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-
ROAD TRAFFIC NOISE AND ITS PREDICTION
BY COMPUTER SIMULATION
WITH PARTICULAR REFERENCE TO SIGNALISED INTERSECTIONS

BY

HAFIDH SALMAN AL-SAMARRAI, B.Sc., M.Eng., M.I.O.A.

A Doctoral Thesis
Submitted in partial fulfilment of the requirements for the award of Ph.D. of the Loughborough University of Technology

1979

(C) by Hafidh Salman Al-Samarrai, 1979
SUMMARY

Interrupted or congested traffic flow situations increase the number of possibly relevant variables over the free flow case and it becomes virtually impossible to obtain enough uncorrelated measured data to establish the regression coefficients for all these variables.

Computer simulation offers an alternative approach. Models have been developed to predict road traffic noise from freely-flowing and interrupted flow traffic at signalised intersection (which can also be used for signalised T junctions) using stochastic techniques. The best available, and some new traffic and noise data have been used, but this could be changed very easily to include time and place effects.

Data have been collected at a number of sites in the Loughborough area using a video tape technique and a multiple, simultaneous, level recording of noise to validate the models.

The freely-flowing and the interrupted flow models have given results which are in good agreement with the "Standard" free-flow prediction method and with the measurements carried out in Loughborough.

The video tape technique has proved to be a very useful tool when used in noise studies, especially at complex situations (e.g. signalised intersections) by reducing the manpower required for data collection significantly, and permitting detailed study of vehicle behaviour and noise relationships.

As the trend in the U.K. and most other countries is to move towards area traffic control systems wherever a number of signalised intersections exist close to each other it must be
beneficial to study the effect of these kinds of schemes on noise. A third model using a similar technique to those of free-flowing and interrupted flow traffic noise models has been developed which enables the study of the effect of different systems on noise and also the effect of some traffic management schemes.

All three models have been built to be as accurate, realistic and representative of actual life as possible without undue complications. At the same time the models have been simplified to save computer time whenever this was possible and does not affect the accuracy of the noise results; as this was the basic philosophy of the approach to the present project.

The results of the various traffic control strategies have shown that significant changes of noise level can be achieved of around 1 or 2\,dBA in $L_{10}$ for flows associated with signalised intersections.

These models would form a good basis for a comprehensive package to study and predict road traffic noise.
ACKNOWLEDGEMENTS

The author would like to express his most sincere gratitude to Mr. D.M. Waters for his extremely generous advice, assistance and understanding throughout the duration of this study.

Thanks are also due to Professor D.J. Johns, the Director of Research for his support and for making the facilities of the Department of Transport Technology available.

Thanks are extended to the staff of the Department of Transport Technology, AVA and a number of other people who helped in various parts of the work, who are too numerous to mention.

Appreciation is also expressed to Dr. P. Nelson and Mr. P. Abbott of the TRRL for providing the facilities to carry out some of the experiments.

Thanks are also due to the Iraqi Ministry of Higher Education and Scientific Research for generously supporting the project.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUMMARY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>INDEX OF FIGURES</td>
<td></td>
<td>iii</td>
</tr>
<tr>
<td>CHAPTER 1 INTRODUCTION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1 General</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1.2 Traffic Growth in Developed Countries</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>1.3 Traffic Growth in Developing Countries</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>1.4 Environmental Effects of Traffic</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>1.4.1 Main Effects</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>1.4.2 Methods of Study</td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>1.4.3 Developing Countries</td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>1.5 Traffic Management and Other Measures to Alleviate Traffic Problems</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>1.6 Cost Benefit Analysis and the Cost of Noise</td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>1.7 The Aim of the Study</td>
<td></td>
<td>24</td>
</tr>
<tr>
<td>CHAPTER 2 LITERATURE SURVEY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1 General</td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>2.2 Measurements of Noise Levels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2.1 Traffic Streams</td>
<td></td>
<td>27</td>
</tr>
<tr>
<td>2.2.2 Individual Vehicles</td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>2.2.3 Speed Effects</td>
<td></td>
<td>31</td>
</tr>
<tr>
<td>2.2.4 Acceleration Effects</td>
<td></td>
<td>33</td>
</tr>
<tr>
<td>2.2.5 Interrupted Flow</td>
<td></td>
<td>36</td>
</tr>
<tr>
<td>2.3 Regression Analysis</td>
<td></td>
<td>39</td>
</tr>
<tr>
<td>2.4 Theoretical Methods</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.4.1 Non-statistical Methods</td>
<td></td>
<td>53</td>
</tr>
<tr>
<td>2.4.2 Statistical Models</td>
<td></td>
<td>58</td>
</tr>
<tr>
<td>2.5 Scale Models</td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>2.6 Simulation Techniques</td>
<td></td>
<td>62</td>
</tr>
<tr>
<td>CHAPTER 3 THE PRINCIPALS AND DESCRIPTION OF THE FREE-FLOWING TRAFFIC MODEL</td>
<td></td>
<td>67</td>
</tr>
<tr>
<td>3.1 General</td>
<td></td>
<td>67</td>
</tr>
<tr>
<td>3.2 Advantages of Simulation</td>
<td></td>
<td>67</td>
</tr>
<tr>
<td>3.3 Disadvantages of Simulation</td>
<td></td>
<td>68</td>
</tr>
<tr>
<td>3.4 What Kind of Model?</td>
<td></td>
<td>68</td>
</tr>
<tr>
<td>3.5 Approaches to Simulation and the Present Model Philosophy</td>
<td></td>
<td>69</td>
</tr>
<tr>
<td>3.6 Choosing the Appropriate Simulation Language</td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>3.7 General Description of the Free-flowing Model</td>
<td></td>
<td>72</td>
</tr>
<tr>
<td>3.8 Random Number Generation</td>
<td></td>
<td>73</td>
</tr>
<tr>
<td>3.9 Arrival Distribution</td>
<td></td>
<td>76</td>
</tr>
<tr>
<td>3.10 Vehicle Type</td>
<td></td>
<td>82</td>
</tr>
<tr>
<td>3.11 Vehicle's Characteristics and Initial Values</td>
<td></td>
<td>85</td>
</tr>
</tbody>
</table>
3.11.1 Vehicle Length
3.11.2 Initial Distance
3.11.3 Desired Speed
3.11.4 Vehicle Maximum Acceleration

3.12 Car-following Consideration
3.12.1 Introduction
3.12.2 A Historical Resume of the Development of Car-following Theories
  3.12.2.1 Constant Sensitivity
  3.12.2.2 Reciprocal Spacing
  3.12.2.3 Step Function
  3.12.2.4 Visual Angle Models
  3.12.2.5 Generalised Form of Car-following Theory

3.13 Summary of Existing Models
3.14 The Use of Car-following Laws for Simulation and the Model Adopted
3.15 Applicability of Car-following Theory
3.16 Background Noise Level
3.17 Scanning
3.18 Calculations of Noise Levels and Indices
  3.18.1 Sampling
  3.18.2 Noise Levels Calculations
  3.18.3 Calculations of Different Noise Indices
3.19 Calculations of Noise From More Than One Lane
3.20 Calculations of Achieved Flow Parameters
  3.20.1 Achieved Flow Rate
  3.20.2 Percentage of Heavy Commercial Vehicles
  3.20.3 Achieved Mean Speed
3.21 Model Description and Use
  3.21.1 Rules of Operation
  3.21.2 Flow Chart and Subroutines Description

CHAPTER 4 PRINCIPLES OF SIGNALISED INTERSECTIONS MODELS

4.1 Introduction
4.2 Vehicles Braking
  4.2.1 Response to Amber Period
  4.2.2 Deceleration Performance
  4.2.3 Maximum Deceleration
4.3 Starting Performance
  4.3.1 Reaction Time
  4.3.2 Starting Performance of the Vehicle at the Head of the Queue.
  4.3.3 Starting Performance of Following Vehicles

CHAPTER 5 SIGNALISED INTERSECTIONS MODELS

5.1 General
5.2 A Single Signalised Intersection Model
  5.2.1 Rules of Operation
  5.2.2 Flow Chart and Subroutines Description
5.3 Linking of Traffic Signals and Urban Traffic Control (UTC) Systems
  5.3.1 Historical Introduction
  5.3.2 A Pair of Signalised Intersections
  5.3.3 Rules of Operation
  5.3.4 Flow Chart and Subroutines Description
CHAPTER 6  THE COLLECTION AND ANALYSIS OF DATA

6.1 General
6.2 Methods Used for Data Collection
   6.2.1 Manual Method
   6.2.2 Time Lapse Photography
   6.2.3 Video Tape Technique
6.3 Equipment Used on Site
   6.3.1 Noise Equipment
   6.3.2 Video Equipment
   6.3.3 Miscellaneous Equipment
6.4 Sites Description
   6.4.1 Criteria for Choice of Sites
   6.4.2 Location and Physical Characteristics of Sites
6.5 Procedure on Site
6.6 Equipment Used in the Laboratory
6.7 Analysis Procedure
   6.7.1 Analysis of Noise Tapes
   6.7.2 The Process of Adding the Time Base on the Video Tape
   6.7.3 Analysis of the Video Tape
6.8 Individual Vehicle Noise Study
   6.8.1 Site and Vehicles Used
   6.8.2 Equipment and Procedure Used on Site
   6.8.3 Analysis Procedure

CHAPTER 7  VALIDATION OF MODELS AND COMPARISONS WITH SOME OTHER STUDIES

7.1 Introduction
7.2 Input and Output Parameters
   7.2.1 Total Flow
   7.2.2 Percentage of Medium and Heavy Commercial Vehicles
   7.2.3 Speed
7.3 The Traffic Model
   7.3.1 Number of Queueing Vehicles
   7.3.2 Vehicles Crossing the Stop Line
7.4 Results of the Individual Vehicle Noise Study
7.5 The Free-flow Model
7.6 The Signalised Intersection Model

CHAPTER 8  STUDIES USING THE MODELS

8.1 General
8.2 Effect of Including Three Classes of Vehicle Rather Than Two on the Free-flow Model
8.3 Effect of Cycle Time
8.4 The Effect of the Introduction of Quieter Vehicles
8.5 The Effect of Linking of Traffic Signals
8.6 Transyt Method
8.7 Effect of Bus Lanes
8.8 The Effect of the Scan Interval
CHAPTER 9 THE EFFECT OF A UTC SYSTEM ON NOISE LEVELS – A BEFORE AND AFTER STUDY

9.1 Introduction 269
9.2 Leicester Urban Traffic Control System 269
  9.2.1 Aims and Objectives 270
  9.2.2 Benefits 271
  9.2.3 Linking of Loughborough to Leicester UTC System 271
9.3 The Noise Survey Within the Area of UTC System 272
9.4 Results and Discussion 272

CHAPTER 10 CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH 288

10.1 Conclusions 288
10.2 Suggestions for Further Research 289

REFERENCES

APPENDICES:

1. Frequency Distributions Applied to Noise Levels
2. Listing of Program Calculation of Road Traffic Noise
3. A. Lengths and Starting Accelerations – Medium Commercial Vehicles
   B. Lengths and Starting Accelerations – Heavy Commercial Vehicles
4. Starting Acceleration (Max. Acceleration) for a Sample of Cars
5. A. Input Data and Output Options for FFNOISE
   B. Listing of FFNOISE
6. A. Input Data and Output Options for SGINNS
   b. Listing of SGINNS
7. A. Data Input and Output of PAIRSINSE
   B. Listing of PAIRSINSE
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Motor Vehicle Indicators</td>
</tr>
<tr>
<td>1.2</td>
<td>Results of Noise Measurements in Baghdad</td>
</tr>
<tr>
<td>2.1</td>
<td>Individual Vehicle Noise</td>
</tr>
<tr>
<td>2.2</td>
<td>Summary of Individual Vehicles Speed - Noise Studies</td>
</tr>
<tr>
<td>2.3</td>
<td>Percentile Levels on the Central Island of a Busy Five-way Light-Controlled Intersection in Leicester.</td>
</tr>
<tr>
<td>3.1</td>
<td>A Sample of Vehicles with Maximum Lengths</td>
</tr>
<tr>
<td>3.2</td>
<td>Measurements of Speed by Three Methods.</td>
</tr>
<tr>
<td>3.3</td>
<td>Summary of Samples of Vehicle's Acceleration (m/sec.$^2$)</td>
</tr>
<tr>
<td>3.4</td>
<td>Range of Noise Levels at Locations in Which Traffic Noise Predominates</td>
</tr>
<tr>
<td>3.5</td>
<td>Corrections for Type of District in the Neighbourhood of the Measuring Position</td>
</tr>
<tr>
<td>3.6</td>
<td>Comparison of Coefficients Found by Attenborough and Clark with Those of B.S. 4142.</td>
</tr>
<tr>
<td>3.7</td>
<td>Sites Description</td>
</tr>
<tr>
<td>3.8</td>
<td>Results of Noise Measurements at Sites of Table 3.7</td>
</tr>
<tr>
<td>3.9</td>
<td>Equations of the Noise Level Speed Characteristics Described in Table 3.10.</td>
</tr>
<tr>
<td>3.10</td>
<td>Description and Manner of Formation of the Vehicle Categories for Different Levels of Categorisation of the Total Vehicle Population.</td>
</tr>
<tr>
<td>3.11</td>
<td>The Effect of Acceleration on Noise Emitted by Cars and HCV's.</td>
</tr>
<tr>
<td>3.12</td>
<td>Required Input Values for the Free-flow Model FFNOISE.</td>
</tr>
<tr>
<td>4.1</td>
<td>Beginning of Critical Section</td>
</tr>
<tr>
<td>4.2</td>
<td>Summary of Deceleration Studies.</td>
</tr>
<tr>
<td>4.3</td>
<td>Results of a Survey on Values of Reaction Times Used by Different Cities in U.S.A.</td>
</tr>
<tr>
<td>5.1</td>
<td>Required Input Values for SGINNS.</td>
</tr>
<tr>
<td>5.2</td>
<td>Required Input Values for PAIRSINSE</td>
</tr>
</tbody>
</table>
6.1 Summary of the Characteristics and Physical Features of the Sites Studied.

7.1 Specified Input and the Output Values of Flow.

7.2 Specified Input and the Output Values of Medium and Heavy Commercial Vehicles.

7.3 Comparison Between the Number of Queueing Vehicles From the Signalised Intersection Model with That Found by Little's Formula.

