applied on parts of the network with rutting between 15 mm and 19 mm or with major deterioration on 20% to 39% of the carriageway area. The maintenance standard also specifies the order in which treatments are to be applied. Table 2 shows that reconstruction will be the first treatment to be applied on the road network followed by overlays, then resurfacing, surface dressing and finally patching. This sequence of treatment application can be altered by specifying a different treatment priority order. Within each treatment, the defect priority defines the order in which defects are to be treated. For example, Table 2 shows that parts of the road network with 40% or more cracking will be reconstructed before sections with rutting equal to or greater than 20 mm.

Table 2: Specification of maintenance standards for a road network

<table>
<thead>
<tr>
<th>Treatment Type</th>
<th>Treatment Priority</th>
<th>Defect Type</th>
<th>Defect Priority</th>
<th>Intervention Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconstruct</td>
<td>1</td>
<td>WT Cracking</td>
<td>1</td>
<td>&gt;=40%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WT Rutting</td>
<td>2</td>
<td>&gt;=20 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WC Major</td>
<td>3</td>
<td>&gt;=40%</td>
</tr>
<tr>
<td>Overlays</td>
<td>2</td>
<td>WT Rutting</td>
<td>1</td>
<td>15 mm - 19 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WC Major</td>
<td>2</td>
<td>20% - 39%</td>
</tr>
<tr>
<td>Resurfacing</td>
<td>3</td>
<td>WC Major</td>
<td>1</td>
<td>20% - 39%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WC Minor</td>
<td>2</td>
<td>Severity 6</td>
</tr>
<tr>
<td>Surface Dress</td>
<td>4</td>
<td>WC minor</td>
<td>1</td>
<td>Severity 1 - 5</td>
</tr>
<tr>
<td>Patching</td>
<td>5</td>
<td>WT Cracking</td>
<td>1</td>
<td>10% - 19%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WC Major</td>
<td>2</td>
<td>10% - 19%</td>
</tr>
</tbody>
</table>

3.2 The TRL Residual Life Model

In addition to the maintenance intervention levels given in Table 2, NETCOM also estimates the total requirement for structural maintenance (reconstruction and overlays) on trunk roads and motorways by using the central kernel of the Residual Life Model (3) developed at the TRL. The Residual Life Model simulates the year-by-year structural deterioration of a road network as modified by structural treatments. In any given year, the structural condition of the network is represented by a frequency distribution of residual lives divided into 41 severity bands, each representing the percentage of the network with residual lives in 1 year intervals ranging from -10 to +30 years of residual life.
The specification of intervention levels for reconstruction and overlays, based on residual life, is done independently of the maintenance scenario described in section 3.1 above. For example overlays may be applied when the residual life is between 0 to 4 years before the onset of critical condition. Reconstruction is assumed to be required for pavements 5 to 10 years past critical condition (i.e. between -5 to -10 years of residual life).

3.3 Calculating the budget required for a specified maintenance standard

3.3.1 Single defect rectification

The percentage of a road network requiring maintenance is obtained from the sum of the proportions of the network with defect severity levels which exceed the intervention levels specified in a maintenance standard. For example, Table 2 specifies critical defect severities at which various types of treatment are to be applied together with a priority order for their application. The proportion of the road network requiring reconstruction is given by the sum of the percentages of the network with remaining lives of between -5 to -10 years plus the proportion with rutting at or above 20 mm or with cracking or major deterioration at or more than 40% of the carriageway. These latter items are calculated by NETCOM from defect distributions such as those given in Table 1 and illustrated in Figure 1. This process is repeated for all treatment types given in the maintenance standard.

When a maintenance treatment is applied, it is assumed to eliminate the causative defect. For example, if 0.6% of the network is reconstructed to eliminate wheel track rutting of severity greater than or equal to 20 mm, this would alter the defect severity distributions by increasing the percentage of the network with no defects by 0.6%. However, the percentage of the road network that can be reconstructed will be limited by the maintenance budget specified for reconstruction. Figure 3 shows the distribution of rut depths prior to the application of a maintenance treatment and the distributions immediately after maintenance and after simulating the ageing process for one year. The figure illustrates the three phases used in modelling defect progressions from year to year. This is discussed further in section 3.6.

