The estimation of environmental impacts for transport policy assessment

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Abstract. The analysis of traffic and transport alternatives by means of mathematical models is well-established as an aid to design and economic assessment. The emphasis in the past has been on the traffic effects of the policies involved, and it is only recently that methods have been devised to give approximate estimates of the levels of and degree of exposure to noise, air pollution, and pedestrian interference as an essential part of the study of traffic and transport proposals. This paper covers the design and use of special models, and the collection and analysis of noise and pollution data in a form suitable for forecasting. The application of the techniques is illustrated by means of models of Coventry drawn from the Transportation Study report. One model was designed to simulate conditions in 1967, and another to simulate extreme (and unlikely) conditions in a future where congestion and pollution are both severe. The environmental impact estimation process has been integrated into the RRLTAP transportation modelling research system. The strengths and weaknesses of this approach are brought out by an illustrative application. Special attention has been paid to the different pollution estimation equations as a basis for forecasting, and the degree to which a particular choice could affect the results.

Introduction
Transportation planning models developed and used during the last decade have been concerned mainly with traffic flow and demand variables. The rapid growth of public concern about noise pollution, atmospheric pollution, and environmental disturbance has not yet been adequately matched by the ability of the analysts to forecast these impacts: a considerable amount of data has been collected and some progress has been made in sorting this out into the form of empirical relationships. The creation of the Environmental Protection Agency (EPA) in the USA has accelerated this work, and several analytic tools are now available. Initial applications have been made by Wendell et al. (1973), Joyce and Williams (1974), Gilbert and Crompton (1970; 1972a; 1972b), Department of the Environment (1972), Lassiere (1973), and City of Coventry (CTSG, 1972) among others. These applications have met with mixed success, but the Coventry noise impact study (Vass, 1972) showed that the use of noise equations for $L_{10}$ could be applied to forecasts of traffic flow over a network to give a helpful appreciation of the effects of flow changes, and design guidance has been given on the basis of $L_{10}$ values (Department of the Environment, 1972). The evaluation of the patterns subsequently produced has not been straightforward and work to find an effective technique to employ such noise forecasts is continuing (Waller, 1972; Dowling, 1972; Joyce and Williams, 1974). Substantial effort is required to produce even purely descriptive results such as those of Eyles and Myatt (1970). Automated or semiautomated techniques are needed so that such detailed efforts may be used to best effect in the areas of conflict. Evaluation of the subjective aspects (for example, Hedges, 1973) must at some point also be put into a more readily manipulated form. One characteristic of the attempts to determine the empirical relationships between noise, pollution, and visual intrusion data is that the variables found effective in explaining the variance are not always the same as the variables used for transport forecasting. Where possible, transportation models and the categories of data collected for noise levels, vehicle exhaust emissions, atmospheric pollution
levels, and visual impacts should both be adapted to allow swift transformation of empirical results into forecasting evaluation models. We can provide only detailed differential impact statements at present, but these will ensure that a wider range of the effects of transport policies are considered, and reduce the undue influence that traffic flow measures acquire within such assessments because of the relatively detailed and numerical form of their presentation.

The inclusion of externalities such as noise and vehicle exhaust emissions within the framework of transport investment alternatives brings with it a number of conflicting requirements. The current state of the art of analytical transport modelling tends to treat these effects as by-products of otherwise satisfactory alternatives, and may therefore conflict with the standards set by agencies such as the EPA. The difficulties inherent in economic assessment of noise levels and emission concentrations make the design of an 'optimal' system of traffic control an intractable task. Analytic methods exist, but still await the specification of an objective function that includes travel cost, consumer surplus, and noise-atmospheric pollution impact on commensurate scales.

A practical approach to the problem of incorporating transport and environmental impact variables is to state a set of standards that must be met for each environmental impact measure. The flow assignment problem may then be solved with these additional constraints, but using only the 'simple' transport variables in the objective function. Horie and Fan (1973a; 1973b) take this line of attack for two simplified examples. If an assignment of traffic flow is determined by an optimising model, shadow prices may be deduced for the 'cost' of meeting each constraint. These 'costs' express the opportunities lost by the imposition of each constraint under the condition simulated.

If increasing concern with atmospheric pollution levels, noise levels, and other traffic related environmental impacts gives rise to arbitrary standards in the form of upper limits on vehicle exhaust production, noise intensities at specified points, and local exhaust emission concentrations, then these will operate as constraints on the flow-demand optimisation, whatever the objective function, and these variables will not appear in the objective function at all.

Arbitrary standard setting of this type could become very costly in terms of resource utilisation. The constraints that represent the standards will affect the traffic flow distribution desired without providing any direct means of modifying traffic behaviour to meet the local standards. This suggests that the desired objectives may be expressed in terms of a minimisation of privately perceived user costs, subject to the new constraints, which will finally produce a pattern of flow and demand that meets the standards. But there is no assurance that private behaviour will be modified to allow this situation to occur unless it is influenced in some way.

Some pattern of regulation or of charges must be generated to allow the overall standards to be met on the ground by affecting traveller behaviour. Road usage is therefore charged for in order to influence private free decisions which then combine to meet the standards for local concentrations of noise and pollutants. This will satisfy the regulations, and enable the 'best' solution both to be found and to be achieved. This approach does not ascribe any benefit to the achievement of the standards which are imposed and which constrain the system's behaviour. To calculate the losses incurred in meeting the standards at minimum (generalised) cost to the travellers requires the treatment of the unconstrained and constrained situations as pre- and post-situations for a normal economic assessment. In most cases this will give a net 'loss' in both consumer surplus and resource terms, unless a value can be given to achieving the standards specified. The consequent 'loss' is therefore effectively a shadow cost of the standards for this particular situation.
If the behaviour of travellers in this optimising model is made sensitive to charges, a set of charges can be determined which will produce the desired situation: in effect this is an extension of arguments used to discuss road pricing (Wigan, 1974a).

The approaches discussed so far are independent of any valuation of specified levels of pollutant. The inclusion of (negative) valuations of pollution levels as components of the objective function developed in the formulation presented earlier would influence both selfish and socially maximising patterns. The shadow costs attributable to dual variable and objective function variations would then reflect this set of pollution valuations.

If generalised mathematical programming techniques are used for this investigation there are further technical properties which can be exploited. The objective function can be extended to include each of the elements of the situation to which we wish to ascribe a value, and an indeterminate coefficient given to each. The optimisations can then be carried out in such a manner that the relative weight of each element can be varied independently. Some variation of these coefficients can be achieved without further optimisation, as the constraints limit the degree to which the optimal traffic flows and charges can respond. If a number of sets of different environmental standards are applied to the network and adjusted to give the same value of the objective function after the constrained optimisation, then a series of curves of equal effect can be constructed and show how each environmental standard interacts with the others through the behaviour of the traffic. In many cases it may prove to be impossible to find any traffic solution which can satisfy the environmental standards at a given total cost: but this, too, will help to clarify the issues.