7.4 Simulated and Predicted $L_{10}$ values - Free-flow Model - Attenuation Constant $= \frac{1}{20}$.

7.5 Simulated and Predicted $L_{10}$ Values - Free-flow Model - Attenuation Constant $= \frac{1}{10}$.

7.6 $L_{10}$ Increment Due to Increasing Distance.

7.7 Regression Results of Measured Against Predicted Levels.

8.1 The Effect of Including Three Classes of Vehicles on the Free-flow Model.

8.2 Effect of Cycle Time.

8.3 Effect of Noise Control Policies.

8.4 Paired Traffic Signal Levels.

8.5 Paired Traffic Signal Levels - Transyt Linking.

9.1 Results of the Analysis of Data of Belton Rd/Derby Rd. - 1977.

9.2 Results of the Analysis of Data of Belton Rd/Derby Rd. - 1978.

9.3 As Table 9.1 for Leicester Rd/King St.

9.4 As Table 9.2 for Leicester Rd/King St.

9.5 As Table 9.1 for High St/Woodgate.

9.6 As Table 9.2 for High St/Woodgate.

9.7 As Table 9.1 for Meadow Lane/Belton Rd.

9.8 As Table 9.2 for Meadow Lane/Belton Rd.

9.9 Summary of the Before-After Noise Survey of the Area Within the UTC System - Loughborough.

9.10 Details of Fig. 9.1.

9.11 Changes in Traffic Parameters, $L_{10}$ Values & Expected Changes in $L_{10}$ Values.
## INDEX OF FIGURES

<table>
<thead>
<tr>
<th>Fig. No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Index of Vehicle Kilometers: Different Classes of Vehicles (1965 - 2005)</td>
</tr>
<tr>
<td>1.2</td>
<td>Growth of Car Ownership in Selected Countries From 1968 to 1973</td>
</tr>
<tr>
<td>2.1</td>
<td>Comparison of Road Load Noise to Maximum Noise</td>
</tr>
<tr>
<td>2.2</td>
<td>Chart, Based on Traffic Noise Survey, Showing Percent of Time That Overall SPL Lies Below Any Arbitrary Value</td>
</tr>
<tr>
<td>2.3</td>
<td>Flow Chart of the Calculation of Road Traffic Noise Procedure</td>
</tr>
<tr>
<td>2.4</td>
<td>Single Line Flow Analysis.</td>
</tr>
<tr>
<td>3.1</td>
<td>The Process of Vehicle Type Selection</td>
</tr>
<tr>
<td>3.2</td>
<td>Concentration Against Speed and Against Flow</td>
</tr>
<tr>
<td>3.3</td>
<td>Existing Traffic-flow Models</td>
</tr>
<tr>
<td>3.4</td>
<td>Noise Survey - Data Log</td>
</tr>
<tr>
<td>3.5</td>
<td>Noise Level/Speed Characteristics for the Three Classes of Vehicles Used in the Present Simulation</td>
</tr>
<tr>
<td>3.6</td>
<td>Increase in Noise Levels Produced by Individual Vehicles During Max. Acceleration</td>
</tr>
<tr>
<td>3.7</td>
<td>The Calculation of the Vehicle Position</td>
</tr>
<tr>
<td>3.8</td>
<td>Flow Chart of the Free-flow Model &quot;FFNOISE&quot;</td>
</tr>
<tr>
<td>4.1</td>
<td>Percentage of Drivers Stopping Satisfactorily From Various Distances From the Stop-line When the Amber Signal Appeared</td>
</tr>
<tr>
<td>5.1</td>
<td>Flow Chart of the Single Signalised Intersection Model &quot;SGINNS&quot;</td>
</tr>
<tr>
<td>5.2</td>
<td>Diagram of Simulated Pair of Intersections</td>
</tr>
<tr>
<td>5.3</td>
<td>Flow Chart of the Pair of Intersections Model PAIRSINSE</td>
</tr>
<tr>
<td>6.1</td>
<td>A Map Showing the Junctions Used in the Study</td>
</tr>
<tr>
<td>6.2</td>
<td>The Overall Appearance of the Sites</td>
</tr>
</tbody>
</table>
6.3 The Process of Adding Time Base

6.4 The Process of Superimposing the Cross Bars on the Video Picture

7.1 Results of Individual Vehicle Study - Constant Speed Runs

7.2 a) Individual Vehicle Noise Study - Additional Noise vs. Acceleration - Lorry
    b) Results from Ref. 55

7.3 a) As Fig. 7.2 - Cars
    b) Results from Ref. 54.

7.4 Additional Noise vs. Deceleration - Cars

7.5 Additional Noise vs. Deceleration - Lorry

7.6 Free-flow Simulated and Predicted by CORTN - Attenuation Constant = 20

7.7 Free-flow Simulated and Predicted by CORTN - Attenuation Constant = 18

7.8 Simulated vs. Measured Noise Levels - 4-way Intersection

7.9 Simulated vs. Measured Noise Levels - 3-way Intersection

7.10 Measured vs. Predicted $L_{10}$ dBA For Belton Rd/Derby Rd. Intersection

7.11 Measured vs. Predicted $L_{10}$ dBA For Leicester Rd/King St. Intersection

7.12 Measured vs. Predicted $L_{10}$ dBA For High St/Woodgate Intersection

7.13 Noise Histories (a) Simulated; (b) Measured

8.1 Simulated vs. Predicted by 'CORTN' - Base Line Distance (10m)

8.2 Effect of Distance - Simulated Noise Levels - Different Linking Systems

9.1 The Effect of UTC System on Noise Levels

- iv -
1.1 GENERAL

Growing urbanisation, the rising number of automobiles and heavy commercial vehicles (HCV) and the quantity of traffic have had the effect of increasing noise levels. Concern over this noise has led to numerous studies of various aspects of the problem with varying degrees of sophistication. The present study uses a computer-aided simulation technique to predict noise levels in complex traffic situations.

Of all the present-day sources of noise, the noise from surface transportation, especially that from road vehicles, is the most diffuse. Everywhere it is growing in intensity, spreading to areas until now unaffected, reaching even further into the night hours and creating great concern.

It has been shown that prolonged exposure to intense noise such as that experienced in some factories produces permanent hearing loss. However, very much lower noise levels, for example that from road traffic, interfere with normal conversation, hinder concentrated mental effort, induce stress, cause inefficiency at work, prevent sleep, cause irritability and interfere with relaxation and recreation.

To ensure that noise does not impede mobility, one of the challenges is to develop the framework in which advancing technology can be applied to the reduction of noise. The development of guidelines, standards and regulations ensures consideration of noise abatement in the design, planning, location and development of vehicles and transportation systems.

It is therefore essential to provide accurate and
simple noise prediction methods for the planners to utilize and help them in constraining noise at the drawing board stage.

1.2 TRAFFIC GROWTH IN DEVELOPED COUNTRIES

It has been through mobility that man has been able to progress. This mobility radically changes the influence of time and position on his activities.

The first motor vehicle to run on the roads of Britain was a Benz three-wheeler imported from the Continent. The year was 1888. By the outbreak of the war in 1914 there were nearly 400,000 vehicles in use in Britain\(^1\).

The increasing world population and rising levels of economic affluence that have occurred since the Second World War have been accompanied by a staggering increase in the number of motor vehicles.

Roads and road vehicles play a massive part in the life of the country and indications are that the amount of road traffic will increase. Fig. 1.1 shows indices of vehicle kilometers for various classes of vehicles (1965-2005)\(^2\). Fig. 1.1 also shows traffic forecasts for the same classes of vehicles taken from the Calculation of Road Traffic Noise\(^3\) (CORTN) (the current statutory noise prediction method for planners).

The problem of traffic growth varies in size from one country to another, this being more pronounced in developing countries, as is well illustrated in Fig. 1.2\(^4\) and Table 1.1\(^5\).

From what has been stated above and from Table 1.1 and Figs. 1.1 and 1.2, the following points emerge:
Fig. 1.2 GROWTH OF CAR OWNERSHIP IN SELECTED COUNTRIES FROM 1968 TO 1973
### Table 1.1 Motor Vehicle Indicators

**a) Total Vehicle Population (passenger cars + commercial vehicles) (in thousands)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
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### Table 1.1 Motor Vehicle Indicators

**b) Vehicle Population: Passenger Cars (in thousands)**

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<thead>
<tr>
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</table>
1. Traffic is growing, bringing with it all sorts of problems and noise is one of them.

2. Traffic growth varies from one country to another and there is a tendency to make more than one forecast to include possible changes in the forecast parameters.

The present work is mainly concerned with traffic noise—a function of flow and composition—which are obtainable from these traffic forecasts.

Noise prediction methods are very useful in evaluating the expected levels associated with long-term planning strategies.

1.3 TRAFFIC GROWTH IN DEVELOPING COUNTRIES

The traffic growth in developing countries is more complicated than that in developed countries, it also seems to have different characteristics which can be summarised as follows:

1. Rate of growth tends to fluctuate with time rather than progressive increase or decrease, for example, in Iraq figures for growth, quoted 3.5\(^6\), 4.0 and 11.0\(^7\) per annum. This may be due to the fact that regulations which have a direct effect on the growth can be changed more easily than those in developed countries.

2. Although most of the growth characteristics are common, it is difficult to generalize them for all countries. For example, in 1970 while Kuwait had a passenger car for every 5 persons, Nigeria had one for every 817 and India had one for every 902 persons, which is related to per
capita income. This makes the current traffic growth follow different patterns for these countries.

3. While motorisation and the recent disillusionment with cars in cities took place over a period of half a century in the U.S.A. and a quarter-century in Europe, in the developing countries, the periods of motorization and of serious misgivings about it are happening almost simultaneously. Whereas the number of motor vehicles in the U.S.A. increased 35% during the 1960's, the increase was 100% in South America and 300% in Asia. The number of vehicles increased nearly five-fold in Thailand and tripled in Pakistan and the Philippines. Cities already overcrowded and suffering critical shortages of housing and public services will double their population by the end of this decade and triple their ownership of automobiles. By the end of the century the world is expected to have 524 million cars in operation. Developing countries, which accounted for fewer than 17 million cars in 1970 may own over 100 million by the year 2000(8).

4. Half to three-quarters of all cars are concentrated in major metropolitan areas. "There are more automobiles in Mexico City and Sao Paulo than in Philadelphia or Dallas"(8) (or Birmingham - U.K.).

5. The upward trend of registrations is generally accounted for largely by the private car, which becomes an increasing proportion of the motor vehicle total as national incomes rise. Passenger cars are still only 56% of the total in developing countries but moving rapidly towards the 80% mark already achieved in Europe and North America(8).
Given the present state of transport technology, it must be concluded that the automobile revolution is irreversible and that the question posed for developing countries is how to achieve the greatest advantage from the car while reducing its unwanted side effects.

1.4 **ENVIRONMENTAL EFFECTS OF TRAFFIC**

Traffic growth in modern times creates a number of problems that are particularly difficult to solve in city and suburban areas. One aspect of the problem is that roads previously found adequate to allow a satisfactory flow of traffic become quite unsuitable for the widespread use of motor vehicles. This aspect might be partly solved by widening present roads or by constructing new highways which may pass through areas previously little affected by traffic. The penetration of motor vehicles throughout urban areas is bringing its own peculiar penalties of accidents, anxiety, intimidation by large or fast vehicles which seem out of scale with the surroundings, noise, pollution, vibration, dirt and visual intrusion on a vast scale.

1.4.1 **Main Effects**

The main acknowledged effects on the environment are:

1. **Noise**

Environmental noise is not an entirely new phenomenon, but rather is a problem that has grown steadily worse with time. Since 1882 it has been realised that noise causes a noticeable decrease in hearing and deafness for boiler makers (9). Fortunately road traffic does not generate noise.
levels so high that they will cause hearing damage. It is more significant here to consider those human responses having to do with description of specific activities and general annoyance.

a. Annoyance in homes:

In a study of urban traffic noise, one is generally most concerned with the subjective effects; that is, a knowledge of what fraction of the population will be annoyed or dissatisfied in certain noise situations. As early as 1948 a study by Chapman(10) showed that the most frequently reported external noises in British houses were from road traffic and domestic animals.

One of the most comprehensive surveys ever made was the London Survey in 1961(11). Noise measurements were made at 540 locations in Central London, and 1400 residents at those locations were interviewed. The measurements showed that traffic noise predominated at 84% of the points, and about one-third of the people interviewed specifically mentioned motor vehicle noise as a major irritant. Equally significant is the fact that comparison of the results with the results of the 1948 survey showed that the percentage of people disturbed by noise arising outside the home increased from 23% in 1948 to 50% in 1961(12).

Although the urban population densities are different in the U.S.A., it has been suggested that a somewhat similar state of affairs exists there(13).

Griffiths and Langdon(14) found that dissatisfaction with noise conditions was well correlated with a composite noise unit (TNI), while Robinson(15) showed that noise
pollution level, \( L_{NP} \), (see Appendix 1) can accommodate the results of traffic, aircraft, and laboratory noise disturbance studies.

Recently Langdon found that over the range of noise levels from 60 to 80dBA for free-flowing traffic, nuisance was highly correlated with noise level measured as \( L_{10} \) (the level exceeded for 10% of time, see section 6.9.1 and Appendix 1) over 24, 18 or 12 hours, as \( L_{eq} \) over 24 hours, or as traffic volume as the logarithm of vehicle flow. For non-freely flowing traffic, however, he found that a measure of traffic composition (logarithm of percentage of heavy vehicles) was found to yield useful nuisance predictions\(^{16}\). This finding has been supported by Jones & Waters\(^{17}\).

The linear regression line of \( L_{10} \) with dissatisfaction score in the Griffiths and Langdon survey\(^ {14}\) gives an average neutral response at 68dBA measured externally (at 1m from the building facade). However, the explained variance of individual scores is very low at around 10%.

b. Speech Interference:

A more objective effect of traffic noise is interference with communication. By speech interference we also imply interference with listening to television and radio, or the ability to use a telephone satisfactorily. Relatively simple experiments allow criteria to be developed that specify how loud a noise will be before speech intelligibility is degraded. These criteria take into account the distance between people wishing to communicate, the voice power used, e.g. normal voice or raised voice, and the nature of the space in which communication takes place, e.g. living room, office, school room, factory, or out-of-doors\(^ {18}\).
Noise interference with speech is usually a masking process. As a result of background noise, a person may hear only a few or perhaps none of the speech sounds necessary for satisfactory intelligibility. Also, noise of a certain level may mask some speech sounds and not others, depending on the talking level, the particular sound, and the relative frequency distribution of the sound and of the noise (19).