3.3.2 Multiple occurrence of defects

The procedure described above assumes that all defects occur independently of each other. For example it assumes that road sections with rutting have no other defects. In practice however, maintenance applied to eliminate one type of defect will treat other defects occurring on the same road section. For example, reconstruction applied to road sections with rutting greater than 20 mm will eliminate all other defects previously present on the reconstructed sites. In order to take account of this in NETCOM, the joint occurrence of more than one defect on the same road section has to be specified. Table 3 gives an example of the observed joint occurrence of defects extracted from the TRL database on the performance of maintenance treatments. The table shows the percentage of a road network with a given primary defect having other secondary defects on the same site. For example, Table 3 shows that out of the proportion of the road network which has rutting, 30% also has cracking, 5% has major deterioration and 3% has minor deterioration. The two-dimensional table is a simplified form of an otherwise complex multi-dimensional relationship. Many parts of a road network will have more than two types of defect occurring at the same time, and consequently the sum of joint occurrences for a primary defect in Table 3 may exceed 100%.

The multiple occurrence of defects shown in Table 3 is used in the calculation of the total percentage of a road network which requires maintenance. As each primary defect is treated, the severity distributions of secondary defects are also affected. For example, if 0.6% of the network with rutting greater than 20 mm is reconstructed, this would imply that approximately 0.18% of this, which also had cracking, will be treated (i.e. 30% of 0.6%). In this case the distribution of cracking severities is adjusted so that the percentage of the network with no cracking is increased by 0.18%. The method of adjusting the severity distributions of secondary defects assumes that all severity levels are affected by the applied treatment with the exception of those which would trigger higher order treatments.
In the above example, reconstruction will treat all severity levels of cracking. However, if the treatment had been an overlay, which does not treat road sections with more than 40% cracking (see Table 2), then only the distributions of cracking severities below the 40% intervention level would be treated by the overlay.

Table 3: Extent of multiple defects on sections of the road network

<table>
<thead>
<tr>
<th>Primary Defect</th>
<th>WT Rutting</th>
<th>WT Cracking</th>
<th>WC Major</th>
<th>WC Minor</th>
</tr>
</thead>
<tbody>
<tr>
<td>WT Rutting</td>
<td>-----</td>
<td>30%</td>
<td>5%</td>
<td>3%</td>
</tr>
<tr>
<td>WT Cracking</td>
<td>30%</td>
<td>-----</td>
<td>36%</td>
<td>5%</td>
</tr>
<tr>
<td>WC Major</td>
<td>7%</td>
<td>38%</td>
<td>-----</td>
<td>0%</td>
</tr>
<tr>
<td>WC Minor</td>
<td>4%</td>
<td>3%</td>
<td>0%</td>
<td>-----</td>
</tr>
</tbody>
</table>

The procedure described above is carried out in a stepwise process. The first step is to take the treatment assigned the highest priority in Table 2 and apply it to eliminate the first primary defect which can trigger the treatment. The next step is then to recalculate the distributions of secondary defects which occur on the same road sections with the primary defect according to the multiple occurrence proportions given in Table 3. This is repeated for all defects which trigger the treatment, and then for all maintenance treatments in the specified treatment order. When this is completed, the resulting distributions of defect severities represent the change in condition of the road network due to annual maintenance. In addition, the percentage of the network, calculated to have received treatment, represents the total maintenance requirement for the road network based on the specified maintenance standard.

3.4 Maintenance budget limits

The preceding section describes how defective parts of a road network would be treated if the budget was infinite. In practice, the amount of treatment that can be applied depends on the amount of money available for each type of treatment. In NETCOM, maintenance budget limits are specified for each type of treatment in each year of operation. Table 4 shows the proportion of the annual maintenance budget allocated to each treatment type together with the unit costs of treatment and the delay caused to road users for each maintenance scheme.