Within the context of transport planning, any systematic assessment procedure for noise and exhaust emissions must be based on transport planning variables which can be forecast or modelled. Characteristics of this approach are:
1 quantification of these externalities permits calculation of each externality on the solution obtained;
2 upper bounds on the local values of each impact intensity can be included without explicit regard for the total economic costs of setting such standards;
3 the 'ideal' optimising approach where the valuation of each level of each impact intensity has a direct influence on the traffic flow allowed and the means of control or persuasion required to obtain it.

At each stage it is possible to set up simplified analytical models to determine the most effective way to proceed, and to highlight any gaps in our empirical knowledge. This line of approach is essentially medium-term in outlook, and it may well take too long to produce effective results for current needs.

An intermediate approach is to marshal all the available empirical data on the production of noise levels and emissions, and apply them to a simulated transport system. This requires a suitable system of analysis in order to obtain the best estimates for each local circumstance, and the resulting outputs of simulated impacts may then be applied both to recheck the empirical relationships used and to obtain systematic expressions of the likely problem areas on the networks under study.

PANIC is a system of this kind: it is an acronym for Pollution, Pedestrian, and Noise Impact Computation, which expresses precisely the short-term objective specified for the model. The PANIC approach requires all transportation model-related data to be in an appropriate format to allow empirical equations to be used over their calibrated regions. Several such equations may be applicable to any particular part of the network. This framework was completed in early 1973 (Wigan, 1975) and has been in use since then.
Systems analysis

The aim is to provide a set of submodels that bring together the significant transport variables in a form suitable for environmental calculations to be made. In the following sections the manner in which this has been done is explained, and the particular submodels defined as they have been fitted into the general framework under which the RRLTAP general purpose transport modelling system operates (Wigan and Bamford, 1971).

The essential requirements for environmental calculations are:

1. data on a link by link basis on road widths, households, retail shopping space, numbers of person-hours at risk, etc;
2. traffic flow data, including traffic composition;
3. a framework capable of bringing together all the data for each link in a form suitable for each of the empirical relationships that can be applied;
4. a framework for defining the conditions of applicability of each of a range of empirical equations;
5. manipulation of output files and associated data files (for example $L_{10} \times$ households $\times$ exposure time);
6. graphical presentation of the results in the form of histograms, cumulative frequency diagrams, etc;
7. some form of accumulating the different degrees of annoyance felt by individuals to the same pollutant exposure level and duration.

If the calculations are properly specified, each component of this system can be of general utility and can include the introduction of parametric changes and variations of the empirical formulae employed.

The required operations listed above all belong to the general family of network and matrix manipulations that are useful within transportation planning systems. The natural place to include environmental calculation models is within a general transportation planning system. The addition of extra functions (1, 2, 5, 6, and 7) would then be of wider application. The RRLTAP control system was designed specifically for this purpose, and the PANIC environmental subsystem has therefore been included simply by adding suitable routines.

The main advantage of this simplified approach is that a detailed and empirically based set of impact values can be obtained in the course of normal day-to-day traffic model analyses so that these impacts can be given due weight in the design and assessment stages.

Clearly there is much room for improvement at all stages of the process: the empirical equations are likely to be too limited in scope, the criteria for evaluation of impact levels are likely to be inadequate, and the inclusion of other traffic related disbenefits such as physical severance and visual intrusion cannot readily be included. The object of the PANIC model is to marshal the best directly available data into a form where it can be used to improve our appreciation of the situations that we wish to study, and to stimulate more work on these lines.

The main value of this scheme is the ability to interpret traffic and transport predictions in environmental terms by exploiting the ready access to calculation and display procedures provided by integrating traffic models, transportation, and empirical environmental data.

An American approach

The US Federal Highways Administration system (1973b) has a rather different orientation, but is designed to provide a similar synoptic view of environmental factors for road proposals. The Special Area Analysis (SAA) developed in America
has broader coverage, but makes little attempt to estimate noise and other pollution concentrations. The noise component of SAA emphasises the $L_{50}$ level for peak hour traffic, which is the basis of the 1972 US noise standards (Federal Highways Administration, 1973a). The $L_{50}$ equations used are drawn from the Highway Research Board (1971) design guide, and distinguish between 'trucks' and 'autos':

autos:  
\[ L_{50} = 10 \log q_a - 15 \log d_r + 30 \log V_t + 10 \log \left( \tanh(1.19 \times 10^{-4}) \frac{q_a d_r}{V_t} \right) + 29 , \]

trucks:  
\[ L_{50} = 10 \log q_t - 10 \log V_t - 15 \log d_r + 10 \log \left( \tanh(1.19 \times 10^{-4}) \frac{q_t d_r}{V_t} \right) + 95 , \]

where

$q_a$ is the volume $h^{-1}$ of autos,
$q_t$ is the volume $h^{-1}$ of trucks,
$d_r$ is the distance from the roadway in feet,
$V_t$ is the average traffic speed in mph.

The underlying assumptions made on the determination of speed are essentially those for uncongested conditions, and the form of these equations shows how the SAA is directed more towards trucks or suburban roads with high service levels. No provision is made for weighting the noise levels according to numbers of people or the length of exposure of these people.

The air pollution phase of SAA is explicitly restricted to air pollution emission volumes and makes no attempt at all to estimate concentrations. The emphasis on meteorological conditions and diffusion factors in the discussion of this emission shows how different are the expectations of stability in such forecast conditions in the USA and the UK.

As the estimation of air pollution concentration is not attempted, the impact of airborne emissions is similarly neglected. The SAA does however go on to cover other environmental aspects at a similar level, and is in this respect at least, more broadly based than the simple PANIC system design presented here.