Speech interference starts at a noise level some 18dB below the speech level and intelligibility is totally lost when the noise level exceeds the speech by 12dB. For example, a noise level of about 58dBA allows conversation at 1.3m at normal voice level and reasonably satisfactory telephone conversation, a minimum requirement for office but well above that permissible in conference rooms and class rooms (20).

The amount of attenuation of windows, through which most sound normally passes, depends upon the type of construction. It is usual to assume an average attenuation of about 15 or 20dBA (higher attenuation can be achieved by properly designed and fitted units), when windows are open, as they frequently are in summer time, reductions of 10dBA and less are common. Thus to preserve a good indoor living environment, ideally outdoor traffic noise levels $L_{10}$ should not exceed 55 to 60dBA. This is of course rather less than the 68dBA limit specified in the Noise Insulation Regulations (21).

d. Human Performance:

The effects of noise on task performance have been extensively studied, but mainly with reference to noise of higher intensity and frequencies than that due to road traffic. The main problem, as indicated above, is in the indirect effects of poor communication by sound, and dis-
traction in complex task performance particularly when constructive thought is involved, but the effect is complicated by the stimulating effect of 'noise' on less demanding tasks.

e. Disturbance of Sleep:

Sociological surveys show that the disturbance of sleep is often given as a main reason for annoyance. People are disturbed by traffic noise if this interrupts their sleep or prevents them from falling asleep. The increase in traffic noise during the night may change the sleeping habits of city dwellers, and the cumulative physiological effect of insufficient sleep may be harmful.

ii. Air Pollution\(^5\),\(^22\)

Pollution of the atmosphere due to motor vehicles is viewed as a rising threat to public health and to the welfare of the people. The actual effects which pollutants may cause will depend on the length of exposure and the ambient concentrations. The latter, in turn, will be a function of traffic density, climate and topography. Moreover, due to the variety of pollution sources in urban areas and the complexity of the chemical and photochemical reactions taking place in the atmosphere, it is difficult to single out and define the degree of responsibility of each of the pollutants. They can be divided into:

1) Toxic pollutants such as: Carbon Monoxide, Nitrogen Oxides and Lead Compounds.

2) Pollutants which have indirect effects: Hydrocarbons and Photochemical Oxidants.
3) Substances whose effects on human health or welfare have not been established for example, particulate materials, nitrogen compounds other than nitrogen oxides such as ammonia.

iii. Vibration

Both noise and vibration may be directly experienced as unpleasant sensations, and vibration can further disturb people because of fears of damage to the building fabric.

Traffic-induced vibration can be generated in buildings either by ground-borne vibrations or by air-borne, low-frequency sound.

It was found that vibration due to road traffic on pavements of reasonably smooth surfaces should be barely perceptible to people even at distances of 3 to 4m from the edge of the road, and should cause no harm at all to buildings, although sensitive scientific equipment might be affected. Vibrations from roads in poor condition can certainly be annoying to people and cause or aggravate minor damage in buildings.

Recently, Martin (24) found that there was a high degree of bother with traffic vibrations and where ground vibrations were not significant, air-borne, low-frequency noise was responsible for floor vibrations in buildings.

iv. Visual Intrusion

The extent of visual intrusion will depend upon the taste and occupation of the individual, the size, the distance and character of the object viewed, and so on.

Discomfort caused by a flicker of vehicle lights at
night, both to the pedestrian and the resident, and also by the high standards of street lighting provided on major routes are presumably also visual intrusion. These are probably best cured by segregation policies.

It may be possible to envisage some subjective scale of visual intrusion. The results from ref. (17) give some indication towards achieving this.

1.4.2 Methods of Study

Studies looking into the entire problem of environmental effects of traffic can be classified into three classes depending on the method of investigation, namely:

(i) Social surveys: substantial amount of work has been done in this field. It can be subdivided into:

a. social surveys accompanied by physical measurements (16), (17), (26), and

b. social surveys only (opinion surveys) (10), (25). Results from such surveys have shown a general trend towards increasing population dissatisfaction with various aspects of the environment as traffic intensity increases.

(ii) Analysis of Complaints: The Wilson Committee on the problem of noise in 1960 questioned local authorities on the sources of noise complaints. The Committee stated that the information only gives a picture of the types of noises that caused complaint, it does not necessarily give a guide to the number of people annoyed. People who are annoyed may not complain because they do not know to whom to address their complaint, or they feel it will not do any good, and many
other reasons. In addition the seriousness of the complaint is not known.

(iii) Physical Measurements: There are only a limited number of studies in this field, some of them have been concerned with noise and pollution\(^{(27)}\), while others deal with noise and vibration\(^{(24)}\). The study made at Imperial College for which a Traffic Environmental Analyser\(^{(28)}\) has been developed, collected data on traffic characteristics, noise levels, vibration, diesel smoke and carbon monoxide concentration, delay to pedestrians and visual obstruction caused by parked and moving vehicles.

These studies are very important and represent a very useful starting point for a comprehensive understanding of the environmental problem.

1.4.3 Developing Countries

In developing countries, most published work seems to be dealing with accidents. This is perhaps due to the fact that deaths from road accidents represent a high proportion of the total deaths. It was found that road accidents accounted for almost 17% of the total number of deaths studied\(^{(29)}\).

The author is unaware of any published work on environmental problems, and therefore did some crude noise measurements while on holiday in Iraq during the period December 1978 - January 1979\(^*\) using the same technique explained in

\(^*\)Traffic characteristics are not expected to be different during this period because only the 1st of January is a public holiday.
section 3.16. The results are shown in Table 1.2.

Noise levels from road traffic are higher than those from similar roads and conditions in the U.K. (rough comparison between them shows that they are at least 2dBA higher). This was expected due to the fact that driving habits in Iraq are different from those in the U.K., e.g. excessive use of horn. Other reasons could be the lower standard of vehicle maintenance and the enforcement of noise legislation is not so strict.

Background noise levels in residential areas, however, are lower than those in the U.K. (see Table 3.7).

These factors would probably contribute towards making noise more annoying.

Some of the results of a study made in Iran(30) were that:

1. there were some extremely noisy areas in Tehran;
2. people in those areas were bothered by noise;
3. in the noisy areas, noise interfered with sleep and other activities in the home;
4. in the noisy areas, noise was ranked as a major environmental problem;
5. people who lived in quiet areas appreciated their quieter environment;
6. road traffic noise and aircraft noise were significant problems in Tehran;
7. the equivalent sound level ($L_{eq}$), measured in dBA, was a satisfactory environmental noise descriptor for Tehran.
<table>
<thead>
<tr>
<th>Distance from kerb metre</th>
<th>Site</th>
<th>Site Characteristics</th>
<th>Noise Level dBA</th>
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<tr>
<td></td>
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<td>$L_{10}$</td>
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<tr>
<td>2</td>
<td>Tel-Mohamad</td>
<td>Residential Area - Traffic flow less than 60 VPH.</td>
<td>62</td>
</tr>
<tr>
<td>3</td>
<td>Alameria</td>
<td>Residential Area - Hardly any traffic.</td>
<td>58</td>
</tr>
<tr>
<td>4</td>
<td>Alsadoon Street</td>
<td>4-lane, 2-way Urban Road - Traffic flow was well below road capacity. Low percentage of HCV. Parking is allowed. Speed = 50-60KPH.</td>
<td>76</td>
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<tr>
<td>5</td>
<td>AbyGraib Road</td>
<td>4-lane, 2-way Arterial Road. Flow near capacity. About 20% HCV. Speed about 60KPH.</td>
<td>78</td>
</tr>
</tbody>
</table>
Unfortunately the main emphasis in trying to solve traffic problems in developing countries is placed on reduction of congestion and giving priority to public transport since these two points are the obvious solutions to the present pressing problems. It would be much better if comprehensive transport plans were applied from the beginning which take account of the majority of the problems, e.g. congestion, accidents and environment. Unfortunately this does not seem to be happening for several reasons, mainly:

1. Present technology is limited and many related subjects still need research and investigations.
2. Most developing countries do not have the financial means and/or skilled manpower.
3. Motorization is happening very quickly.

1.5 TRAFFIC MANAGEMENT AND OTHER MEASURES TO ALLEVIATE TRAFFIC PROBLEMS

"The main aim of traffic management is to maximise the use of the existing street system and improve road safety, without impairing environmental quality."(31) It is most appropriately applied to short-term and low capital cost improvements. Traffic management could be achieved by one, or a combination of, the following:

1. Route restrictions such as a one-way system, banning right-turning movements, bus lanes or closing side streets.
2. Parking restrictions that prevent drivers terminating journeys at certain zones.
3. Pedestrian management either by channelisation, Pelican crossings or building footbridges/subways.
4. Carriageway markings and traffic signs to inform the motorist about different actions to take especially at junctions.

Some of the more advanced and costly measures to alleviate traffic problems are:

a. Traffic management in public transport such as improved bus routes, bus-only streets, bus precincts and signal pre-emption.
b. Substituting uncontrolled junctions or roundabouts by signalised intersections.
c. Co-ordinated control systems, achieved either by some form of linking of two or more junctions that are in close proximity on a main route, or by using computer-based urban traffic control (UTC) systems, (formerly "Area Traffic Control").

Most of these schemes have immediate advantages to transport but their effect on the environment is not yet fully known or investigated, and it should be mentioned that some of these schemes are being used despite their adverse effect on the environment, a classic example being one-way streets.

1.6 COST BENEFIT ANALYSIS AND THE COST OF NOISE

Cost-benefit analysis is the technique applied to the evaluation of alternative transportation plans. The basic aim of evaluating any proposed transportation improvement is to compare the expected benefits with the cost of introducing the scheme. The standard process is to express the annual
benefits of a scheme as some fraction or rate of return on the initial or capital cost.

One aim of cost-benefit analysis is to extend the scope of economic evaluation so that intangible "goods", such as the time savings, or as in this case, quietness, can be taken into account. This requires money values to be attached to those "goods", so that they can be put into the balance.

Although time savings, or quietness, are never sold as such, there are nevertheless occasions when the individual is able to pay money to obtain such things. The amount that he is prepared to pay is a measure of the value placed on them. For example, a man who is house hunting and has the choice between a quiet and a noisy house, must make up his mind what it is worth to him to live free from noise. Ideally, then, the analyst should find such situations and observe what choices people make.

Clearly it would greatly help in decision-making if the impact of noise could be related to the familiar scale of monetary cost. In this way, the disbenefit of noise can be set in its proper perspective alongside other more tangible considerations such as the economic benefit of the development.

If compensation is to be considered then the ability to place a cost on this particular environmental nuisance becomes the starting point for rational debate and negotiation.

Different methods of approach to put a monetary value on noise now exist.
1. House prices: It is likely that some difference in prices will exist between quiet and noisy houses which are similar in other respects. The house market is at first sight an attractive source of data for research into the values people place on peace and quiet, since it reflects real-life purchasing decisions. Unfortunately, notwithstanding the several attempts that have been made, this is not after all a suitable source (32).

2. Social Surveys: An alternative method of approach is to ask people to state what their values are. Social surveys methods have one great advantage that the sample may be specified, which is an advantage over interpreting market data where one rarely knows who the people making up the market are. The main difficulty is in knowing what reliance can be put on answers to hypothetical questions (33).

3. Experiments: A method is required which will retain the advantages of a social survey but will at the same time draw on actual behaviour rather than on answers to hypothetical questions. The essence of the experimental approach is that the noise effect to be tested is simulated, by means of a recording or in some other way, and people are then asked to accept the noise in their homes in return for a payment. Such an experiment can be objected to since (a) it distorts the reactions of the participants so that the sample no longer remains representative of any
wider population. Such an objection could be raised about any experiment and even about some surveys; (b) the attempt to isolate the noise nuisance of road traffic from its other effects may not be realistic (33).

4. Games: The method is an extension of the more traditional attitude survey used in social survey work. During the course of the interview a gadget is used - like an electrified questionnaire - which is referred to as a Priority Evaluator. The main use of the Priority Evaluator is in assessing relative priorities (34). However, since the method consists essentially of trading-off improvements in one variable against sacrifices in another, it can be used to relate preferences to monetary values by the inclusion of a money variable (or a variable such as travel time that can be converted into money values).

5. Simulation: Is an experiment designed to test the viability of obtaining evaluations by use of the TRRL-Environmental Simulator (35); it comprises two rooms separated by a window and a partition. One room houses projection and amplification equipment and is used for projecting films of different external environments on to a screen. The films, which are accompanied by synchronised sound, are observed through the window from the other room, which is furnished as a lounge.

Subjects compare two pairs of films representing
environments before and after changes in road and traffic characteristics. Subjects make scale assessments of the environment and estimate the amount of money that would compensate their households for disturbance that they envisage changes from 'before' to 'after' would cause.

The same objections made on experiments apply to this approach.

It has been concluded that the controlled conditions afforded by the simulator do not overcome the difficulties inherent in asking members of the public to place a monetary value on their experience of environmental disturbance.

Despite the conclusion made by Rosman that further work directed towards obtaining money values is unlikely to be more successful; environmental effects need to be put on a comparable basis with each other and with the other parameters.

Gatlow and Thirlwall (36) were appointed in 1974 to study and report on the subject of environmental impact analysis. Some of the terms of reference which they were given are:

a. to survey the techniques now being used or developed to measure the environmental impact of large-scale projects;

b. to consider the circumstances in which development proposals would give rise to the need for environmental impact analysis;
c. to consider the ground to be covered in such an analysis and whether any standardised method of presenting the required information is appropriate.

They stated that those responsible for major development projects both in the public and the private sectors can no longer take decisions based strictly on economic considerations, they must take account of environmental costs and benefits in the widest sense.

They also stated that "it is rather a question of how the operation of the planning system can be geared to deal with this kind of development in the right degree of depth so that decisions can be made in the light of better knowledge of what the environmental consequences are likely to be and the public are not dismayed by results which were not foreseen when permission was given."

The above seems to be a step to put environmental effects on a comparable basis with the other parameters. Indeed, this is what seems to be happening in the U.S.A. when an environmental impact statement (EIS) is prepared prior to any major action or reporting on legislation likely to significantly affect the environment.

1.7 THE AIM OF THE STUDY

The Department of the Environment's memorandum "Calculation of Road Traffic Noise"(3) is the latest of a number of official prediction documents and it is the most detailed one.