Table 4: Specification of annual maintenance budget limits

<table>
<thead>
<tr>
<th>Treatment Type</th>
<th>Proportion of Maintenance Budget (%)</th>
<th>Unit Maintenance Costs (£/m2)</th>
<th>Average Scheme Length (Lane km)</th>
<th>Period of Road Closure (days)</th>
<th>Delay Costs per Scheme (£/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconstruct</td>
<td>20</td>
<td>44</td>
<td>1.3</td>
<td>40</td>
<td>1,500</td>
</tr>
<tr>
<td>Overlays</td>
<td>29</td>
<td>17</td>
<td>1.2</td>
<td>30</td>
<td>1,500</td>
</tr>
<tr>
<td>Resurfacing</td>
<td>33</td>
<td>5</td>
<td>1.0</td>
<td>15</td>
<td>1,500</td>
</tr>
<tr>
<td>Surface Dress</td>
<td>4</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
<td>1,500</td>
</tr>
<tr>
<td>Patching</td>
<td>14</td>
<td>11</td>
<td>0.1</td>
<td>2</td>
<td>1,500</td>
</tr>
</tbody>
</table>

Total annual maintenance budget = £ 52.8 million
Percent of budget to be spent annually = 120.0 %
Maintenance treatments are assumed to be applied until the relevant budget is exhausted. If the total budget requirement calculated for the unconstrained case in section 3.3, exceeds the percentage treatable under the given budget, there will be a shortfall in the maintenance budget and parts of the road network will remain untreated. If however, the calculated budget requirement is less than the specified budget, then a surplus occurs and it remains unused with no transfer of funds allowed between the budgets for different treatment types. Sensitivity analyses can be performed using NETCOM to study the effects on budget allocations of varying the percentages spent on different treatment types and by applying a multiplying factor (expressed in percentage terms) on the initially specified total annual budget. This factor may exceed 100% in order to study the effects of larger budget allocations.

3.5 Calculation of road user delay costs

In addition to the calculation of maintenance expenditures, NETCOM also estimates road user delay costs due to maintenance applied over the network. This is based on user specified average maintenance treatment scheme lengths, together with the number of days of road closure per scheme and an estimate of the cost of delay to road users. An example of the specification of road user delay cost parameters is given in Table 4. For example, the average scheme length for reconstruction projects is given as 1.3 lane km, with an average maintenance duration of 40 days at a cost to road users of £1,500 per scheme per day. The length of the network receiving each type of treatment is obtained from the proportion of the network with defect severities given in the maintenance scenario as discussed in sections 3.3 and 3.4. The total road user delay cost is estimated from the number of maintenance schemes predicted for each treatment. It should be noted that in practice, user delay costs due to maintenance works are very site specific and should ideally be worked out using Quadro (4). This will require the user to make a number of assumptions to define a typical road network, its traffic flows, the diversions available and hence the resulting aggregated delay costs per maintenance scheme.

3.6 Pavement defect progressions

The final step in the modelling process is carried out after calculating the effect of maintenance on defect severity distributions. This predicts annual changes in the distribution of road network condition using observed distributions of the deterioration in defect severities. Table 5 illustrates a typical specification of the annualised change in WT rutting severity (see section 5). The first line in the table shows the observed progression in rut depth severities. For example, 93% of the road network with no signs of rutting in a given year will continue to show no rutting in the following year, but 4% of the network with no rutting will deteriorate to rut depths of between 1 - 4 mm, 2% will deteriorate to between 5 - 9 mm, etc. The second line shows the proportion of the network with between 1 - 4 mm of rut depth in the current year. In the following year, 90% of these will remain within the same band, but 6% will deteriorate to the next band between 5 - 9 mm, 3% to between 10 - 14 mm, and so on. It is envisaged that the distribution of defect progressions represented in Table 5 can be obtained from observed performance of the road network under study using data collected in previous years.