The production of vehicle exhaust emissions such as carbon monoxide, smoke, lead compounds, nitrogen oxides, and various hydrocarbons is also related to traffic flow and composition, but the link between the pollutant levels and the corresponding traffic is complex. The diffusion of airborne pollutants through the atmosphere depends not only on the production rate but also on wind speed, temperature, humidity, and the layout of the surroundings. While emissions may be readily linked to the traffic flow the estimation of the concentrations of atmospheric pollutants requires a diffusion model. For one particular airborne pollutant—carbon monoxide—such a model exists and has been checked in several locations. The APRAC-1A model for carbon monoxide, built by the Stanford Research Institute (Manusco and Ludwig, 1972), has been obtained to complement the PANIC system. The input to APRAC-1A was generated by a further Stanford model, which was designed to simulate traffic over several time periods during the day. This model (DHTM—Dynamic Highway Traffic Model) (Sandys, 1971) is also available but its place is currently taken by RRLTAP for the purposes of the PANIC model work. For the restricted purposes of PANIC the greater complexity of DHTM is not worthwhile, but further work may well justify its use, especially on a local scale where the DHTM has considerable advantages in detailed representation of queues and traffic control systems. Neither of these models is really suitable for the local environmental scale, where no effective tool has yet been produced.
Estimating equations for environmental factors: noise

The transport impacts initially included in PANIC are the noise levels and exhaust emissions produced by motor vehicles with provision for delays caused to pedestrians; accidents can be handled in the same way. The noise produced by a stream of vehicles is of interest in the form of combined noise levels at particular locations, usually either on pavements or at house or shop fronts. The combination of noise from several different sources to produce a resultant level at a given point is discussed by Nelson (1973) and Robinson (1969).

There are a considerable number of studies on the noise levels produced by traffic flow, and a variety of empirical relationships have been derived from these measurements. The central question from the point of view of PANIC is to determine the set of variables and their functional forms to be included in the 'general' equation. The set chosen is given in table 1. The eleven coefficients take different values for each set of empirical data analysed and reported in the references, but the range of functional forms is adequate to cover work from several sources.

A useful example of the use of such an equation (set up in appropriate terms for the $L_{10}$ noise index) is an environmental study of the City of Coventry (CTSG, 1972) carried out by the Department of the Environment in conjunction with the Coventry Transport Study Group. The equation used for $L_{10}$ estimates was:

$$L_{10} = 43 + 10^{-2.3} \lg [Q(1 + 0.09p_t)]$$

which is a version of one of the Imperial College empirical equations for non-free-flow urban conditions when a particular traffic arrival pattern is assumed to obtain at every point.

This raises most of the relevant points for discussion: the functional forms available for equation definition will clearly allow different measures (for example $L_{90}, L_{50}$) to be expressed as a set of eleven coefficient values. The $L_{10}$ index (defined as a noise level in dBA exceeded for 10% of the time) has been found to correlate tolerably well (Lassiere, 1973; Griffiths, 1968) with other measures of noise nuisance, and—surprisingly—with some measures of pedestrian delays, although other measures of noise nuisance have also been proposed.

There are several centres of continuing work on empirical noise measurements. Those on which we have drawn include Imperial College (Gilbert and Crompton, 1970; 1971; 1972), TRRL (Harland, 1970; Watkins, 1972; Wigan et al., 1974; Colwill, 1973) and the National Physical Laboratory (Delany, 1972a; 1972b). Other centres are also carrying out substantial programmes of descriptive work, but the variety of conditions covered by these sources is adequate to set up an analysis system as long as provision is made to experiment with sets of coefficients determined elsewhere.

On the basis of some measurements made in Edinburgh (Gilbert and Crompton, 1972a) the noise level exceeded 50% of the time ($L_{50}$) was not significantly dependent on either the percentage of heavy goods vehicles or on vehicular speeds for speeds below 20 mph. Stephenson and Vulkan (1967) conclude that a special weighting (of about 5 times) for heavy goods vehicles was still justified for $L_{50}$ by the same class of data. Either conclusion can be incorporated within the scheme of coefficients and functional forms listed in table 1. It should be emphasized that for $L_{10}$ measurements, Stephenson and Vulkan conclude that a weighting of 10 times for heavy vehicles definitely improved the fit to the data and Joyce and Williams (1974) adopt the same value. Stephenson and Vulkan's data were drawn primarily from the Edinburgh measurements made by Gilbert and Crompton (1970) on 170 sites and from other data collected in London. Equation 5 of table 1 was the best obtained, and a version with $T$ set to 0.85 was used for the Coventry work (Vass, 1972).
Table 1. A selection of equations for hourly $L_{NN}$ from different sources.

<table>
<thead>
<tr>
<th>Equation format in PANIC</th>
<th>$L_{NN}$</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$l$</td>
</tr>
<tr>
<td>1 Nelson (1974): free-flow and urban conditions; low-medium flows; $30 \leq Q \leq 4000$</td>
<td>$L_{10}$</td>
<td>27·4</td>
</tr>
<tr>
<td>2 Delany (1972a): free flow; medium-high flows; $780 \leq Q \leq 4500$</td>
<td>$L_{10}$</td>
<td>31·0</td>
</tr>
<tr>
<td>3 Gilbert and Crompton (1970): medium flow; 311 urban sites</td>
<td>$L_{10}$</td>
<td>58·58</td>
</tr>
<tr>
<td>4 Gilbert and Crompton (1972a): medium flow; one-way streets (Camden data)</td>
<td>$L_{10}$</td>
<td>49·8</td>
</tr>
<tr>
<td>5 Gilbert and Crompton (1970): Coventry study when $T = 0·85$; $Q = 0·2600$ vph; $p_t = 0·40%$</td>
<td>$L_{10}$</td>
<td>44·37</td>
</tr>
<tr>
<td>6 Gilbert and Crompton (1972a): medium flow; one-way streets (Camden data)</td>
<td>$L_{10}$</td>
<td>56·75</td>
</tr>
<tr>
<td>7 Copley (1972): average daily flow; $C = 0$ for freeways; $C = 6$ for twisty steep roads</td>
<td>$L_{10}$</td>
<td>C·16</td>
</tr>
<tr>
<td>8 Gilbert and Crompton (1972b):</td>
<td>$L_{10}$</td>
<td>56·6</td>
</tr>
<tr>
<td>9 Wigan et al. (1974):</td>
<td>$L_{10}$</td>
<td>54·0</td>
</tr>
<tr>
<td>10 Wigan et al. (1974):</td>
<td>$L_{50}$</td>
<td>32·0</td>
</tr>
<tr>
<td>11 Wigan et al. (1974):</td>
<td>$L_{90}$</td>
<td>30·0</td>
</tr>
<tr>
<td>12 Gilbert and Crompton (1970):</td>
<td>$L_{90}$</td>
<td>35·05</td>
</tr>
</tbody>
</table>