The "Calculation of Road Traffic Noise" (CORTN) is based on work carried out by a number of organisations such
as the Building Research Establishment (BRE), National Physical Laboratory (NPL) and Transport & Road Research Laboratory (TRRL). It is primarily a free-flow situation method, although it does suggest an approach to the interrupted flow case at intersections. This official document is to be reviewed in the light of its years in operation and a number of studies of interrupted and congested flow situations.

The aim of this study is to provide an accurate, yet easy to use prediction method for interrupted flow at intersections, also to cover the complicated traffic situation when a pair of signalised intersections are in proximity to one another. The latter was sought in order to study in detail the effect of Urban Traffic Control (UTC) systems on environmental noise.

Stochastic technique has been used to build three simulation models. The first covers free-flowing conditions, details of which can be found in Chapter 3 and the other two models cover single signalised intersections and a pair of signalised intersections respectively, their details are given in Chapters 4 and 5. Data have been collected using standard noise equipment and video tape equipment were used to collect the required traffic data. Methods of data collection and analysis are described in Chapter 6. Models validation was carried out by comparing the free-flow model with the "Calculation of Road Traffic Noise" and the signalised intersection model with measured data. The results of this investigation are shown in Chapter 7. Chapter 8 gives some examples of the use of the models and Chapter 9 describes the measured effect of the application of a UTC system.
CHAPTER 2  LITERATURE SURVEY

2.1 GENERAL

Vehicular traffic on highways is becoming more and more a source of community noise. As the volume of road traffic increases, motorways penetrate urban areas (and the noise levels emitted by vehicles are only slowly reducing) concern about the noise from road traffic grows.

It was estimated in 1963 that 19% of the urban population live in dwellings exposed to noise levels which might be regarded as unacceptably high. With no reduction in individual vehicle noise levels and allowing for the expected increase in numbers of vehicles, this may rise to 30% of the population by 1980\(^{37}\). Several attempts have been made to predict future noise levels and their effects on the population, and that mentioned above is only one of these.

If noise prediction is required at more complex situations of a traffic network, and to cover possible changes in (a) individual vehicles' noise levels, and/or (b) traffic parameters, and/or (c) the traffic network, they become more and more complicated.

The present literature survey will give more weight to work carried out in the U.K., where the present study has been made, for the reason that the pattern of traffic and methods of driving on both urban and rural roads is somewhat different from other countries. The investigations relevant to this present work could be classified as follows:

1. Measurements of Noise Levels
2. Regression Analysis
3. Theoretical Models
4. Scale Models, and
5. Simulation

As it will be seen some overlapping in these classifications is inevitable

2.2 MEASUREMENTS OF NOISE LEVELS

2.2.1 Traffic Streams

The earliest attempt to quantify people's assessment of "noise" was the Wartime Social Survey of 1943, reported in 1948(10). This produced statistics on those that noticed, and those that were bothered by noise but did not relate the results to physical measurements of sound levels.

The London County Council reached a decision in 1960 that the time had come to obtain information about the general background noise in London, in order to assist them in dealing with certain planning matters. They accordingly resolved that, in conjunction with the Building Research Station (BRS), then of the Department of Scientific and Industrial Research, now Ministry of Technology, a systematic survey of an area approximately 44 square miles (113.96km²) in Central London containing a resident population of 1½ million should be undertaken. In addition, they asked for measurements and recordings of sound levels in connection with detailed surveys in selected areas, at various floor levels in high buildings, and for evaluation of the effect of traffic noise on noise-sensitive buildings.

A summary of the results obtained from the then uncompleted noise survey was submitted as evidence to the Committee on
the Problem of Noise appointed by the Minister of Science (Wilson Committee (12)). Part of the results of the study of traffic noise have been included in the report 'Traffic in Towns' of the Steering Group and Working Group appointed by the Minister of Transport (Buchanan Report) (1). An account of the London Noise Survey has been given by Purkis (38). The Wilson Committee on the problem of noise (12) did suggest a criterion of desirable 'living room' noise levels using $L_{10}$ in dBA units as the standard measure. This began to establish the use of $L_{10}$ and dBA.

A new survey examining noise from road traffic alone was conducted for the Building Research Station (BRS) in 1963 and reported in 1968 (14). Noise samples were taken at hourly intervals over 24 hours at a point 1m from the facade of representative site dwellings. The overall subjective response was scored on a seven point 1-7, 'semantic' differential scale from 'completely satisfied' to 'completely dissatisfied'. The best correlation was obtained on a site average basis using a composite noise scale called by the authors the 'Traffic Noise Index', $(TNI = 4(L_{10} - L_{90}) + L_{90} - 30)$. However, difficulties with the measurements of $L_{90}$, which is the 'average background' level and which may be due to sources other than the road producing the $L_{10}$ values, have prevented its general application. Poorer, but roughly equal, correlations were obtained when $L_{10}$ or the Equivalent Energy Level, $L_{eq}$, were used. Because of the variability of the night-time levels, and the practical difficulties of obtaining measurements, the use of an 18-hour day $L_{10}$ value (06.00 - 24.00) was examined, and the correlation with group median dissatisfaction rose
from 0.6 to 0.7. By this time $L_{10}$ was becoming an accepted measure for traffic noise and instruments were appearing which would evaluate it relatively simply.

In 1968 Johnson & Saunders (39) described the results of roadside surveys made during the period 1963-65 in a wide range of situations so as to obtain some indication of the current 'climate' as they called it, of noise levels due to road traffic, and they attempted to study how these levels were related to the simple variables of freely-flowing traffic. The majority of the measurements were made on straight and level roadways but two sites on hills were included to investigate the influence of road gradient.

The way in which traffic noise varies with distance from the roadway was studied at each site; account was taken of the attenuation effect of different ground surfaces. An empirical relationship was derived from the measurements as will be explained in Section 2.4.

2.2.2 Individual Vehicles

Stephenson and Vulkan (40) carried out sound level measurements on about 1100 vehicles to assess the amount of noise contributed by different types of vehicles, and the range of levels produced by vehicles of one type. The measurement site was level, straight, no buildings or trees within 31m, free-flow, low traffic density and low background noise. Vehicles passing in both directions were counted and all measurements made in clear, dry weather with only slight winds. The vehicle categories selected are shown in Table 2.1,
<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Mean Level (dBA)</th>
<th>Total No. of Vehicles</th>
<th>Standard Deviation (dBA)</th>
<th>Noise Level Range for 80% of Vehicles (dBA)</th>
<th>Noise Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light car (under 1100cc)</td>
<td>70</td>
<td>211</td>
<td>2.5</td>
<td>67-75</td>
<td></td>
</tr>
<tr>
<td>Medium car (1100-1600cc)</td>
<td>71</td>
<td>252</td>
<td>2.6</td>
<td>67-75</td>
<td></td>
</tr>
<tr>
<td>Heavy car (over 1600cc)</td>
<td>72</td>
<td>149</td>
<td>2.9</td>
<td>68-77</td>
<td></td>
</tr>
<tr>
<td>Light commercial (four-wheeled)</td>
<td>73</td>
<td>110</td>
<td>2.4</td>
<td>69-77</td>
<td>1.5</td>
</tr>
<tr>
<td>Heavy commercial</td>
<td>81</td>
<td>370</td>
<td>3.3</td>
<td>76-86</td>
<td>10</td>
</tr>
<tr>
<td>L.T. buses</td>
<td>83</td>
<td>24</td>
<td>1.9</td>
<td>80-85</td>
<td>16</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>77</td>
<td>53</td>
<td>3.9</td>
<td>72-83</td>
<td>4</td>
</tr>
</tbody>
</table>
which shows the mean noise level and the standard deviation within each category and also the noise level range for 80% of the vehicles in each category. The last column gives the relative sound intensities of different categories of vehicles, a unit which they called "noise equivalent".

They found that with heavy vehicles there was a considerably greater increase in noise due to climbing than is the case with light vehicles, but there were insufficient results to obtain statistically significant conclusions with the number of variables involved.

2.2.3 Speed Effects

In order to extend the understanding of the way in which traffic noise varies with vehicles operating conditions, and to provide computer simulations of traffic noise with part of their input, equations have been developed to describe the noise output of some classes of vehicles as a function of speed. A number of studies have been carried out in this respect and as a result of these studies it has been generally accepted that noise emitted by vehicles takes the form:

\[ L = \alpha + \beta \log V \]

where \( L \) is the peak sound level

\( V \) is the speed in Kph or mph, and

\( \alpha \) & \( \beta \) are constants.

Table 2.2 gives a summary of the results of some studies in this field. It can be seen that a good agreement exists between some results, although they are independent. However, it has been stated that the speed-level characteristics given
<table>
<thead>
<tr>
<th>Date</th>
<th>Research</th>
<th>Effect of 10-fold of speed doubling</th>
<th>Effect of doubling speed</th>
<th>α</th>
<th>β</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971</td>
<td>Ross (41)</td>
<td>36/</td>
<td></td>
<td>12.6</td>
<td>33.6</td>
<td>Speed in kph</td>
</tr>
<tr>
<td>1973</td>
<td>Lewis (42)</td>
<td>33/</td>
<td></td>
<td>14.9</td>
<td>32.8</td>
<td>Speed in kph – Light Vehicles</td>
</tr>
<tr>
<td>1977</td>
<td>Lewis (43)</td>
<td>27/</td>
<td></td>
<td>5.6</td>
<td>37.7</td>
<td>For light vehicles*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>31.1</td>
<td>28.6</td>
<td>For heavy vehicles*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*in this case L is mean peak sound levels &amp; ( V = \bar{V} ) is mean site vehicle speed in kph</td>
</tr>
<tr>
<td>1972</td>
<td>Olson (44)</td>
<td>/8.5</td>
<td></td>
<td>16.13</td>
<td>32.7</td>
<td>For cars α &amp; β have not been derived by Olson.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>For trucks α &amp; β have not been derived by Olson.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16</td>
<td>30</td>
<td>Speed in mph</td>
</tr>
<tr>
<td>1969</td>
<td>Gallaway (45)</td>
<td>/9.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1977</td>
<td>Nelson &amp; Piner (46)</td>
<td></td>
<td></td>
<td>22.4</td>
<td>29.9</td>
<td>For light vehicles, Speed ≥ 27.1 kph</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>29.5</td>
<td>29.9</td>
<td>For heavy vehicles, Speed ≥ 39.4 kph</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(this work is based on many studies, e.g. Lewis (42) and Christie (48),(49) et al.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>More details are given in Section 3.18.2)</td>
</tr>
<tr>
<td>1978</td>
<td>Diggory (47)</td>
<td></td>
<td></td>
<td>19.9</td>
<td>29.9</td>
<td>For light vehicles, speed in kph</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>28.1</td>
<td>29.9</td>
<td>For heavy vehicles, speed in kph</td>
</tr>
</tbody>
</table>
by Nelson and Piner in Ref. (46) "which are the most detailed" are far from complete (50).

There is quite a wide disparity between the noise a vehicle will make at wide open throttle and the noise it makes at road load, that is, when it is expending just enough power to maintain a constant speed. Figure 2.1 shows sound levels for twenty passenger cars (including some prototypes not produced) arranged in increasing order of their 60mph (96.54kph) road load sound levels. The maximum wide open throttle sound level is also shown, arranged in each group of vehicles in increasing order. For groups of cars showing the same road load sound level, the maximum sound levels vary from each other by 5 to 15dBA (51).

2.2.4 Acceleration Effects

It has been generally accepted that for petrol engines, the noise increases with load, and with the acceleration of the car, and acceleration has more effect on noise level at low speeds, particularly in starting off (51), (52), (53), (54).

Rønheim & Storeheira (54) stated that it would seem reasonable to expect the increase in noise level during acceleration (relative to constant speed noise level at same speed) to be proportional to the magnitude of acceleration. Their measurements showed that this assumption is approximately correct but that the increase during maximum acceleration is generally less than 5dBA in 2nd, 3rd and 4th gears (acceleration less than 2m/s²) and between 10 and 20dBA in 1st gear when acceleration usually lies between 2 and...
Fig. 2.1 Comparison of Road Load Noise to Maximum Noise
3m/s² (see Section 3.18.2, Fig.3.6). Storeheire et al(55) in their work on heavy vehicles have also found that the increase in noise level during acceleration depends on the magnitude of acceleration (see Fig. 3.6).

Waters(53),(56) made measurements of the noise produced by two vehicles (1500cc car and 9½ ton truck) under conditions of maximum acceleration. In the case of the truck the maximum noise produced in each gear during acceleration was found about the same as that produced at maximum constant engine speed, but the noise level produced immediately after a gear change was from 3 to 9dBA higher than the equivalent constant speed value. In the case of the car, the maximum levels reached were up to 3dBA higher in bottom gear and 3dBA lower in second and third gears than the equivalent constant speed levels. The levels immediately after a gear change were from 2 to 9dBA higher than the equivalent constant speed levels. Olson(44) found that for heavy trucks, acceleration (starting from stop) is equivalent to cruising in the 40 - 49mph (64.4-78.8Kph) range. For tractor trailers it is slightly below 40 - 49mph (64.4 - 78.8Kph) and for cement mixers slightly below 30 - 39mph (48.3 - 62.8Kph).

The ISO test procedure(57) which is based on a moving vehicle test* (an acceleration test, at full throttle from a stated running condition) was extended for the TRRL(58) (RRL previously) investigations to include measurements of full throttle acceleration in all gears from a range of engine speeds.

---

*It relates to vehicle conditions which give the highest noise level consistent with normal driving and which lead to reproducible noise emission.
Sound levels from an 1100c.c. motor car were measured during acceleration in all gears, steady-speed drive pasts in various gears, and coasting. In each gear it was found that there is an envelope of sound levels, the upper edge representing the car accelerating hard, the lower edge representing the car driven steadily. Under acceleration the sound level is high and does not vary much with speed, but driven at constant speeds the sound level in each gear increases with speed at about 10 to 17dBA per doubling of speed.

Tests on six lorries with gross vehicle weight exceeding eight tons gave the conclusion that at speeds below 60Kph under full throttle acceleration the vehicle emitted sound at the same levels as in the ISO test.

Jones(59) has produced curves from some 1000 data points where the effect of acceleration/deceleration on noise is given as a function of speed. Light and heavy vehicles' noise was found to increase by about 6.5dBA per doubling of speed when driven with zero acceleration. This is compared with values between 9 - 13dBA for light vehicles and 9.0dBA for HCV's found by other workers(56),(58),(60). It has also been found that acceleration at high speed reduces noise and causes it to increase at low speed; deceleration has an opposite effect and this finding is applicable to light and heavy vehicles alike.