Table 5: Distribution of annual changes in rut depths

<table>
<thead>
<tr>
<th>Current Rut Depth (mm)</th>
<th>Rut Depth Severity Range in the following year (mm)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1 - 4</td>
<td>5 - 9</td>
</tr>
<tr>
<td>0</td>
<td>93%</td>
<td>4%</td>
</tr>
<tr>
<td>1 - 4</td>
<td>90%</td>
<td>6%</td>
</tr>
<tr>
<td>5 - 9</td>
<td>85%</td>
<td>11%</td>
</tr>
<tr>
<td>10 - 14</td>
<td>86%</td>
<td>11%</td>
</tr>
<tr>
<td>15 - 19</td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>&gt;=20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7
Table 5 is used in the modelling process to simulate defect progressions from year to year and is an alternative method of modelling pavement defect progression to those derived from regression analyses. The defect progression, or ageing process, is performed after maintenance has been applied since it is known that pavements recently maintained can show signs of deterioration soon after treatment. The relationships shown in Table 5 represent a network wide change in condition and may not be applicable to a single length of road in isolation. It represents the aggregated effects of traffic loading, the environment and averaged pavement structural performance over the entire network. It assumes for example that pavements in the road network were designed to take into account current traffic growth rates. However, if it is expected that significant deviations in the traffic loading pattern will occur, the effects of this can be integrated into the ageing process in Table 5 or indeed a separate run of the model could be done using a new defect progression table to account for the expected change.

3.7 Calculation of equivalent NRMCS Defects Indices

In order both to evaluate the model and to have a common measure of pavement condition, NETCOM also calculates an equivalent NRMCS defects index for each year of the analysis period. This is based on the NRMCS formula for calculating the defects index (5). The NRMCS defects index represents the average cost of maintenance required to repair a 100 m length of the road network in England and Wales to an acceptable condition. It is obtained by applying standard unit costs (based on 1977 prices) to maintenance treatments required to restore the entire road network to an acceptable condition. The defects index is calculated from the cost of applying one or more of the following maintenance treatments required to remove carriageway and footway defects; major strengthening or thick overlays, resurfacing, surface dressing, patching, kerbing or haunching. The cost is then averaged over the total number of 100m sections in the road network. A similar approach is adopted in the calculation of the equivalent defects index in NETCOM. The main difference, however, is that not all of the maintenance treatments included in the calculation of the NRMCS defects Index are applied in NETCOM. In addition, the defects index calculated by NETCOM is expressed as a percentage of the index calculated for the first year in the analysis period, whilst the NRMCS defects index, in contrast, is expressed as a percentage of the defects index calculated for a fixed year (i.e. 1977).

4 OUTPUT FROM NETCOM

NETCOM is designed to provide a number of output tables and graphs containing a wide range of information. These include summary information on annual maintenance expenditure by type of treatment, the predicted trend in road network condition, the distribution of defects over the network and a summary of any surplus or shortfall in the specified maintenance budget over the analysis period. Table 6 and Figures 4 to 8 show typical results obtained using data from a simulation of the performance of the NRMCS road network over the ten year period from 1977 to 1986. The simulation exercise is described in more detail in section 5.1 of this report.

Table 6: Summary statistics from NETCOM

| Analysis Period: | 10 (Years) |
| Total Maintenance Budget Specified: | £442 (£m) |
| Total Maintenance Expenditure Utilised: | £441 (£m) |
| Total Maintenance Budget Surplus: | £1 (£m) |
| Average Visual Condition Index (VCI): | 58 (%) |
| Average Structural Condition Index (SCI): | 13 (Years) |
4.1 Summary of costs and average condition

Table 6 gives an example of the summary information calculated by the model for the NRMCS road network over the period 1977 - 1986. For the worked example, the maintenance budget specified for this period is shown to be marginally greater than the total maintenance expenditure calculated by NETCOM. This is a result of a sub-optimal allocation of the maintenance budget between the different treatment types simulated in the worked example. A graph showing maintenance expenditure and maintenance budget as illustrated in Figure 4 can be used to identify the years in which sub-optimal budget allocations occur. NETCOM also gives an estimate of the total budget required to sustain a specified maintenance standard. This is calculated from the cost of various treatments required to keep defects within the road network at or below the condition specified in the maintenance intervention levels as described in section 3.1. A large budget requirement would result from a combination of high maintenance standards (i.e. low defect intervention levels) and high unit costs specified for maintenance treatments. The total budget requirement therefore reflects the amount of money needed to achieve the specified maintenance standard throughout the road network. In practice, a significant proportion of a road network will frequently be below the required maintenance standard and hence NETCOM will compute for the network under study a large backlog in the budget requirement over an extended period of time.