Key: $l$ is a constant; $p_t$ is the percentage of heavy goods vehicles in two-way traffic; $\overline{V}$ is the vehicle space mean speed averaged over two-way flow (mph); $Q$ is the total two-way flow (vph); $d_{rel}$ is the distance from the road centreline to the point of equation application (m); $\tau$ is the Gilbert and Crompton index of traffic arrival patterns; $d_{rel} - d_t$ is the half width of the roadway (m); $L_{10}$ is the noise level in dBA exceeded 10% of the time; $C$ is a correction factor for different types of roads.
The rationale for each of the research groups was different, and the variation in the $L_{NN}$ indices was accounted for in different ways. The Imperial College approach was to try to find a proxy variable for acceleration noise and the traffic arrival patterns that gave rise to it. This led them to define a ‘$T$’ index of arrival patterns, which ranged from about 0.94 for flows of up to 400 vehicles h$^{-1}$, 1.08 for flows up to 900 vehicles h$^{-1}$, 1.06 for flows up to 1700 vehicles h$^{-1}$, and to 1.13 for vehicle flows above this figure. These are qualitative figures, as the ‘meaning’ of $T$ has been lost in the definition of appropriate flow levels. $T$ values of 0.85–1.15 are loosely described as ‘random’ flow. The practical range of $T$ values lies between 0.3 and 3.3, and a range of 0.5–1.5 appears to be adequate to characterise most types of flow observed in practice. Clearly such a qualitative variable demands an independent estimating equation if it is to be of any real use, and a number of attempts were made (Gilbert and Crompton, 1971a) to find an appropriate predictive equation. None of these were entirely successful, and the best equation deduced explained less than half the variance of the measurements. This equation was

$$r = 0.45 \exp \left( 0.026 \frac{f^2 Q_{P_t}}{d_{rel} - d_t} \right),$$

where $f$ is the frequency of major intersections per 1000 yards, and the other variables are as defined in table 1. The data on which this equation is based were limited to central Edinburgh and Greenwich, and the range of observed Arrival Pattern Index ($T$) values was limited to 0.5–1.6. The utility of the Arrival Pattern Index for quantitative work is therefore as yet unproven, although the qualitative value of the index for descriptive purposes is better established.

The National Physical Laboratory work, led by Delany (1972a; 1972b), included a systematic study of the likely critical variables before measurements were done. The resulting equation (2 of table 1) for free-flow conditions is perhaps the most useful in the calibrated range from 800–4000 vehicles h$^{-1}$ at medium speeds. It should be noted that the data on which this 1972 report was based were collected in the early 1960s and thus the heavy goods vehicle contribution may no longer be effectively represented in view of the trend to larger vehicles. Nelson (1972) used a similar approach, also including ‘speed’, but it will be noted that although the propagation constant of $-16$ differs from Delany’s $-14.7$, the effect on $L_{10}$ estimates is marginal at normal distances at which $L_{10}$ values are likely to be needed in practice. Copley (1972) covers propagation variables in considerable detail. The use of a ‘speed’ variable raises difficulties for forecasting, as it is not clear whether the space or time mean speed is used. In addition, any usable forecast of speeds in transport planning projections will require special equilibrium techniques to obtain the required degree of internal consistency. For a detailed study of this question see Wigan (1974a; 1974b).

The Highway Research Board (1969; 1971) has published engineering design guides for some appropriate circumstances. Measurements such as $L_{10}$, $L_{50}$, and $L_{90}$ can also be expressed in the terms of table 1, and alternatives such as the Traffic Noise Index (TNI) may then be derived. The limited set of equations discussed and ranges of applicability quoted suffice to show that to make best use of them all would require considerable care. Recent work (Wigan et al., 1974) has confirmed that equations of this general form can be transferred with some confidence from areas in which they were derived to different districts.

Any model framework designed to utilize these equations should therefore be flexible enough to allow any given equation to be applied only under specified circumstances, and to enable the model operators to vary coefficients and equations as the local circumstances demand. PANIC satisfies these requirements.
The links between objective measures such as 18-hour or 24-hour $L_{10}$, $L_{90}$ indices and overall dissatisfaction have been examined by Griffiths (1968), Griffiths and Langdon (1968), and others. The weighted combination of $L_{10}$, $L_{90}$ that forms the Traffic Noise Index showed better correlations in this early work than the simple $L_{10}$, $L_{90}$ values themselves, although the 18-hour $L_{10}$ (that is the sound level exceeded only 10% of the time over the period 0600 hours–2400 hours) was a better indicator than $L_{10}$ defined over 24 hours. Further measures incorporating the variability of noise levels have also been put forward, and further discussion and references are given by Wendell et al. (1973), Griffiths (1968), Robinson (1969), and the TRRL working group (1970). An illuminating analysis of the composition of the events and vehicles that provide noise impacts above $L_{10}$ is given by Christie et al. (1973). In this analysis the dominant effect of heavy goods vehicles is given quantitative foundation. A special analysis of the influence of goods vehicles on noise levels is given in Wigan et al. (1974) and is based on data from six different towns.

The work referred to here is only a sample of the current activity, and is not exhaustive. Many groups are currently working in this field, amongst them Johnson and Saunders (1968), Struwe (1972), Blitz (1973), Joyce and Williams (1974). There is as yet no commonly accepted basis for noise predictions, and the empirical relationships discussed here are representative of those available in March 1973 when the review of other work and the design of PANIC (Wigan, 1975) was completed. The same dateline applies to the vehicle exhaust emission and pedestrian impact equations discussed in later sections, although later work is referred to in cases where it is an advance over 1973 sources.

**Air pollution**

A variety of empirical relationships for atmospheric pollution caused by traffic have been produced. An Imperial College group have achieved a variance explained by empirical relationships rarely exceeding 50%, and this compared unfavourably with the 85%–95% variance explanation obtainable from some empirical noise level relationships, although other groups have obtained considerably better fits—to some sets of data. The central difficulty with pollutant concentration analysis is that, unlike noise production, the effects from different times and from different places combine to produce the local levels of pollutant concentration that can actually be observed. The emission rates can be reasonably well-defined and codified in equation format, but the local concentrations do not bear a close relationship to production levels, and a full gaseous mixture and diffusion model is required to relate emission productions and local concentrations. The quantitative aspects of pollutant prediction thus fall into three distinct classes:

1. production equations;
2. diffusion processes;
3. concentration equations.