2.2.5 **Interrupted Flow**

Sparkes(61) proposed a predictive method to determine noise emitted by an accelerating queue of vehicles based on an M.I.T. simulation of performance characteristics of the
average heavy vehicle (7.8 litre diesel engine) and the average light vehicle (1.6 litre petrol engine), the power unit being the major source of noise and being treated as a point source, with the inclusion of rolling noise at higher speeds.

Lewis and James (62) have measured data on individual vehicles at roundabouts and shown significant differences in the noise level against distance from roundabout associated with the layouts of the site; but they have consistently shown lower than free-flow levels when decelerating with a more variable increase associated with acceleration (when heavy vehicles showed the largest increases).

To assist in the understanding of congested urban traffic flow with many intersections, Pachiaudi and Favre (63) examined the increase of noise caused by the setting of a vehicle in an acceleration state and its effect on the noise in the surroundings of an intersection. They made their measurements at 7.5m from a Renault R16 vehicle pulling along a road of zero slope in a free environment. Records of gear, the distance travelled as a function of time, and the noise level in dBA were made.

It was found that at a given gear the noise emitted by one vehicle was a linear increasing function of the acceleration. In the first gear, the effect of acceleration on the noise was identical whatever the gear (uniform increase of 6dBA between 0 and 2m/s²). For the other ratios, it was particularly sensitive to the lower gear.

For a given acceleration and ratio, the noise level was a logarithmic function of speed.
From these results, theoretical analysis and measurements of noise at signalised intersections were made. Particular interest was paid to the effect of the distance from the lights and the duration of their cycles.

The increase of noise due to the acceleration of the vehicles was felt in the zone situated at the level and downside the lights. This zone was marked by a strong slope of increasing noise and by important levels of peaks in fluid traffic (the increase of the peak level may be of 6dBA). This character is all the more pronounced as the cycle is faster, hence traffic more chopped and accelerations more frequent.

Jones and Waters (17) made measurements at distances up to 150m from light controlled intersections and looked at the difference between measured values and those predicted by the Delany (64) free-flow prediction method for all flows at the intersection. Apart from those included in the prediction method, no other parameters could be isolated, and simple linear regression of the data from all sites was used giving a 3dBA increase in $L_{10}$ at the intersection, reducing to zero at around 300m.

Measurements at a roundabout and intersections reported in references (59) and (65) are compared with simulation results and the prediction method given in the Calculation of Road Traffic Noise (3) respectively. The simulation was found to overpredict at the roundabout, but to be in good agreement at the intersection.

Further traffic noise in urban areas has been measured at kerbside to avoid pedestrian interference (66) and either to build or validate different models (67), (68), (69), (70); it
has also been measured in many cities where it is considered to be a serious problem\(^{(71),(72),(73)}\).

2.3 **REGRESSION ANALYSIS**

In order to make the best use of any measurements, they can be used in conjunction with theory to build models utilizing the regression analysis technique. Such modelling seems to have begun as early as the measurements themselves, and free-flowing models were the first to be derived.

The earliest free-flowing model found in the literature is by Bolt et al\(^{(74)}\), who summarized results of noise measurements for uniformly moving traffic in a chart reproduced in Fig. 2.2. The chart refers to noise levels found at a distance of 20 to 30 ft. (6.1 - 9.1 m) from a traffic lane used by average passenger cars at speeds from 35 to 45 mph (56.3 - 72.4 kph). The results are given in terms of the percent of time during which the level will lie below a specified value. The average number of vehicles per minute appears as a parameter. The chart terminates at 95% when the traffic rate is of the order of 100 vehicles per minute (6000VPH), the level remains near to the maximum value of 75 dB at all times. The results are then summarized to apply for a mixture of truck and passenger car traffic and to a distance of up to 200 ft. (60.96 m). The time average of the overall sound pressure level (SPL) under the conditions is given in the following formula:

\[
SPL = 83 + 8.5 \log q - 20 \log d
\]

where \(d\) is the distance in feet from the traffic lane to point of observation, and

\(q\) is the number of vehicles per minute.
Fig. 2.2 Chart, based on traffic noise survey, showing percent of time that overall SPL lies below any arbitrary value. It applies to observation at 70-30ft. from traffic lane, average passenger cars at 35-45mph. SPL values should be reduced by 15db for distances of 150 to 200ft. Levels for heavy truck traffic are 15db above passenger car values.

Fig. 2.3 Flow Chart for Predicting Straightforward Single Road Situations
Buildings and other reflecting objects were assumed to be absent and it was emphasized that the above equation only gives an approximate effective time average for a fluctuating noise phenomena.

In 1970 the Greater London Council accepted the Wilson Committee Criteria as 'desirable standards' in its planning policy, and its Scientific Branch responded with its Urban Design Bulletin No.1 \(^{(75)}\) to give guidance on criteria levels and typical levels for various situations. This was followed in 1971 by the Building Research Station's Digest 135 'Motorway Noise and Dwelling' \(^{(76)}\) which gave charts and tables for the prediction of 18-hour \(L_{10}\) values on the basis of flow, speed, \% of heavy vehicles, distance and barrier effects. This was extended and became the Department of the Environment's 'New Housing and Road Traffic Noise' (DB26) \(^{(77)}\) in 1972.

In parallel with the work at B.R.S. the acoustic group at the National Physical Laboratory had also carried out a number of measurement projects \(^{(39),(78)}\) and evolved prediction methods \(^{(64),(79)}\). In common with the B.R.S. method the prediction relies on regression analysis based on factors, such as volume flow, distance, etc., that, from acoustic principles, are likely to be important. A standard deviation of 1.17dBA between the overall prediction and measured data is claimed which implies that 96% of measured data will lie within \(\pm 2.34\)dBA of prediction for this free flow case.

In 1970 the Transport and Road Research Laboratory entered the scene with its 'Review of Road Traffic Noise' \(^{(80)}\) which has been followed by a series of reports on the noise associated with various sources on the vehicle, the develop-
ment of computer programmes for the prediction of traffic noise (81), (83) and examples of their application (81), (82) (more details about this are given below and in Section 2.6).

The basic prediction equation for both Delaney (62) and Nelson (79) are of the form

\[ L = a + \beta \log_{10} V + \gamma \log_{10} Q + \delta p - \epsilon \log d \]  

where \( L \) is the Noise Level \( L_{10}, L_{50} \) or \( L_{90} \) in dBA units, \( V \) is the mean speed of the traffic, \( Q \) is the vehicle flow, \( p \) the \% of heavy lorries, and \( d \) the distance of observation point from the nearside kerb. The regression coefficients \( a, \beta, \gamma, \delta \) and \( \epsilon \) are obtained for the appropriate percentile level from the best linear fit of measured data points, measured over defined surfaces.

Delaney used simple independent coefficients, but Nelson found some interdependence particularly with the \% of heavy vehicles. The appropriate coefficients for \( L_{10} \) over short grass are given below.

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Delaney</th>
<th>Nelson</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a )</td>
<td>17.56</td>
<td>(11.4 + 0.3p)</td>
</tr>
<tr>
<td>( \beta )</td>
<td>16.36</td>
<td>(20.3 + 0.18p)</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>8.97</td>
<td>(8.0 + 0.06p)</td>
</tr>
<tr>
<td>( \delta )</td>
<td>0.118</td>
<td>0.3</td>
</tr>
<tr>
<td>( \epsilon )</td>
<td>14.8</td>
<td>16.0</td>
</tr>
</tbody>
</table>

For typical % heavies of around 20% the coefficients \( a, \beta \) and \( \gamma \) are in close agreement. The equivalent expressions could be derived from the curves presented in Design Bulletin 26 (DB 26).
Although the overall predictions are not too dissimilar differences in the individual coefficients imply apparent differences in the effectiveness of various strategies to control noise. Nelson examines these differences in Ref. (80). Distance is more effective in the T.R.R.L. prediction at -4.7dBA/doubling of distances whereas Delaney gives 4.4 and DB26 only 4.0. Speed is more significant in the T.R.R.L. low % heavy vehicle case at 6.1dBA/doubling, or DB26 at 6.0/doubling, whereas Delaney gives 4.9 and the T.R.R.L. high % heavies 4.3/doubling. The situation reverses again with volume flow T.R.R.L. high % heavies giving 3.0dBA/doubling, Delaney 2.7, and DB26 or T.R.R.L. low % heavies 2.4/doubling. The effect of % heavies alone from the T.R.R.L. model is fairly complex with an increase of 40% (e.g. from 10% to 50% heavies) giving only 2.2dBA at low flows and high speed by rising to 6.4dBA at high flows and low speed, whereas the other two predictions just give average values of 4.7 for Delaney and 4.0 for DB26. This stronger influence of heavy vehicles at low speeds is probably a consequence of the difference between diesel and petrol engines, the latter having a much greater increase of noise level with engine speed and load than the diesel.

To overcome the problem of a number of conflicting prediction methods from various 'official' sources, and in view of the obvious need of a 'standard' prediction method rather than measurement to detect the 1dBA change required in the Noise Insulation Regulations of the Land Compensation Act, a composite prediction method was evolved and published in 1975 as the 'Calculation of Road Traffic Noise' (CORTN) by
the Department of the Environment(3) and its use required in
the 1975 revision of the Noise Insulation Regulations(21).

The Calculation of Road Traffic Noise seeks to cover all
eventualities and is 'necessary to enable entitlement under the
Noise Insulation Regulations 1975 to be determined.' Fig. 2.3
is the Flow Chart for the Calculation procedure, taken direct
from the H.M.S.O. document (a computer program written by the
author in Basic Language which carries out the calculation pro­
cedure is given in Appendix 2) where the application is de­
cribed in detail. The Regulations require that, for compensation
purposes, a highway improvement scheme should 'cause or be
expected to cause' an increase in $L_{10}$ dBA (18-hour) to equal or
exceed the 'specified level' of 68dBA, coupled with an expected
increase of at least 1dBA over the 'prevailing level' from
highways in the vicinity before the works were begun, and that
the improved highway shall contribute at least 1dBA to the
overall increase. In the 'Calculation' method the design
period of the 'expected increase' is limited to 15 years after
opening to traffic. Thus in applying the method to compensa­
tion cases the Basic Noise Level will be derived from the flow
forecasts up to 15 years ahead to obtain the 'relevant level'
and from existing flows for the 'prevailing level'. In the
absence of better forecasts, the data is provided in Charts
14(a) - (d) on the % increases in vehicle flows by type
(Section 1.2).

The $L_{10}$ (18-hour) basic level is then corrected for
(i) speed v. (from the base level of 75Km/hr) on the basis of
given values for road types, and for the 'prevailing' situation
from the highway authorities own data; (ii) % of heavy vehicles
other than cars; (iii) gradient (in the real case Blitz\textsuperscript{(69)} has found no significant correlation of measured noise levels with gradient, but increased power required to climb a gradient must increase noise levels); (iv) Road surface, which affects tyre noise, particularly if anti-skid grooving is employed.

Two distance attenuation charts are provided, one for hard surfaces, the other for grassland.

Corrections are then applied for 'barriers' interfering with propagation, which in turn can be adjusted for their finite extent along the road side in terms of 'angle of view'.

Finally the effect of reflection from local and opposite facades, etc., can be assessed.

Where the road is not straight, an equivalent series of straight segments may be used, each assessed individually, and for intersections each arm can be treated as a segment (with an appropriate mean speed). The addition of noise levels can then be carried out with a successive addition method.

The combined authors of the Calculation of Road Traffic Noise\textsuperscript{(3)} produced a paper in the Journal of Sound and Vibration\textsuperscript{(86)} in which they state that the mean error between prediction and measurement is +1.4dBA at low noise levels (over-prediction), and -1.2dBA at high noise levels, but around the critical level of 68dBA is no more than +0.3dBA.

In the non-free flow case, more data is required and more variables have to be included in the analysis which makes the problem much more complicated.

An early reported study of interrupted flow is that by Crompton of Imperial College\textsuperscript{(85)} carried out in Edinburgh and
Canterbury. The noise analysis part of the study (which also looked at air pollution, carbon monoxide level, delay to pedestrians crossing the street and other factors) adopted the percentile level approach to describe the time variant noise using $L_{10}$, $L_{50}$ and $L_{90}$. In the event it tended to concentrate on $L_{50}$, since $L_{90}$ was felt to be affected by other than traffic noises and $L_{10}$ was more influenced by arrival patterns than speed or street width. Arrival pattern was measured by an 'Index of Dispersion', where the number of vehicles arriving in successive 10-second intervals is plotted as a frequency distribution, and the Index value is given by the rates of the distribution variance, to its mean. A value near 1.0 indicates 'random' arrival, markedly above 1 indicates 'platoon' arrival and less than 1 'uniform'.

Crompton produced regression equations for $L_{50}$ and $L_{10}$ based on volume flow, $Q$, percentage of heavy vehicles, $p$, mean speed $V$, carriageway width, $Y$, and Index of Dispersion, $T$.

$$L_{50} = 40.35 + 14.1 \log_{10} Q(1 + 0.04P) - 4.71 \log_{10} VY$$

for which the correlation coefficient, $r$ (the indication of 'scatter', for perfect fit $r = 1.0$) was 0.91 for 170 data points, and

$$L_{10} = 44.37 + 10.23 \log_{10} Q(1 + 0.09P) + 1.61T$$

($r = 0.88$)

It can be seen that the effect of heavy vehicles is greater on $L_{10}$ than $L_{50}$, but that, within the range measured, speed and
street width disappear from the \( L_{10} \) equation but 'platooning' effects enter the equation. The negative effect of speed and street width on \( L_{50} \) was felt to be correct since street width increases distance and hence reduces noise, and speed at constant volume flow implies greater vehicle spacing, or reduced vehicle density, which may reduce the mean noise level. The prediction accuracy when applied to the Canterbury results, taken in better weather and where streets were generally narrower, did not show adequate correlations for design or compensation purposes (with errors up to ± 5dBA).

A modified technique (48), (49) was employed for congested flows based on detailed analysis of noise levels associated with four classes of goods vehicles or buses. The percentage of time that specified noise levels were exceeded were established as functions of the hourly flows of each vehicle class, e.g. the % time over 80dBA in Putney High Street was given by

\[
T(80) = 1.48 + 0.016F_1 + 0.063F_2 + 0.123F_3 + 0.041F_4 \quad 2.6
\]

where \( F_1 = (Q_1) \) is the hourly flow of 2 axle commercial vehicles of 5 - 10 ton GVW

\( F_2 = (Q_2) \) is the hourly flow of 2 axle commercial vehicles of 10 - 16 ton GVW

\( F_3 = (Q_3) \) is the hourly flow of commercial vehicles with more than 2 axles

\( F_4 = (Q_4) \) is the hourly flow of buses

From a series of such equations the cumulative distribution of noise level against time can be drawn and \( L_{10} \) established.
The authors stress that the results may be peculiar to Putney High Street and indeed found this to be the case by repeating the study in Newbury and Camberley\(^{(49)}\).