4.2 Maintenance expenditure by treatment types

In addition to the summary information described above, detailed information is provided on maintenance expenditure, maintenance shortfalls and surpluses, and the length of the road network treated in each year with different types of treatment. Figure 5 illustrates a sample output of the annual maintenance budget expenditure by type of treatment. The corresponding road network length receiving treatment in each year is illustrated in Figure 6.

4.3 Maintenance delay costs

Associated with each type of maintenance treatment is the cost of delays to road users during maintenance works. For each year of the program run, the total delay costs due to all treatments undertaken in each year, are calculated and can be displayed either as a table of annual costs or as a graph of delay costs incurred in each year of the analysis period.

4.4 Road network condition indices

Two types of road condition indicators are defined in the model representing network wide condition. The visual condition index (VCI) represents the percentage of the road network in 'good' condition. This is calculated from the percentage of the network which does not require maintenance. The assumption here is that the specified maintenance intervention levels represent both the engineers' and road users' perception of unacceptable road condition. Hence any part of the road network which does not require treatment (i.e. where none of the intervention levels have been exceeded) is assumed to be in 'good' condition. The second indicator, the structural condition index (SCI), represents the average number of years required for structural defects to progress to over 50% of the network. Figure 7 illustrates a simulated trend in the two condition indices.

4.5 Equivalent NRMCS Defects Index trend

NETCOM can also be used to plot the predicted trend in the equivalent NRMCS defects index described in Section 3.7. Figure 8 shows a graph of the predicted trend in the equivalent NRMCS defects index calculated for a road network by NETCOM. Figure 8 is intended to illustrate the predicted trend in road network condition in a similar manner to that illustrated by plots of the Defects Index given in annual NRMCS reports.
5 EVALUATION OF NETCOM

Three studies were performed to assess the performance and applicability of NETCOM. These were conducted to achieve two objectives; firstly to determine whether NETCOM gives acceptable results, and secondly to ascertain what calibration, if any, would be required in order to model observed trends in network condition more closely.

5.1 Study 1: Evaluation of NETCOM Relationships

The first study was designed to check the accuracy and applicability of the relationships built into NETCOM as well as to test the reliability of the program code. In the latter case, the objective was simply to ascertain that no errors exist in the program code. The main objective of the first case study however was to evaluate the relationships built into NETCOM, particularly those used to predict road network condition. An important feature of the defect progression mechanisms, or transition matrices, used in NETCOM is the ease with which observed deterioration trends can be used to derive models for predicting future network performance. NETCOM does not use fixed defect progression relationships, but rather, it provides a performance matrix which can be calibrated to match observed performance. The objective is to enable NETCOM to be used to study a wide range of networks with different characteristics. In each case, the transition matrices would need to be set up from observed trends in defect progressions for the network under scrutiny.