The bulk production of different airborne pollutants is the simplest quantitative statement that we can make. The 1965 Delaware Valley figures (Kurtzweg, 1973) for emissions from transport systems are given in table 2. The significant transport contribution to carbon monoxide production, together with the large absolute production of the gas, had led to a concentration on the measurement and analysis of emissions and concentrations, perhaps also influenced by the toxic effect that can be produced at high concentrations in an enclosed space although there is little evidence of toxic concentrations occurring at the kerbside in the UK. Dockerty and Bayley (1974) report that 300+ ppm h$^{-1}$ of exposure to carbon monoxide produces a just perceptible effect, 600+ causes nausea and headaches, while 900+ is the danger threshold.
Sherwood and Bowers (1970) point out that diesel exhausts contain far less carbon monoxide than do petrol exhausts, emphasizing the disparity in emission characteristics of the two types of engine. Rose et al. (1965) showed that exhaust production could be expressed as

\[ \text{emissions} = A (\text{route mean speed})^{-B} \]

The measured and predicted values of \( A \) and \( B \) are given by Klein and Moon (undated) and Kurtzweg (1973), and are used by Moon at Stanford (Moon and Ludwig, 1972) as input to the APRAC-1A carbon monoxide production and diffusion model (Manusco and Ludwig, 1972; Ludwig et al., 1973).

The Moon model of carbon monoxide production (Curry and Anderson, 1971) was input to the APRAC-1A diffusion model, and the whole system was linked to the Dynamic Highway Traffic Model of Sandys (1971) to form a complete traffic model of carbon monoxide production and dispersion; a complex and awkward synthesis albeit a useful one (see Dabbert and Sandys, 1974).

Work on direct prediction of kerbside concentrations of exhaust emissions has focused on carbon monoxide. Gilbert and Crompton at Imperial College produced several equations (table 3) of varying degrees of complexity, but there was little improvement in \( R^2 \) with the more complex equations, even when petrol-engined vehicles were carefully isolated in the analysis.

Other UK work includes that of the Environment Division at TRRL (Watkins, 1972), where a measurement programme is under way to determine the concentrations of different pollutants in areas affected by traffic. The first reports of this programme are based on measurements in Reading (Colwill, 1973). The pollutants measured were carbon monoxide, hydrocarbons, oxides of nitrogen, sulphur dioxide, lead, and smoke. Two sites were used, one immediately adjacent to a busy road, and the other well away from heavy traffic. Measurements were continued through the summer and winter of 1971. The results of this and subsequent work are given in table 3 for a range of pollutants.

The linear and nonlinear equations presented in table 3 provide direct estimates of the concentrations under standard conditions at points adjacent to flowing traffic. The impacts suffered by those further away from the traffic are also important, and diffusion effects must therefore be considered.

Horie and Fan (1971; 1973a; 1973b) used a steady state mass balance equation to forecast local concentrations, in much the same way as Gilbert and Crompton (1971b) fitted their kerbside carbon monoxide concentration measurements. Stanford Research Institute set up a more detailed diffusion model specifically for carbon monoxide predictions. Initial attempts to reproduce measured concentrations in San Jose were not entirely successful, but with greater attention paid to canyon diffusion and mixing effects the APRAC-1A model achieved considerable success in reproducing the measured carbon monoxide concentration levels in St. Louis over the whole day.

Table 2. Bulk emissions in the Delaware Valley.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Production levels</th>
<th>percentage of all such emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>tons day(^{-1})</td>
<td></td>
</tr>
<tr>
<td>Oxides of sulphur</td>
<td>27</td>
<td>1</td>
</tr>
<tr>
<td>Oxides of nitrogen</td>
<td>272</td>
<td>27</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>1318</td>
<td>58</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>6058</td>
<td>70</td>
</tr>
<tr>
<td>Particulates</td>
<td>47</td>
<td>7</td>
</tr>
</tbody>
</table>
Table 3. Some equations for pollutant concentrations caused by vehicle exhaust emissions.

<table>
<thead>
<tr>
<th>Equation format in PANIC</th>
<th>Constant</th>
<th>Coefficients</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Gilbert and Crompton (1971b): carbon monoxide</td>
<td>2.26</td>
<td>(q_p)</td>
<td>ppm</td>
</tr>
<tr>
<td>2 Gilbert and Crompton (1971b): carbon monoxide</td>
<td>3.66</td>
<td>(q_p^P)</td>
<td>ppm</td>
</tr>
<tr>
<td>3 Colwill (1973): carbon monoxide</td>
<td>1.69</td>
<td>(q_p^2)</td>
<td>ppm</td>
</tr>
<tr>
<td>4 Colwill (1973): carbon monoxide</td>
<td>2.69</td>
<td>(T)</td>
<td>ppm</td>
</tr>
<tr>
<td>5 Wigan (1974a; 1974b): carbon monoxide</td>
<td>0.05</td>
<td>(\bar{V}_w)</td>
<td>ppm</td>
</tr>
<tr>
<td>6 Colwill (1973): nitrogen oxides</td>
<td>-73.9</td>
<td>(q_p/T)</td>
<td>(\mu g m^{-3})</td>
</tr>
<tr>
<td>7 Colwill (1973): nitrogen oxides</td>
<td>46.9</td>
<td>(\bar{V}_w)</td>
<td>(\mu g m^{-3})</td>
</tr>
<tr>
<td>8 Wigan et al. (1974): nitrogen oxides</td>
<td>0.03</td>
<td>(q_p^2)</td>
<td>ppm</td>
</tr>
<tr>
<td>9 Colwill (1973): smoke</td>
<td>9.49</td>
<td></td>
<td>ppm</td>
</tr>
<tr>
<td>10 Colwill (1973): lead</td>
<td>0.0431</td>
<td></td>
<td>ppm</td>
</tr>
<tr>
<td>11 Bevan et al. (1974): lead</td>
<td>35.0</td>
<td></td>
<td>ppm</td>
</tr>
<tr>
<td>12 Wigan et al. (1974): hydrocarbons</td>
<td>2.45</td>
<td></td>
<td>ppm</td>
</tr>
</tbody>
</table>

Key: \(H\) is the relative humidity in %; \(q_p\) is the flow of petrol-driven vehicles; \(P\) is the percentage of diesel vehicles; \(\bar{V}_w\) is the mean wind speed (mph); \(T\) is the ambient temperature (°C); other variables are defined as in table 1.
The links between the levels of concentration of different pollutants have been examined in preliminary manner by Brief et al. (1960) and Wigan et al. (1974) amongst others. Brief deduced the simple relationship:

$$\text{lead (g m}^{-3}\text{)} = 0.516 + 0.268 \text{ carbon monoxide (ppm by volume)}$$

but the techniques and detailed locations of the measurements of each pollutant leave this relationship in some doubt as to its applicability elsewhere. A principal component analysis by Wigan (1974) included $L_{10}$, $L_{50}$, and $L_{90}$ for carbon monoxide, hydrocarbons, and oxides of nitrogen but could not include the lead data because of the very different measurement technique. Some indicative relationships were selected, but this promising line of investigation requires further coordinated measurement programmes to make any progress.