The actual \(L_{10}\) values are given below together with the expected effect of changes in traffic composition on \(L_{10}\), which vary at each site, both because of the values above and the initial composition.

<table>
<thead>
<tr>
<th></th>
<th>Putney</th>
<th>Newbury</th>
<th>Camberley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual (L_{10})</td>
<td>80</td>
<td>74</td>
<td>72</td>
</tr>
<tr>
<td>Removal of all vehicles with more than 2 axles</td>
<td>-1.5</td>
<td>-0.2</td>
<td>-0.2</td>
</tr>
<tr>
<td>Removal of all vehicles over 10t</td>
<td>-2.6</td>
<td>-0.6</td>
<td>-0.8</td>
</tr>
<tr>
<td>Removal of buses</td>
<td>-1.7</td>
<td>-0.8</td>
<td>-0.6</td>
</tr>
</tbody>
</table>

The difference in the results for the three towns suggests that the peculiarities of the sites are important in particular the effects of congestion in terms of mean speed and the degree of 'roughness' of the flow (as suggested by Gilbert\(^{(67)}\)). Daily variations in flow, congestion and weather will also contribute to correlation difficulties. Table 2.3 shows the daily variation of percentile levels measured on the central island of a busy five-way light-controlled intersection in Leicester (Welford Place). A continuous monitoring technique was used with an automatic camera recording the Bruel and Kjaer 4420 Statistical Analyser display every hour\(^{(27)}\).

More recently Gilbert\(^{(67)}\) has extended Crompton's experiment by gathering additional data in Rotherham and Sheffield, but has restricted his analysis to \(L_{10}\). He quotes a revised
Table 2.3a Percentile Levels Measured on the Central Island of a Busy 5-way Light-Controlled Intersection in Leicester
'DAY-TIME' (06.00 - 24.00)

<table>
<thead>
<tr>
<th>DAY</th>
<th>SAT.</th>
<th>SUN.</th>
<th>MON.</th>
<th>TUES.</th>
<th>WED.</th>
<th>THURS.</th>
<th>FRI.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{10}$</td>
<td>75.0</td>
<td>72.2</td>
<td>78.0</td>
<td>72.3</td>
<td>76.7</td>
<td>76.3</td>
<td>-</td>
</tr>
<tr>
<td>$L_{50}$</td>
<td>70.2</td>
<td>66.5</td>
<td>72.4</td>
<td>66.3</td>
<td>71.2</td>
<td>71.2</td>
<td>-</td>
</tr>
<tr>
<td>$L_{90}$</td>
<td>63.7</td>
<td>59.0</td>
<td>64.6</td>
<td>58.7</td>
<td>63.6</td>
<td>64.4</td>
<td>-</td>
</tr>
<tr>
<td>$L_{10}-L_{90}$</td>
<td>11.6</td>
<td>13.2</td>
<td>13.4</td>
<td>13.6</td>
<td>13.1</td>
<td>11.9</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2.3b
'NIGHT TIME' (0.00 - 06.00)

<table>
<thead>
<tr>
<th>NIGHT</th>
<th>FRI.</th>
<th>SAT.</th>
<th>SUN.</th>
<th>MON.</th>
<th>TUES.</th>
<th>WED.</th>
<th>THURS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{10}$</td>
<td>68.5</td>
<td>69.0</td>
<td>65.2</td>
<td>66.6</td>
<td>66.6</td>
<td>67.6</td>
<td>68.0</td>
</tr>
<tr>
<td>$L_{50}$</td>
<td>60.0</td>
<td>60.2</td>
<td>53.0</td>
<td>57.2</td>
<td>54.9</td>
<td>57.2</td>
<td>58.0</td>
</tr>
<tr>
<td>$L_{90}$</td>
<td>48.0</td>
<td>46.8</td>
<td>41.8</td>
<td>47.8</td>
<td>44.3</td>
<td>45.3</td>
<td>46.3</td>
</tr>
<tr>
<td>$L_{10}-L_{90}$</td>
<td>20.5</td>
<td>22.2</td>
<td>23.4</td>
<td>18.8</td>
<td>22.3</td>
<td>22.3</td>
<td>21.7</td>
</tr>
<tr>
<td>$L_{0.1}$</td>
<td>75</td>
<td>76</td>
<td>73</td>
<td>73</td>
<td>77</td>
<td>77</td>
<td>79</td>
</tr>
</tbody>
</table>
form of Crompton's regression result for flows less than 1000vhp.

\[ L_{10} = 55.7 + 9.18 \log_{10} Q(1 + 0.09p) - 4.20 \log_{10} VY + 2.31T \quad 2.7 \]

using 190 data points and having \( r = 0.82 \), for which 95% of data lies between \( \pm 5.4 \) dBA.

Using Sheffield data (134 values), the best correlation was obtained by introducing some new variables, gradient \( G \), and distance of measuring point from kerb \( d_k \). In the previous work it was argued that in urban areas with near continuous facades measurements at kerb or façade were not significantly different, as indicated in (66).

\[ L_{10} = 48.5 + 10.52 \log_{10} Q(1 + 0.04p) - 5.74 \log_{10} (d_k + 0.5Y) + 2.38 \log_{10} G \]

\[ \ldots \quad 2.8 \]

for which \( r = 0.83 \) and 95% of data lies within \( \pm 5.8 \) dBA.

A further factor that was felt to be important but could not be assessed from the experimental technique was the 'roughness' of flow due to acceleration and decelerations.

The final prediction equation proposed takes some account of this 'roughness' of flow by introducing the frequency of intersections /km, \( F_1 \), the number of traffic lanes, \( n \), and the distance to the next major intersection, \( d_1 \), combined with index of dispersion \( T \) in a 'level of service' index \( S \).

\[ S = F_1 T / n \cdot d_1 \]
and after eliminating some 35 sites which had some peculiarity that might be expected to produce an anomaly, the final 99 sites gave

\[ L_{10} = 54.96 + 9.66 \log_{10} Q (1 + 0.08p) - 5.77 \log_{10} (d + 0.5y) + 3.1 \log_{10} G + 0.93 \log_{10} S \]

for which \( r = 0.87 \) and 95% of data lies within \( \pm 5 \text{dBA} \). The 'level of service' term \( S \) can make as much as 3.5dBA difference between typical sites with few intersections and a congested city centre site with many intersections.

The series of regression equations (2.5), (2.7), (2.8) and (2.9) clearly illustrate the main problem of technique which is that of ensuring that the significant variables are included and that they are in the correct form for multiple linear regression analysis, e.g. should the gradient term enter as \( \log_{10} G \), why not \( G \) or \( G^2 \)? The form can usually be argued on physical acoustics grounds, but any variation affects the coefficients, and hence the apparent importance of the other variables. It can be noticed how the percentage of heavy vehicles, \( p \), coefficient has varied from 0.04 to 0.09; the choice would affect the apparent effectiveness of a strategy to control noise by controlling heavy vehicles. The problem of testing the appropriate hypothesis is fundamental to regression analysis.

The Ontario, Canada, Ministry of Transportation and Communication\(^{(87)}\) collected data on sound levels in the vicinity of proposed and existing provincial freeways and highways for various planning and design purposes. The data were used as a basis for a study which has two objectives: (1) to determine
the precision and reliability of existing highway noise prediction methods using province-wide data, and (ii) to develop a more precise highway noise prediction method.

More than 50 different models relating sound levels \((L_{50}, L_{10}, L_5)\) to variables (i.e. volume, speed of car and truck flows, and distance) were developed and evaluated. The models ranged from simple to more complex – the latter included up to three interactions (e.g. variable of a type: logarithm of truck volume multiplied by distance and divided by speed).

While it was possible to slightly improve the accuracy and reliability by including various interactions, the models became rather complicated. The following equation is one of three which were chosen for their accuracy and simplicity to predict \(L_{50}, L_{10}\) and \(L_5\) values.

\[
L_{10} = 52.7 + 11.2 \log_{10}(Q_c + 3Q_t) - 14.8 \log_{10}d + 0.21V
\]

where
- \(Q_c\) = total volume of cars (per hour)
- \(Q_t\) = total volume of trucks (per hour)
- \(d\) = distance to edge of pavement of the first traffic lane, feet
- \(V\) = average speed of traffic flow, mph.

The standard error of estimate for the model predicting \(L_{10}\) values was 2.5dBA for 133 observations.

The results of the 133 sound measurements were compared with Delaney’s (16) and BBN (91) methods and it was surprisingly found that Delaney’s British method was superior to the BBN (American) method in estimating the highway noise levels.
In conclusion it can be said that the inclusion of more data and more factors might improve the prediction accuracy, but masses of data are required that are not intercorrelated (e.g. % of heavy vehicles must not correlate with volume flow, etc.) if reliable regression coefficients are to be established.

2.4 THEORETICAL METHODS

A number of methods have been used to predict the behaviour of road traffic noise, using mathematical methods. Difficulties arise from the presence of numerous variables, some of which do not respond well to theoretical treatment and resort must be made to experimental data to obtain a prediction. By reducing the number of variables to a minimum by considering simpler examples of traffic flow, a number of forecasts of road traffic noise purely from theoretical considerations have been made.

2.4.1 Non-statistical Methods

Rathe (88) and Mackawa (89) reviewed methods for calculating the sound level distribution caused by noise sources of various shapes (point source, a line source, and a plane source). It was assumed that the air as an ideal, homogeneous and loss-free medium, further, that all noise sources were composed of numberless point sources and each element point source radiates noise energy incoherently in all directions, neglecting the nature of wave motion.

The intensity $I$ for a point source is given by

$$I = \frac{W}{4\pi d^2}$$
where W is the sound power, in the free field
d is the distance to the receiving point

This equation shows that an intensity decreases inversely with the square of a distance. Sound level, \( L_{dB} \) is expressed by using the definition of sound power level

\[
PWL = 10 \log_{10} \left( \frac{W}{10^{-12}} \right)
\]

\[
L = PWL - 10 \log 4\pi - 10 \log d^2
\]

\[
L = PWL - 10 - 20 \log d \text{ dB}
\]

This relation is the inverse square law. This formula shows that the sound level decreases 6dB for every doubling of distance.

Mackawa (89) treated road traffic noise as an infinite line sound source. Interference was neglected because the phase of each point source is random. Noise energies diverge as a cylindrical wave having the centre axis on the line source. The total sound intensity at a receiving point which is at a distance \( d \) from the axis of the source is given by:

\[
I = \frac{W}{2\pi d}
\]

because the sound power per unit length, \( W \), should be equal to the total energy which passes through the surface area \( 2\pi d \) per unit length of the cylinder.

This equation shows the sound intensity decreases inversely with distance. When power level, \( PWL \), shows sound power per unit length of the line source, the above equation can be shown as:
This formula shows that the sound level decreases 3dB for every doubling of the distance from a line source. Rathe\(^{(88)}\) arrived at the same formula by considering the line source formed by a row of point sources.

A simple method of predicting road traffic noise applied by Johnson and Saunders\(^{(38)}\) was first put forward by Rathe\(^{(90)}\). It assumed a flow of vehicles, equally spaced apart by distance \(S\), along a straight line at a constant speed \(V\). Fig. 2.4. Each vehicle is considered to have the same acoustic power output. Assuming that a given vehicle passes the point nearest

\[ L = PWL - 8 - 10\log d \text{ dB} \]

Fig. 2.4  Single Line Flow Analysis
(i) Pattern of sound propagation
(ii) Time distribution of sound level
to the observer at a time \( t = 0 \), the resultant intensity \( I \) at any time \( t \) is given by:

\[
I = P \sum_{n=-\infty}^{n=+\infty} \frac{1}{d^2 + (Vt + ns)^2} \quad 2.15
\]

Where \( n \) is an integer (i.e. 0, \( \pm 1 \), \( \pm 2 \), etc.) and \( P \) a parameter having the dimensions of power and a value dependent on the straight of the source and the characteristics of the wave propagation. The summation of this series can be represented as follows:

\[
I = P \frac{\pi}{Sd} \left[ \frac{\sin h \frac{2\pi d}{S}}{\cosh \frac{2\pi d}{S} - \cos \frac{2\pi Vt}{S}} \right] \quad 2.16
\]

This expression defines the variation of sound intensity with time which clearly follows the cycling of the periodic term in the denominator and takes the form shown in Fig. 2.4(ii) where for convenience the vertical scale is represented in the logarithmic form of sound level rather than in absolute terms. The actual shape depends on the values of \( s \) and \( d \) but for a given configuration, maximum and minimum levels are obtained when the cosine function reaches its limiting values of +1 and -1, respectively. These occur at \( t = 0 \) when a noise source is immediately opposite the observation point and \( t = s/2v \) when the nearest sources are equidistant on either side.

From Fig. 2.4(ii) it can be seen that the mean value above which (or below which) the sound level lies for half of the time, \((L_{50})\), is equal to the instantaneous value at the quarter
period position, i.e. when $t = s/4v$. Hence

$$L_{50} = 10p \log_{10} \frac{\pi}{sd} \left[ \frac{\text{Sinh} \frac{2\pi d}{s}}{\text{Cosh} \frac{2\pi d}{s} - \text{Cos} \frac{2\pi v}{s} \frac{s}{4v}} \right]$$

2.17

$$L_{50} = 10p \log_{10} \frac{\pi}{sd} \tanh \frac{2\pi d}{s}$$

for $x > 1.5$, $\tanh = 1$ and for $x < 0.5$, $\tanh = x$

$$L_{50} = 10p \log_{10} \frac{1}{sd} \text{ for } \frac{d}{s} > 1/4$$

$$L_{50} = 10p \log_{10} \frac{1}{s^2} \text{ for } \frac{d}{s} < 1/12$$

The same method has also been adopted by Gordon\textsuperscript{(91)} et al.

Cleyden\textsuperscript{(92)} et al described a mathematical model for the prediction of traffic noise levels in an urban or suburban situation. They claimed that the model is ultimately intended to provide an alternative to existing prediction methods, however, only noise levels produced by stationary sound sources were considered.