It was decided at an early stage to use results from the NRMCS to test the ability of NETCOM to simulate the observed trend in NRMCS Defects index. It was therefore necessary to see if the transition matrices in NETCOM could be calibrated to match defect distributions observed in the NRMCS. Initially an attempt was made to model the changes in NRMCS defect distributions using defect progression relationships extracted from the Performance of Maintenance Operations (PMO) database held at the TRL. The PMO database contains road condition data from pavement sections which have previously received some form of maintenance treatment. It was clear that this would give unrepresentative defect progression relationships as the database does not contain data on pavement sections prior to maintenance. Consequently, it was decided to calibrate the transition matrices in NETCOM using observed defect distributions from NRMCS results for the years 1977 to 1981. The severity distributions for wheel track rutting and cracking measured in 1977, 1979 and 1981 were obtained for this purpose from the Department of Transport to establish the prototype deterioration models. In addition, the distribution of remaining lives of pavements within the trunk road network (required as input for the Remaining Life model) was extracted from the NRMCS report for 1981. Table 7 shows the severity distributions for wheel track rutting and cracking obtained from NETCOM compared to the corresponding defect distributions extracted from results of NRMCS surveys conducted in 1977 and 1981. It may be seen from Table 7 that the calculated defect severities are largely within 5% of the observed values. This demonstrates that the transition matrices used in NETCOM can be calibrated and used to simulate changes in road network condition to greater effect than simple regression equations.

In order to test the ability of this technique to predict future road condition, the defect progression relationships derived from NRMCS data for 1977, 1979 and 1981 were then used to predict the condition of the NRMCS road network from 1982 to 1986. The results from the these trials are given in terms of the equivalent NRMCS defects index calculated by NETCOM in order to facilitate its comparison against observed NRMCS defect indices. Table 8 shows both the calculated and observed NRMCS Indices. It may be seen that the predicted indices calculated for the period from 1982 to 1986 are within 6 to 27% of the observed values. Figure 8 shows a plot of the trend in the equivalent NRMCS defects index. It should be noted that at this stage more significance is given to the shape of the overall trend line in Figure 8 rather than the actual values of the equivalent NRMCS defects index given in Table 8. This is a consequence of the fact that the equivalent NRMCS defects index calculated by NETCOM does not include all of the defects surveyed in the NRMCS and, for this trial exercise, is based on data from 1977 to 1981.
It will be appreciated that it is a relatively trivial matter to upgrade the relationships to include all data now available (i.e. up to 1990). It was also found that an increase of 25% to the maintenance budget (i.e. from £442m to £553m) gave simulated NRMCS indices close to the observed values. This is well within the margin of error for the maintenance budget when compared to the annual expenditure on 'all maintenance operations' given in the NRMCS reports.

Table 7: Comparison of observed and calculated defect distributions

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed (%)</td>
<td>Calculated (%)</td>
<td>Observed (%)</td>
<td>Calculated (%)</td>
</tr>
<tr>
<td>1</td>
<td>41.9</td>
<td>39.4</td>
<td>40.4</td>
<td>76.8</td>
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<td>2</td>
<td>36.1</td>
<td>34.7</td>
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<td>19.1</td>
<td>22.2</td>
<td>5.6</td>
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<td>4</td>
<td>2.8</td>
<td>3.9</td>
<td>3.3</td>
<td>1.2</td>
</tr>
<tr>
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<td>0.9</td>
<td>2.0</td>
<td>0.3</td>
<td>1.2</td>
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<tr>
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<td>0.0</td>
<td>0.9</td>
<td>0.0</td>
<td>0.4</td>
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</tbody>
</table>

Table 8: Simulated NRMCS defects index

<table>
<thead>
<tr>
<th>Year</th>
<th>Observed NRMCS Index</th>
<th>Calculated NRMCS Index (Budget = £442m)</th>
<th>Calculated NRMCS Index (Budget = £553m)</th>
<th>Deviation From Observed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>0.0</td>
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<tr>
<td>1978</td>
<td>102.2</td>
<td>102.1</td>
<td>97.6</td>
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<td>1979</td>
<td>95.6</td>
<td>109.8</td>
<td>104.0</td>
<td>8.8</td>
</tr>
<tr>
<td>1980</td>
<td>98.6</td>
<td>113.7</td>
<td>107.3</td>
<td>8.8</td>
</tr>
<tr>
<td>1981</td>
<td>104.0</td>
<td>123.5</td>
<td>112.7</td>
<td>8.4</td>
</tr>
<tr>
<td>1982</td>
<td>98.6</td>
<td>141.1</td>
<td>125.4</td>
<td>27.2</td>
</tr>
<tr>
<td>1983</td>
<td>100.9</td>
<td>146.0</td>
<td>122.6</td>
<td>21.6</td>
</tr>
<tr>
<td>1984</td>
<td>106.3</td>
<td>141.4</td>
<td>113.0</td>
<td>6.3</td>
</tr>
<tr>
<td>1985</td>
<td>123.8</td>
<td>149.2</td>
<td>114.6</td>
<td>7.4</td>
</tr>
<tr>
<td>1986</td>
<td>119.7</td>
<td>150.2</td>
<td>110.0</td>
<td>8.1</td>
</tr>
</tbody>
</table>