The exposure periods and numbers of people exposed in houses, offices, and shops will all differ, and the time profiles of the presence of population exposed for given periods will differ quite markedly between themselves and from the time profiles of both traffic levels and traffic composition that give rise to the pollution concentrations.

Research should be commissioned to determine the actual environmental sensitivity of such different land uses in order to inform the general discussion of apparent or 'obvious' environmental sensitivity: separation in time of people and pollutants may well be more important to the population that are actually present to suffer them than other aspects of environmental disturbance.

Work on pedestrian movements is not usually carried out in a form suitable for environmental impact analysis. A considerable amount of work has been done on concentration/flow characteristics. Unfortunately the variable that is really needed is the product of numbers of pedestrians present beside a given length of road and the mean exposure time to the kerbside conditions that they suffer. While retail shopping space is a good index of pedestrian concentration—as demonstrated by Edwards and Shipley (1972) and implicitly accepted by Hasell (1973)—the other indices required to convert concentration into people hours of exposure/hour are not yet known. Research is necessary to establish this, as the pedestrians involved are typically ten times as numerous as the vehicles passing by them.

Quantitative data on pedestrian delays used by PANIC still rely on the results of a survey carried out in Coventry (Edwards and Shipley, 1972; Bowers, 1973). These results were applied to an environmental evaluation in the Coventry Transportation Study. The data are limited to crossing delays in shopping areas, and only the forms of the equations obtained for Coventry have been provided for in PANIC. None of the equations obtained included traffic flow as an important variable, in agreement with other work on pedestrian movement (Ness, 1972; Johnson, 1972). Some more recent work in Hammersmith (Joyce and Williams, 1974) may soon improve the basis for forecasting pedestrian delays, but the best available results are those from Coventry and these are given in table 4. This part of PANIC is clearly appropriate for accident-forecasting equations, when the 'retail shopping space' variable may be replaced by another more appropriate explanatory variable. If suitable pedestrian concentration equations could be developed, this skeleton equation permits their immediate use.

The form of the PANIC outputs is considered in the following example, but one facility is not used: the spread of individual reactions to a given pollutant level can be produced by a spreading function built into the summary output stage. Attempts to use the results of the National Environment Survey (Hedges, 1973) to determine the form met with mixed success, and the function used was a simple normal form. This type of transformation of exposure to numbers of pedestrians annoyed to different degrees would be more helpful if the nature of aggregation did not cut its effective discriminatory power to a low level.
Discussion has so far covered a range of approaches to the attachment of environmental effects and standards to the normal process of transport policy assessment. The equations introduced and discussed in the later sections are a fair cross section of the empirical results so far available from the work of different measurement groups. When a broader coverage of the practical situations has been achieved, then significant changes in the way in which environmental impacts are assessed may be possible. Until that time the PANIC approach provides an interim assessment tool which can be readily adjusted to employ new information. In the Stanford Research Institute work the limitation of the APRAC-1A diffusion model to carbon monoxide is less significant than the effective agreement finally obtained between APRAC-1A forecasts and measurements of CO concentration in the areas concerned. Improvements can be expected in forecasts of noise and vehicle exhaust emission production and local concentration. The traffic requirements are also likely to change. The use of traffic management and traffic restraint to alter—and perhaps reduce—traffic flows over a wide area will permit reductions in environmental impact. Some limited studies of this type have already been made. The detailed representation of time variations in traffic flow—together with specific models of starting, stopping, and queueing behaviour—are likely to prove essential if the most effective use is to be made of our potential ability to control traffic flow so as to minimise environmental disturbance (Wigan, 1976). These requirements are not dissimilar to those of area traffic control, and the possible use of this and other traffic management measures to achieve specified environmental standards is a further likely development.

Table 4. Pedestrian data drawn from shopping areas in Coventry (Bowers, 1973).

<table>
<thead>
<tr>
<th>Equation format in PANIC</th>
<th>Coefficient a</th>
<th>( S )</th>
<th>( Q )</th>
<th>( d_{rel} - d_r )</th>
<th>( \tau )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numbers crossing per hour</td>
<td>137.4</td>
<td>0.24</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>evening peak</td>
<td>44.4</td>
<td>0.27</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>off-peak</td>
<td>9.45</td>
<td>0</td>
<td>0</td>
<td>0.00527</td>
<td>0</td>
</tr>
<tr>
<td>Mean delay per pedestrian (s)</td>
<td>3.69</td>
<td>0.0275</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Numbers of pedestrians</td>
<td>13.87</td>
<td>0.0243</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>off-peak</td>
<td>4.19</td>
<td>0</td>
<td>0.0057</td>
<td>0.586</td>
<td>0</td>
</tr>
<tr>
<td>peak</td>
<td>9.42</td>
<td>0</td>
<td>0.0088</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Crossing time for all groups (s)</td>
<td>11.0</td>
<td>0</td>
<td>0.005</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

a \( S \) is the total retail shopping space by the road \((m^2)\); other variables are as defined in table 1.

An illustrative application of PANIC

The City of Coventry Transportation Study Group (CTSG) published a detailed technical report (1973) in which full details are given of the environmental impact assessment process developed jointly by the Department of the Environment and the CTSG. In order to demonstrate the use of flexibility of the PANIC framework the same basic networks and travel demand matrices were used in a slightly modified form to show how the Coventry results can be both duplicated and extended. The more elegant variations on the use of PANIC facilities for special analysis and presentations are omitted for clarity. The evaluation of the environmental changes predicted by PANIC has been omitted here in view of the substantial uncertainties still surrounding the fiscal consequences of evaluation and the detailed interpretation of the shifts in impact suffered by different groups.
In order to carry out an environmental impact study of the type described the traffic model must respond sensitively to congestion. This could either take the form of alterations in routes chosen or—additionally—include some response to the changing total costs of travel. For this illustration only the routing responses will be required, as the travel demand matrices are taken to have been fixed initially. The CTSG produced three basic models of the city:

1. a model of the city as it was in the survey year of 1970;
2. a model of the city as it might be in 1976;
3. a model of the city as it might be in 1981 if current planning policies were continued, no new roads were built after 1976, and if the level of congestion did not cause a reduction in the transport demand forecast in planning terms.

Situations 1 and 3 were chosen, as the 1973 Coventry environmental assessment work was presented only in terms of these two models. The 1967 situation (1) was only mildly congested, and the compression of network, and travel-demand matrices to reduce the level of detail retained for the area outside the city boundaries produced little alteration in the congestion on the reduced model of Coventry in 1967. This provided a starting point for comparisons. To give an extreme position the Coventry 1981 unrestrained forecast (3) was subjected to exactly the same geographical compression. The effect of removing a substantial amount of road capacity without rebalancing the level of demand as represented by the travel matrices led to a situation even more extreme than the original 1981 forecast—which the CTSG had subsequently reduced by up to 30% to bring it into line with the forecast road capacity likely to be available in that year.