In the model any point in a chosen area is described by its grid co-ordinates. A detail plan of the buildings or other structures in the area and the position(s) of the sound source(s) are needed as input to the model. Noise levels at all grid positions in the area are then calculated on the basis of the attenuation of sound due to direct propagation, diffraction and reflection.

The model was not proved against measurements in real situations because it was in an early stage of development.
2.4.2 **Statistical Models**

Galloway\(^{(93)}\) et al using a computer to simulate traffic flow considered the frequency content of the sources. To simplify the procedure the number of classes of vehicles was reduced to a minimum by considering the mean spectra for each class. Given an array of vehicles, randomly spaced and moving at a mean velocity \(V\) along a straight line, the level \(L\) in dBA at a point of observation was considered to be:

\[
L = 10\log_{10} \left[ \frac{(2\pi W_0)^{-1}}{\sum_i \sum_k W_k n_{ik} d_i^{-2} e^{-a_i d_i}} \right]
\]

where \(W_0\) is a reference power level

- \(W_k\) is the mean acoustic power of a vehicle of the \(k^{th}\) class, as a function of speed
- \(n_{ik}\) is the number of vehicles of the \(k^{th}\) class in the \(i^{th}\) interval
- \(d_i\) is the distance from the mid-point of the \(i^{th}\) interval to the observation point

and \(a_i\) is the attenuation coefficient for propagation and shielding losses for the \(i^{th}\) interval as a function of \(d_i\).

Weiss\(^{(94)}\) proceeding directly from the method used by Rathe\(^{(90)}\) and by Johnson & Saunders\(^{(39)}\) assumed that the probability of vehicle spacing \(s\) is given by an exponential function, i.e. \(1/s \exp(-X/s)\) where \(X\) is measured along the line of traffic. This attempt is of limited use because it considered all vehicles had equal acoustic intensities.
Kurze (95), (96) has produced a more ambitious model, assuming that the array of traffic on a road follows a Poisson distribution and was able to predict values of noise levels for various percentages of time (e.g. $L_{10}$, $L_{50}$, etc.) with mixtures of both light and heavy vehicles, he also considered numerous roads, barriers, and other influences that can be approximated by the superposition of contributions from statistically independent elements.

Takagi et al recently reported investigations on road traffic noise based on an exponentially distributed vehicle model—single line flow of vehicles with same acoustic power. Basically, this is the same problem tackled by Weiss (94), whose model "can be applied only when the value of sound intensity is small". (97)

Theoretical models described above suffer from at least one of the following drawbacks:

1. Traffic flow is not characterized by uniform spacing of vehicles.
2. The absorption of sound during propagation is a function of frequency and distance, which is not accounted for.
3. The identification of a "single-lane equivalent" for multi-lane highways is justifiable only after examination of the effect of assuming multiple lanes first in the analysis.
4. The simple models do not allow for mixture of various vehicle classes based on the noise output of the different types of vehicles.
5. The statistical distribution of noise levels as a function of time cannot be realistically obtained from a deterministic model.
6. Interrupted traffic flows are not considered.

2.5 **SCALE MODELS**

Physical scale modelling offers an effective means of studying a problem too complex for theoretical analysis and too varied for a field study. Acoustical modelling techniques have long been used to evaluate the acoustic design of auditorium and concert halls (98), (99). Recently, a number of model studies have been carried out at MIT in the U.S.A. under the direction of Lyon (100), (101) and in Europe (102), (103), (104), (105), (106), (107). Cann & Lyon (101) suggested that a general purpose modelling system should:

- Be easily understood by those without special training in either acoustics or electronics.
- Give answers directly in decibels.
- Not require any special facilities such as an anechoic or environmental chamber; any reasonable space should suffice.
- Be compact, easily portable, inexpensive.
- Be as accurate as needed to give model data consistent with full-scale noise measurements.
- Be suitable for use with a 1:16 or 1:64 scale model of propagation paths up to 800ft. (243.8m) or more.
- Be able to simulate sources with dominant frequencies over a range of 125Hz to 4KHz.
- Be capable of processing field data for checking the acoustical validity of the model.

Scale models can be used for the prediction of traffic noise levels in built-up areas if every dimension (including the wavelength of the sound) is scaled down by a factor N,
or the frequency is scaled up by that same factor\(^{(104)}\).

Nijs & Heringa\(^{(104)}\) built a scale model for traffic noise measurements with a scale factor of 1:100, this was mainly set by the dimensions of the anechoic test room. The equipment they used allowed them to measure frequencies up to 180KHz. They carried out four cases for the validation of their model: (1) Diffraction around obstacles, (2) a spark-source measurement between two wings of a building; (3) A moving point source simulating a passing train, and (4) Equivalent sound levels along a busy highway.

They described the agreement between theory, outdoor measurements and their model as "quite good".

Delaney et al\(^{(105)}\) have recently reported a 30:1 scale model technique for investigating the propagation of noise from traffic on major roads and motorways. A preliminary report about the model was published in 1972\(^{(106)}\). Validation studies were carried out for a range of different road/housing configurations by comparing relative noise levels obtained using the model with field data obtained specifically for the purpose. The overall prediction accuracy of the model has been given as "the rms error varying from 1.7dBA with simple well-defined sites to 2.4dBA with complex urban sites. The model was used to predict noise propagation from a road in a natural cut, noise prediction through a gap between adjacent blocks of houses, and containment effects associated with unbroken parallel building facades on opposite sides of the road.

In France, the Ministry of Work sponsored a development and study of two tools:
1. A laboratory, fitted out with automatic equipment for the measurements on an acoustic scale model, and
2. A computer program, performing the computation of sound propagation in a built-up area.

It has been claimed that both proved very useful and complementary.

"One of the greatest problems in the expansion of scale modelling is a technique has been the lack of adequate instrumentation." "The model scale chosen immediately limits the choice of modelling microphone. Even the smallest microphone available to-day (1/10" diameter)(2.54mm) represents one 6.5" (165.1mm) in diameter full-scale." 

In addition to the above-mentioned problem, it is very difficult to simulate complex traffic flow situations (e.g. interrupted traffic flow); this is probably behind the limited number of studies in this field.

2.6 SIMULATION TECHNIQUES

It has been realised for some time that road traffic parameters have to be included in traffic noise models (see Johnson & Saunders\(^{(39)}\) - all statistical models (Section 2.4.2)) and the numbers of parameters required increases as the accuracy demanded of the model is increased.

The number and complexity of the parameters also increase as the model extends to cover more complex traffic situations.
such as interrupted flow cases. This is well illustrated in the work carried out by Gilbert (67) who included such parameters as index of dispersion and level of service.

The above factors, together with the availability and speed of digital computers and the growing sophistication of traffic flow theories have stimulated the development of simulation models for freely-flowing traffic and interrupted traffic, in which noise levels are predicted from the simulation of individual vehicle behaviour and a statistical random selection approach to vehicle type and characteristics.

In one of the earliest models found in the literature, Galloway and Clark (93) (see Section 2.4) simulated traffic flow by obtaining a large number of "snap shots", each persisting for 1.0 sec. of different arrays of randomly distributed traffic (following a Poisson distribution) but having the same rate of flow and mean velocity of flow. In this way equation (2.18) is computed a number of times and the resulting histogram simulates the time distribution of noise levels expected from traffic having the characteristics employed in the computation. This model was then extended and used for predicting the time history of noise produced by highway traffic and implemented on a digital computer in 1969 (108).

In 1973 at the TRRL a computer program was developed for predicting the cumulative time level distribution generated from road traffic. The model uses a synthesis principle and it was claimed to contain the desired flexibility for synthesizing noise from complex roadway networks and to be much faster than Monte Carlo models of similar sophistication (81).
In 1976 more details about the models were revealed in a TRRL Supplementary Report 209 UC(82). The report briefly describes three models "FRE:FLO, RURALN and URBANN" and refers to the details in refs. (81), (83), (84) and (109).

FRE:FLO is the program which deals with noise prediction from freely-flowing traffic. The model considers the traffic stream to comprise of two different vehicle categories - 'Cars' (1525kgm's) and 'lorries', each of which travel freely, i.e. in top gear and at constant speed, along a flat roadway and noise is assumed to radiate over a flat plain. The program computes hourly cumulative probability noise level distributions in intervals of 1dBA at a receiver position situated at a specified distance from the road and at a height of 1.2 metres above ground for an internally-generated range of hourly vehicle flows. The program also computes from the distributions the following statistical indices of traffic noise: $L_{10}$, $L_{50}$, $L_{90}$, NC, TNI, $L_{eq}$, $L_{NP}$.

RURALN is a program that has been specifically designed to predict values of $L_{10}$ at distances normally greater than 100 metres from a road in a rural environment. The details of the experimental work associated with the development of this model, its application and validation, are given in Ref. (83). The program has been adapted from FRE:FLO and contains many of its features. The traffic is assumed to flow freely on a 2-lane road and to comprise of two vehicle categories - 'cars' (1525kg) and 'lorries'. The land adjoining the road is classified in the model into three distinct groups: 1 'open sites', or 2 'farm land', or 3 'wood land'.

The program computes cumulative probability-noise level distributions for a range of total hourly traffic flows.
at a receiver position situated at a given distance from the road and at a height of 1.5 metres above the ground. The same statistical indices of traffic noise calculated in FREFLO are calculated.

URBANN is a program specifically designed to predict traffic noise at positions situated close to a roadway (1-20m) where traffic flows are high such that average vehicle speeds fall below the free speed region and are in the range 20-50kph. The model considers traffic to flow on a 2-lane roadway which is either flanked by a continuous row of buildings or is completely open. The traffic stream is assumed to comprise three different vehicle categories which are defined as: (i) light vehicles which include cars, car-based vans and 2-axle commercial vehicles with an unladen weight \( \leq 3000\) kg; (ii) medium heavy vehicles which include commercial vehicles with two axles and an unladen weight of \( \geq 3000\) kg, buses and coaches, and (iii) heavy vehicles which include commercial vehicles, etc. with three or more axles.

The model computes the statistical indices of traffic noise for a specified hourly vehicle flow at a given distance from the road and a receiver height of 1.2 m.

In the same year (1976) in the U.S.A. a detailed design guide (110) for prediction and control of traffic noise was published. This guide has superseded the previous one (91). The new guide contains two methods of prediction:

a. short method: in which prediction is performed quickly through use of two nomographs and knowledge of a few traffic and roadway parameters.
b. complete method (computer program) represents the complete or "exact" prediction procedure of expected noise levels. This method enables the development of noise contours, evaluating sensitive community areas, determining noise reduction requirements for a particular design, and identifying which segment(s) of the highway should be modified to achieve the desired goal.

The method synthesizes noise levels from complex roadway networks, e.g. interchanges (grade separation intersection) by dividing into segments, it can cater for barriers and has the capability for plotting as well as calculating noise. However, the guide does not seem to have a procedure to predict noise levels from interrupted traffic flows. The accuracy of the model is claimed to be $\pm 2\text{dBA}$ of actual measurements except when very low volumes and distances are considered.

In 1977 Rathe published details of a computer model for noise propagation studies involving complex noise source (e.g. road traffic and railway) and topographical characteristics. The model is based on a numeric description of the noise sources, the traffic route, and all the topographic details of interest. The main results are given in numerical tables, or in graphic outputs.

In the U.K. work seems to be recently concentrated on interrupted flow cases, e.g. signalised intersection and roundabouts using snap shot techniques. Three current projects by Diggory (69) at Newcastle Polytechnic, Jones (61) at Bradford and the present study (68), (112) are examples of this technique which is described in detail in Chapters 3 and 4.
CHAPTER 3 THE PRINCIPLES AND DESCRIPTION OF THE FRESH-FLOWING TRAFFIC MODEL

3.1 GENERAL

The purpose of a simulation on an electronic computer is to study phenomena which are too complex or non-linear to study analytically and which may not be conveniently studied empirically in the real situation. Simulation can be used to "predict" operation of a system prior to its completion.

Simulation has experienced widespread application in various fields of science and engineering.

Simulation models are an important supplement to measurements of existing noise levels where the noise is predominantly from highway traffic. The model can be used as a time and money-saving aid to interpolate between sites where measured data have been obtained. It can be said that noise prediction models are the keystone to dealing with highway traffic noise impacts.

3.2 ADVANTAGES OF SIMULATION

1. To give the ability to study the situation with parameters outside the range obtained in the currently existing situation.

2. To study the changes in the simulated system without altering the real system.

Noise prediction models serve an important function in examining various mitigation strategies. One of the more important is the assessment of the reduced noise doses to which the public would be exposed if motor vehicle noise emission levels were reduced at the source by various amounts.
3. The use with which most highway designers are concerned is in forecasting the future traffic noise levels. These levels are used for the assessment of noise impacts on highway improvements. The future noise levels (on which local government controls and future development plans are based) must come from highway traffic noise models.

4. Models are used to examine different location and design alternatives. Decisions to sound-proof public use buildings and to construct costly barriers will depend on the outcome of studies using these models.

3.3 DISADVANTAGES OF SIMULATION

1. They require detailed input information.
2. Any simulation needs continuous monitoring of the program to see whether it is working correctly and that the logic is sound for new input conditions.
3. In the case of traffic models, the varied driving conditions adopted by drivers of motor vehicles on highways may not be fully taken into account.

3.4 WHAT KIND OF MODEL?

To be a useful tool, the model must meet the following criteria:

1. The model must be easy to use and the results have to be available within a short time.
2. The model must be relatively simple and not too 'computer-time' consuming an exercise.
3. The most important criteria for the noise model is its
accuracy. It has to be accurate within a few decibels, ideally to within one decibel.

3.5 APPROACHES TO SIMULATION AND THE PRESENT MODEL PHILOSOPHY

In simulation carried out on a digital computer, two approaches are possible:
1. The most common approach is to make the model as simple as possible, making numerous approximations, so that the computer running time is minimized.
2. The other approach is to simulate every phenomena in the process as accurately as possible, but at the expense of computer time.

Simulation on the other hand, permits the simulator to build any degree of realism that he wishes into the traffic model through the use of stochastic processes.

In developing the model, one must be careful not to attempt to build a perfect representation of the real situation for two reasons:

a) It is very difficult and time-consuming, and
b) the resulting model would likely be impractical to run.

The purpose of the simulation model should be to produce realistic results economically. Therefore it was thought that it would be best to strive and build a model which will adequately represent the important operating characteristics and ignore the unusual or insignificant events.