(a) data used to derive deterioration models
(b) data used to compare with model predictions
5.2 Study II: Sensitivity analysis of the relationships

The second study was designed to evaluate the sensitivity of the relationships built into the network model. There are essentially three algorithms which determine the performance of NETCOM in predicting the future condition of a road network namely: the defect progression relationships (transition matrices), the multiple occurrence of defects and the Residual Life Model.

The evaluation of the ageing processes involved making discrete changes to the defect progression distributions similar to that given in Table 5. The transition matrix shown in Table 5 may be divided into two parts. Firstly, the proportion of the network with any level of defect severity which will continue to have the same level of defect severity in the following year (referred to as the static proportion). Secondly, the proportion of the network which will deteriorate from one level of defect severity to the next (the dynamic proportion). The ratio between the static and dynamic proportions determines the rate at which the road network as a whole deteriorates. In general, the higher the ratio between the static to dynamic proportions, the lower will be the rate of deterioration. In addition it was observed that the most critical ratio was that for the first severity band. This represents the proportion of the network in a defect free state which will begin to show various defect severity levels in the following year. It was found that small changes in the static to dynamic ratio for the first severity band, resulted in significant changes to annual defect progression rates. The sensitivity of defect progressions to the static to dynamic ratio decreases for other defect severity bands demonstrating that the ratio for lower severity bands is more critical than that for higher severity levels.

The method of modelling the multiple occurrence of defects was found to have a significant effect on the calculated total budget requirement. By definition, the annual budget requirement is determined from the total cost of maintenance required to treat all parts of the road network with defect levels exceeding those given in a maintenance scenario. This is obtained by simulating the application of maintenance treatments on defective parts of the network. Consequently the model simulates treatment of large proportions of the network in order to satisfy all defect intervention levels. If a high degree of multiple occurrence of defects is specified, then maintenance treatments applied to eliminate one defect will also eliminate others if appropriate. This results in a lower total budget requirement. In addition, the multiple occurrence relationships also affect the visual and structural condition indices for the same reasons. However, the effect is less pronounced with maintenance carried out under budget constraints. This implies that in practice, due to budget constraints, much less maintenance is carried out than is ideally required and hence the effects of the multiple occurrence of defects is reduced.

In addition to the effects of the transition matrices and the multiple occurrence of defects, it was found that the distribution of the network in various states of remaining life required for the Residual Life Model, significantly affects the annual trend in defect severity distributions. This is largely because NETCOM executes algorithms from the Residual Life Model to apply reconstruction and overlays to parts of the network before all other defects are treated. Thus a higher priority is given to structural maintenance than to other types of maintenance.

5.3 Study III: Effect of changes to maintenance standards

A significant factor in the modelling process is the specified maintenance standard. This was found to affect all aspects of the simulation process, in particular defect distributions and the calculated budget requirement. It should be noted that stringent maintenance standards result in lower rates of defect deterioration from year to year because increasing proportions of the road network are in defect free states. However the consequence of this are very high values for the calculated budget requirement.