Both 1967 and 1981 models were run on the RRLTAP system using generalised cost as a routing criterion and the speed-flow relationships for each road as had been used in the CTSG’s studies. The equilibrium patterns of traffic flow were successfully produced by means of a perturbation technique (Wigan, 1974a, 1974b) in spite of the excessive levels of congestion present in the modified version of 1981, which made convergence difficult to obtain.

The reductions in network capacity outside the city boundary, the use of generalised cost instead of the simpler function used by the Coventry TSG for assignment, the cruder technique used by the CTSG, and the slight differences in the trip matrices supplied from those used by CTSG combined to give slightly different results from the assignments for 1967. A direct comparison between flow measurements taken in 1970, and this new equilibrium assignment showed that the quality of the new assignment was adequate, and that the network reductions led only to an overuse of certain peripheral roads and part of the southwest suburbs.

The ‘1981’ model was excessively congested, beyond even the unrestrained 1981 CTSG situation. The spreading of traffic to take full advantage of any available road capacity is obvious in the results, and this ‘1981+’ situation may be considered to be more severely congested than would be likely at any time in the future.

The comparison between these ‘1967’ and ‘1981’ simulations could therefore be expected to show substantial shifts in environmental impact. The first application of PANIC was to determine the spread in noise impact forecast by different equations. As the percentage of goods vehicles is a critical component in all the forecasting equations, two different ways of calculating the goods flows were tried. For ‘1967’ the CTSG had assembled a matrix of resident goods-vehicle movements, so the nonresident vehicle matrices were built and added to this information to give, admittedly, a poor representation of goods-vehicle movements in 1967. These trips were assigned to a single set of routes on paths of minimum generalised cost, and the

\( \text{Cost function used: } \text{cost per mile} = A + BV^{-1} + CV^2 + DV^{-1} \) where \( V \) is in mph.
calculations based on these flows will be referred to as those 'using a separate goods-vehicle matrix'. The alternative was to take a flat 20% of all vehicles on every road in the network, which has the merit of simplicity if not of reality! As an approximation it is tolerable for present-day conditions as most of the roads on a transport model network tend to be those that would carry goods traffic. It should be noted that 'goods vehicles' included all goods vehicles and other vehicles in course of business.

The CTSG report built up a graph of $L_{10}$ by households exposed by modelling each period of the day approximately, and accumulating the results. The data used for this work were not expressed in terms of households but in terms of population resident on each link. In figure 1 the 'Coventry report result' is shown in population terms. The set of new results was based solely on a single evening peak hour, and this should be noted when viewing the diagrams. CTSG used two different noise prediction equations, one for free-flow conditions and one for urban conditions, and the appropriate equation was selected for each link. As a first trial run the Coventry free-flow equations (which was actually one of Gilbert and Crompton's with an appropriate value of $T$ and road width used throughout) on every road of our evening peak hour simulation. The result is shown in figure 1. Several of the other possible equations were then applied on the same blanket basis, and although the spreads were substantial, the equations using speed as a variable forecast substantially lower noise levels. One reason is that the transportation equilibrium model was valiantly trying to forecast a space mean speed for each link (and succeeding only fairly well) while the forecasting equations were based on time mean speed, which is rather better determined by the measurements.

To assess the relative importance of goods vehicle flow assumptions and the selection of suitable forecasting equations, the same calculations were carried out assuming that goods vehicles comprised 20% of the flow on each and every link (figure 2).

![Figure 1. 1967 $L_{10}$ exposure derived using a separate estimate of goods vehicle flows.](image)
Figure 2. 1967 $L_{10}$ exposure derived using the assumption that 20% of each flow is of goods vehicles.

Figure 3. 1981 comparisons of exposure to noise.
The discrepancies in forecast between the equations is—unsurprisingly—considerably reduced and the general forecast level of $L_{10}$ diminished. The overlap is complete and suggests that it would be difficult to have a choice between ‘goods’ models for this ‘1967’ simulation.

Moving on to ‘1981’, the differences between the CTSG 1981 conditions and our representation of extreme ‘1981’ conditions produce variations from the CTSG forecasts (figures 3 and 4). Although there is good agreement between the non-speed dependent equations for the exposure of population to $L_{10}$ levels in the new cumulative distributions and levels in this ‘1981’ model, the speed dependent equation falls down badly. There are a number of excellent reasons for this, and perhaps the most important (from the point of view of a measurement scientist) is the low quality of even the best transport model forecasts of speeds for highly congested conditions. For low flows (and high speeds) the Nelson equation used is perfectly adequate: it is only the combination of very low speeds and heavy traffic that is currently dealt with inadequately by the combination of traffic-model and forecasting equations. Further investigations of the properties of descriptive equations which use speed as an explicit descriptive variable are included in a further paper which describes surveys and leads to sets of equations for $L_{10}$, $L_{50}$, and $L_{90}$ (amongst other environmental descriptors) based on information gathered over a wide range of locations and conditions (Wigan et al., 1974).

The three equations are compared with the CTSG results for 1981 in figure 3. In view of the greater degree of congestion inherent in our model representing the flows, the $L_{10}$ agreement is surprising to say the least. Even more remarkably the $L_{10}$ predictions are below the CTSG forecasts, suggesting that the considerable congestion-spreading capabilities of our traffic model have compensated for the extra traffic in our ‘1981’ flows. This is a further point at which the underlying traffic model used

![Figure 4. 1981 $L_{10}$ exposure predictions compared for an extreme scenario.](image-url)
causes a drastic alteration in the forecast conditions (the other being the sensitivity to
the model of goods movements adopted), and emphasizes once again the extent to
which environmental impact forecasting should be linked to the forecasting system as
a whole. Just as mismatches in the underlying assumptions at different phases of a
traffic model can completely destroy the value of traffic-restraint forecasting
frameworks (Wigan, 1974a), any mismatch of assumptions in model and environmental-
impact forecasting systems will cause serious distortions in any conclusions that might
be drawn. Figure 3 also shows the $L_{50}$ and $L_{90}$ impacts, and it is evident that only
the last 20% of the population exposed are likely to suffer any substantially different
shift between each of these noise index levels. This is due in part to constraining
$L_{10}$, $L_{50}$, and $L_{90}$ equations to fit identical functional equations by varying the
coefficients, which leads to a further problem when synthesising data for environmental
impact forecasting: if different functional forms were used for each $L_{NN}$ level, and
each is fitted independently, would the forecast changes in $L_{NN}$ be represented better
or worse? One of the four safeguards that can be taken is to draw on information
collected under widely different conditions and conduct $L_{10}$, $L_{50}$, and $L_{90}$ analyses
simultaneously (for example Wigan et al., 1974). Some of the many results obtained
for shift behaviour under varying conditions and with alternative equations are given
in figure 5. The shift results deduced directly from the CTSG 1973 report are shown,
together with $L_{10}$ shift forecasts from our model of '1981' under two different
modelling assumptions for goods traffic in '1967' (the base year to which these shifts
are referred).

The shift which was forecast by our models using separate goods flows in 1967 and
the CTSG free-flow equation agrees very well with the CTSG shifts down to 80% of
the population, and the largest divergencies are in precisely the region where the
congested-flow CTSG equation was used in the Coventry calculations, and the full
impact of the less refined congestion-spreading mechanism used by the CTSG, combine.
The sharp shift induced by adopting the same ‘model’ of goods movement in 1967
and 1981 for this same equation, is startling. It is an increase of between one and
three times the shift produced by varying models between years. A similar effect
occurs for the Wigan et al. (1974) $L_{10}$ equation, although less exaggerated. This is
only to be expected as the equation embodies both congested and uncongested
conditions, but there is still a factor of two between the two forecasts of $L_{10}$ shift.

![Figure 5. The effect of using different models of goods traffic in target and base years.](image-url)
Further lines could have been plotted to show how well other equations agree with these general patterns, notably the $L_{50}$ and $L_{90}$ forecasts, but little further information would have been provided beyond the close correspondence between $L_{10}$, $L_{50}$, and $L_{90}$ shifts under these conditions. This is partly due to the use of the same basic logarithmic form for the empirical function used to describe $L_{10}$, $L_{50}$, and $L_{90}$ for these equations.

The provisions of the Land Compensation Act (1973) allow for compensation to be paid for increases in noise level of about 1 dBA at levels above 68 dBA for the 18-hour $L_{10}$ measure based on 0600 hours–2400 hours. The drastic difference in compensation requirements that would be expected on the basis of the two $L_{10}$ forecasts shows the potential importance of developing effective models, forecasts, equations, and impact measures if proper weight is to be attached to the fiscal compensation implications of transportation innovations.

This form of shift analysis is useful for global presentation of results of this kind, but the extensive range of environmental changes (both improvements and the reverse) will tend to produce a great deal of internal cancellation when accumulating the local changes. It is therefore necessary to split the populations affected into groups affected to different degrees in each direction if compensation or impact calculations are to be conducted sensibly. The collection of output in this form from PANIC is straightforward, but has little explanatory value without a detailed exposition of the application, and is therefore omitted. In practical applications careful attention should be paid to the occupancy profiles of the household, as the traffic nuisance and periods of high occupancy are unlikely to coincide.

PANIC can equally well be used to manipulate air pollution concentration forecasts. A set of these are shown in figure 6. The ratios of '1981' and '1967' levels are shown; the distribution of levels is loosely equivalent to the noise impacts shown in figures 1 and 2, and are useful mainly to determine the degree of importance of the $Q^2$ terms. This point is discussed in detail elsewhere (Wigan et al., 1974) and suffice to say that $Q^2$ terms are highly desirable for forecasting purposes as they appear to bring different equations into good agreement at high pollution levels when compared in this way. It should however be noted that the $Q^2$ terms are calibrated on low pollution levels, where they make little contribution to $R^2$, but have their full effect only at the high levels which dominate these '1981' conditions.

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**Figure 6.** Shifts in air pollution levels predicted: '1967' $\rightarrow$ '1981' scenarios.
The extensive work on carbon monoxide concentration measurement provides a range of different equations to be compared in figure 7. The Imperial College work (Gilbert and Crompton, 1971b) makes use of a 'speed' variable (although it is not clear if this is space or time mean speed), and is therefore dependent on the achievement of good speed–flow equilibria in both 1967 and 1981 to give any worthwhile result. It is therefore somewhat surprising to see the agreement with one of Colwill’s (1973) equations derived from measurements made in Reading in 1972. The inclusion or exclusion of a $Q^2$ term from the regression fits to carbon monoxide and other concentrations has a strong influence on the form of the shift patterns predicted: omission of the $Q^2$ term leads to flat and featureless shift profiles due to the low weight given to the higher concentration recorded at the time of measurement. At the highest congestion levels $Q^2$ terms produce quite unreasonably high levels of carbon monoxide concentration; once again, $Q^2$ terms seem to be valuable, but must be treated with care.

These illustrations have been provided to show how the achievement of a usable analytical framework of this kind raised as many fresh and demanding problems for both measurement scientist and analyst as the system may solve: a normal result of most syntheses of previously unrelated pieces of work. It is clear that the evaluation of the predicted environmental shifts is now a matter of some urgency: the need to balance real resource costs against perceived and actual environmental changes becomes considerably more important when increased emphasis is placed on resource utilisation as a result of current or impending shortages.

![Figure 7. Shifts in carbon monoxide exposure levels: '1967' - '1981' scenarios.](image)

**Summary**

Empirical data now available can be used for simplified forecasts of the effects of traffic on changes in noise levels, vehicle exhaust emission productions and concentrations, and pedestrian delays. An appropriate model (PANIC) employing the empirical relationships concerned has been constructed. Use of this model will help transport analysts to express the effects of transport proposals in broader terms and to focus on the secondary effects of traffic changes that have not as yet received much quantitative attention. A theoretical line of approach to the comparative costing of
pollution control measures has been proposed as the next stage of this work, and illustrations of the practical use of PANIC are given to point out where fresh problems are likely to arise when this sort of tool is to be applied. The illustrations have been tailored to allow detailed comparisons with the approach developed for the Coventry Transportation Study (CTSG, 1973), and used the same basic forecasts of both present ('1967') and future ('1981') traffic. The comparisons also show the effects of using a more precisely convergent traffic model, so that differences between these results and those of the CTSG (1973) have more than one source.

Acknowledgements. Work on these subjects was initiated by the author while at the Transport and Road Research Laboratory, and discussion with many people both within and outside the Department of the Environment has helped to improve the results. While the techniques and results discussed draw upon work initiated while the author was at TRRL, the ideas and proposals are his personal views and do not necessarily reflect those of either TRRL or the Greater London Council. Some of the diagrams contain previously unpublished TRRL data which are used by permission of the Director.

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