The other important factor affecting the predicted maintenance is the size of the specified annual maintenance budget. Changes to the maintenance budget result in significant changes to defect severity distributions from year to year. For example, it was found that a 25% increase in the maintenance budget significantly altered the trend in the simulated NRMCS defects index to a level comparable with the observed values as illustrated in Table 8.
6 CONCLUSIONS

A prototype model for road networks has been developed which can be used to predict the effects of maintenance funding levels on their condition. NETCOM is intended to be used by engineers, planners and administrators in charge of road maintenance as a general purpose tool to study the consequences of a wide range of maintenance scenarios. The user-friendly front end built into the model enables a wide range of road networks with different characteristics to be analysed. Detailed results from the model can be viewed using the versatile data display module.

NETCOM incorporates a versatile mechanism for modelling a variety of defect progressions which can be easily calibrated to match observed network performance. This has been used to simulate the deterioration trends on parts of the road network in England and Wales over the projected period from 1982 to 1986 when primed with observed deterioration from 1977 to 1981. Whilst the ability of the model to predict future condition will be further enhanced with greater access to more recent data (i.e. up to 1990), it is encouraging to note that even with the existing relationships derived using data from 1977 to 1981, the model predicts the NRMCS Index in 1986 to within 8% of the observed value.

The three studies conducted to test NETCOM show that it is a robust tool which, given adequate data, will produce acceptable results. However, in view of the limited scope of the sensitivity studies, at this stage each application of the model should be regarded as experimental. Nevertheless, given appropriate care, there seems every reason to expect the model to produce reliable results. In its present form, NETCOM requires carefully synthesized data, for example, to calibrate the defect progression relationships. This limits use of the model to engineers with expert knowledge of the relationships built into the model.

Although NETCOM has been developed to a state where it can be applied, its performance depends on the quality of data used to calibrate the relationships built into it. Further advances to the model could be made with the integration of vehicle operation cost (VOC) relationships as a function of pavement condition. In addition, the model will benefit from improved defect progression relationships which take into account both traffic loading and significant changes to the structural characteristics of pavements in a road network.

7 ACKNOWLEDGEMENTS

The work described in this report forms part of the research programme of the Pavement Engineering Division of the Highways Group of the TRL. The work was carried out at the University of Birmingham under the co-ordination of Mr P B Still, Mr M H Glover and Mr B J Slee. The computer model was coded by Mr L. Drazek at the University of Birmingham under contract to the TRL. The financial support of the TRL is acknowledged.

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Fig. 1. Typical Defect Severity Distributions.

- Rut depth severity (mm)
  - 0
  - 1-4
  - 5-9
  - 10-14
  - 15-19
  - >=20

- Wheel track cracking (percent)
  - 0
  - 1-9
  - 10-19
  - 20-29
  - 30-39
  - >=40

- Major deterioration (percent)
  - 0
  - 1-9
  - 10-19
  - 20-29
  - 30-39
  - >=40

- Minor deterioration (severity)
  - 0
  - 1
  - 2
  - 3
  - 4
  - 5
Fig. 2. NETCOM Flow Diagram

CONDITION SURVEY

INITIALISE DEFECT DISTRIBUTIONS

MAINTENANCE STANDARDS

CALCULATE TOTAL MAINTENANCE NEED

MAINTENANCE BUDGET LIMITS

CALCULATE TOTAL MAINTENANCE AND EFFECT ON NETWORK CONDITION

CALCULATE ROAD USER DELAY COSTS

CALCULATE EQUVALENT NRMCS INDEX

END OF ANALYSIS PERIOD?

Yes

OUTPUT

RESIDUAL LIFE MODEL

MULTIPLE OCCURRENCE OF DEFECTS

DEFECT PROGRESSION RELATIONSHIPS

CALCULATE NETWORK CONDITION IN "YEAR + 1"

YEAR + 1

No

MAINT. BUDGET CONDITION TRENDS, COST SUMMARIES
Fig. 3. Rut Depth Progression

![Rut Depth Progression Chart]

Fig. 4. Maintenance Budget and Expenditure

![Maintenance Budget and Expenditure Chart]
Fig. 5. Annual Maintenance Expenditure

Year of analysis

Fig. 6. Length of Road Network Treated

Year of analysis
Fig. 8. Equivalent NRMCS Index

Year of analysis

Deterioration

Improvement

Year of analysis