The present model has been built with this basic philosophy in mind. In addition, it has been built to be as general a model as possible, so that it could be utilized in different
studies and can be further developed in the future.

3.6 CHOOSING THE APPROPRIATE SIMULATION LANGUAGE

There are two main basic types of programming language which can be used in simulation models. The first option is to write the simulation program in terms of a high level general purpose programming language, e.g. FORTRAN, ALGOL. The other option is to express the model in terms of a special purpose simulation language, e.g. CSL, GSP.

Main advantages of a special purpose language are:

1. Requires less programming time.
2. Provides error checking techniques superior to those provided in general purpose languages.
3. It takes much of the routine programming away from the programmer because they provide him with a series of subroutines or procedures which carry out the basic simulation operations.
4. Automatically generates certain data needed in simulation runs.
5. Facilitates collection and display of data produced.

Main disadvantages are:

1. Must adhere to output format requirements of the language.
2. Reduced flexibility in models and increased computer running time.
3. The major cited disadvantage of using simulation languages is that because most were developed by individual organisations for their own purposes and released to the public
more as a convenience and intellectual gesture than as a marketed commodity, most users, accustomed to having computer manufacturers do the compiler support work as a service, are not set up to do this themselves (113).

Main advantages of general purpose languages are:

1. Minimum number of restrictions imposed on format of output.
2. It is widely known by programmers. Therefore, to develop a simulation program in terms of such languages the programmer does not usually have to become familiar with an entirely new language.
3. They are widely available on many different ranges of computers, whether they are large or small machines.
4. Programs written in general purpose languages have the advantage that they can easily be transferred from one computer to another and run successfully (if a suitable compiler is available). There is much smaller chance to accomplish such transfer when dealing with special purpose simulation languages.

These advantages seem to have been the main reason for writing FREFLO, RURALN and URBANN (79) as well as the latest American prediction program (107) in FORTRAN.

The above-mentioned advantages meet the basic philosophy set for the present model and therefore FORTRAN was found to be the obvious choice.
3.7 GENERAL DESCRIPTION OF THE FREE-FLOWING MODEL

The Free-flowing Model can generally be described as follows:

1. Vehicles enter the system according to the shifted negative exponential distribution.
2. Vehicle type is determined from a uniform distribution according to their percentages in the flow.
3. Vehicle speed and acceleration are determined from normal distributions according to its type. The acceleration remains constant during the time unit (scan interval) which is specified as 0.25sec.
4. The behaviour of vehicles in the system is governed by the car following theory, during each unit of time, vehicles which are travelling at less than their desired speeds will check for opportunities to increase their speeds.
5. No overtaking is assumed. (See Sections 3.5 and Chapt.S).
6. Noise emitted by each vehicle is a function of its speed and acceleration according to its type.
7. The total noise exposure at any point of observation is obtained by the summation of the noise emitted by all vehicles and a noise sample is taken periodically.
8. Noise indices are determined from the noise samples taken during measurement periods.
9. Confidence in results is assured by employing sufficiently large samples.
3.8 RANDOM-NUMBER GENERATION

"It is not easy to invent a fool-proof random number generator"

D.E. Knuth (114)

When a computer is used to simulate natural phenomena, random numbers are required to make things realistic. Humans are too full of associations to think up truly random numbers; no one would pick three 2's in a row although such a sequence might be part of a random series.

At first, people who needed random numbers in their scientific work would draw balls out of a 'well-stirred run' or would roll dice or deal out cards. In 1927 a table of over 40,000 random digits "taken at random from census reports" was published. Since then, a number of special machines for mechanically-generating random numbers have been built; the first such machine was used to produce a table of 10,000 random digits.

After computers were introduced, searching commenced for efficient ways to obtain random numbers in computer programs. A table or a machine can be used but each of these two methods has its own problems, e.g. memory space and the labour needed to prepare the tapes or cards (to be read in) and the difficulty of reproducing the same calculations exactly a second time when checking out a program.

A satisfactory computer program for generating pseudo random numbers should:

1. Require little storage space in the computer,
2. Be relatively fast in operation, and
3. Generate a sequence of numbers that satisfies the test of randomness (e.g. frequency tests, tests of runs and the lagged produce test. Details of these and other tests can be found in standard texts on simulation).

At first this technique was suggested by using the mean-square method. A K-digit number $R_0$ is squared and from the resulting $2K$ digits the mid-digits are taken as $R_1$. The number $R_1$ is then squared and the process repeated. As an example take $K = 2$ and

$$R_0 = 77 \quad R_0^2 = 5929 \quad R_1 = 92$$

The sequence is: 92, 46, 11, 12, etc.

An objection to this method, how can a sequence generated in such a way be random, since each number is completely determined by its predecessor? The answer is that this sequence is not random but it appears to be. Sequences generated in a deterministic way such as this are usually called pseudo-random sequences.

If the radix used is $r$, then there are $r^{2K}$ possible values of $R$ and consequently the sequence must ultimately repeat some previous value. From that point of the sequence is repeated, i.e. it is cyclic. In practice, the cycle length is considerably less than the theoretical maximum $r^{2K}$. The length of the cycle is dependent on the starting value $R_0$. Certain values can lead to a zero term when the cycle length becomes one.

These objections are sufficient to condemn this method.
Once it is recognised that a pseudo-random sequence will be cyclic, it is possible to require the generation of a cycle of maximum possible length.

The theory of numbers was then used to devise such long cyclic sequences.

A sequence of uniformly distributed pseudo-random numbers in the range 0 to 1 may be generated using the multiplicative congruential method:

\[ R_{r+1} = bR_r \mod M \]  

3.1

Given appropriate values of \( b \), \( M \) and starting value \( R_0 \).

For the purpose of the work explained in this thesis, a standard NAG(115) library subroutine was used whenever random numbers were required. In this subroutine, the problem of correlation between generated random numbers was avoided by generating two multiplicative congruential sequences.

\[ R_{1,r+1} = b_1 R_{1,r} \mod M \]
\[ R_{2,r+1} = b_2 R_{2,r} \mod M \]

and then forms:

\[ R_{r+1} = R_{1,r+1} + R_{2,r+1} \mod M \]

with \( M = 2^{24} \), \( b_1 = 3^{15} \), \( b_2 = 5^9 \)
\[ R_{1,0} = R_{2,0} = 1234567 \]
A facility is available in the same Library (NAG) to start the random numbers from different values.

3.9 ARRIVAL DISTRIBUTION

As vehicles approach at some distance from an isolated intersection, they are not operating under the influence of the intersection (see Section 3.11.2). For this condition, the arrival of vehicles at a point would be generally random. Therefore, it is necessary to describe the arrival pattern of vehicles at one point in the model. This could be done by reading in observed arrival headways, but a more flexible and compact method is to describe the arrival headways by a distribution and to use random sampling (see Section 3.8) when the next arrival gap is required by the model.

Traffic engineers have been for some time familiar with the fact that vehicle arrivals at a point are generally random in nature at relatively low volumes. In 1936 Adam produced field data which was in good agreement with the theoretical distribution produced from the Poisson distribution, he then suggested that light to medium traffic (under volumes of 1000veh/hr. which he said a rate of flow seldom attained!) is distributed at random in both distance and time and could therefore be described by the Poisson distribution (a flow which is controlled by police or a traffic signal at an adjacent site is not included and also if the flow is in narrow roads, sharp bends or there is a difficulty in passing other vehicles freely).
The Poisson distribution is a particular case of the binomial distribution (Poisson distribution is useful to approximate the binomial distribution under appropriate conditions — when the probability of occurrence of an event is small and number of trials is large) and expressed as:

\[ P(n) = \frac{m^n e^{-m}}{n!} \]

where \( m = \frac{qt}{n} \) = mean arrivals in \( t \), and \( q \) is av. flow/unit time

\( n = 0, 1, 2, \ldots \)

\( P(n) \) = probability of occurrence of \( n \) in time \( t \)

\( e \) = natural base of logarithm

The distribution of headway may then be described by the negative exponential distribution (which is derived from the Poisson distribution).

The probability of no vehicles arriving in a time interval \( t \) is

\[ P(0) = \frac{0}{0!} e^{-m} = e^{-m}, \quad P(0) = e^{-qt} \]

\( P(0) \) is the probability that no vehicles will arrive in a time interval \( t \). This is the same as the probability that the next gap is at least as long as \( t \); i.e.

\[ P(g \geq t) = e^{-qt} = e^{-\frac{t}{\bar{t}}} \]

\( \bar{t} \) is the mean headway = \( \frac{1}{q} \).

This distribution is known as the negative exponential distribution and it gives the majority of headways in the range 0-1 sec. Whilst this is true in practice on multi-lane roads with low traffic volumes where vehicles can overtake freely,
increasing volumes limit overtaking and vehicles must flow at some safe distance corresponding to a minimum headway (of the order of \(1\) sec.). This is particularly true of single lane traffic flow and can be represented by shifting an exponential curve to the right by an amount \(\tau\), or

\[
P(g < t) = 1 - e^\frac{-(t-\tau)}{(T-\tau)}
\]

where \(\tau\) = Minimum headway; and

In 1955 Schuhl\(^{117}\) pointed out that a traffic stream can be composed of a combination of free-flow vehicles, and constrained vehicles. If \(\varnothing\) is the fraction of total volume made up of constrained vehicles, and \((1-\varnothing)\) is a fraction of total volume made up of free-flowing vehicles,

\[
P(g < t) = (1-\varnothing)(1 - e^{-\frac{t}{T_1}}) + \varnothing(1 - e^{-\frac{(t-\tau)}{(T_2-\tau)}})
\]

where \(\varnothing\) is proportion of constrained vehicles

- \(T_1\) is mean headway of free-flowing vehicles
- \(T_2\) is mean headway of constrained vehicles
- \(\tau\) is min. headway of constrained vehicles

Owing to the difficulty of deciding upon values for \(\varnothing, T_1\) and \(T_2\) for varying volumes of traffic it is difficult to use Schuhl's distribution in the present simulation. It was decided to use the shifted negative exponential distribution for the following reasons.

*This may be stated as follows. "the probability of a gap between successive vehicles of less than \(\tau\) is zero."
1. It is convenient to handle mathematically and the generation of gaps is simple and fast.

2. It has the advantage that no vehicle can arrive at a headway less than a specified minimum (which has arbitrarily been specified as 1sec. for this work). This is very useful because in this simulation model (where the scanning is only a fraction of the reaction time which is of the order of 1sec. itself) there is a maximum of one vehicle arriving in time $t = Fxt_S$ (assuming reaction time as 1sec. (see Section 4.3.1) where $F$ is the number of fractions in the reaction time and $t_S$ is the scan interval.

3. It has already been used by other researchers (118), even when investigations showed that it did not give a good fit to observed data, however, negative exponential did not improve the situation when fitted to the same data. Sumner (11) agreed to support his choice of shifted negative distribution that both the negative and the shifted negative distributions give similar results over most of the range of gap sizes.

4. Vehicles possess length and obviously can not follow at an infinitesimal headway, as the negative exponential distribution predicts. The shifted negative exponential overcomes this by translating the exponential curve to the right by an amount equal to the minimum observed (which has been specified as 1sec.).

5. For the purpose of this work, the gap length does not have a major effect on the results (noise results) and this can be shown as follows.
a. The effect of Minimum Gap ($\gamma$)

Typical range of speeds catered for (urban situations)
Mean value = 50kph
Standard deviation (S.D.) $\frac{1}{5} \times 50 = 10kph$
99.99% of the observed values of speed lie within
Mean value $\pm 4\times$ (S.D.)

$\therefore$ 99.99% of the observed data would be between 10 and 90kph.

Distance travelled in 1sec. (this is the value of the minimum gap specified for the shifted negative exponential distribution):

i) for speed of 10kph = 2.78 metre
ii) for speed of 90kph = 25 metre

Keeping in mind that the measurement point is far away from the vehicles when they enter the stretch of the road under consideration (see Section 3.11.2 position). This is more effective than the distance travelled within 1sec., which is fairly short as shown.

b. Effect of the total gap

Even when the value of the total gap is considered, it is unlikely to affect the results of noise calculated at the measurement point, because:

i) the measurement point is far away from the point vehicles enter the system;

ii) scanning is made every 0.25sec., which means that each vehicle will be governed by car following formula once it has entered the system (unless certain conditions are satisfied) and the gap effect on vehicles behaviour will be minimum. However,
shifted negative exponential distributions have been used for simulating arrival gaps in order to make the model: (1) as realistic (without any oversimplification) as possible and (2) as general as possible, so that it could be utilized for different studies without having to make major changes in the model.

After it was decided to use shifted negative exponential distributions in this model the following procedure was carried out.

The cumulative form of the shifted negative exponential distribution is

\[ P(g < t) = 1 - e^{-\frac{(t-\ell)}{(\bar{t}-\ell)}} \]

let \( P = R_1 = \) random number in the range 0 - 1.

Taking logarithms of both sides gives

\[ -\frac{t-\ell}{\bar{t}-\ell} = \ln(1-R_1) = \ln R_2 \]

(since \( R_2 = 1-R_1 \) is equally random in range 0-1)

i.e. \( t = \ell + (\bar{t}-\ell)(-\ln R_2) \)

or \( t = \ell + (\bar{t}-\ell)\ln\left(\frac{1}{R_2}\right) \)

where \( \ell \) is the minimum gap
\( \bar{t} \) is the average gap
\( t \) is the random gap sampled from the shifted negative exponential
\( R_2 \) is calculated as explained in (Random Number Generation)
The segment which carries this out in the program is called "GSNEX".

During each scan interval a check is carried out whether there is an arrival or not (this check is made before updating of distances, speeds and accelerations is carried out), if there is, the initial values of the arriving vehicle's distances, speeds and accelerations (whether it is a private car, medium or heavy commercial vehicle) are calculated according to the initial conditions (see Section 3.11 - initial conditions). If there is no arrival during the scan distances, speeds and accelerations of all vehicles running along the segment of the road in consideration are updated according either to the car following theory or to free-flowing conditions.

3.10 VEHICLE TYPE

The acoustic classification of vehicle types under free-flowing conditions has been considered by various workers, notably Ross\(^{(41)}\) and Lewis\(^{(42)}\). Both agreed that, with respect to noise generation, vehicles can be broadly classified into two groups. The first group can be described as 'cars' and consists almost entirely of petrol-fuelled vehicles having the general operating characteristics of passenger cars. The second group covers all vehicles exceeding 30cwt. (1525kg). This group may be referred to as 'lorries'.

The same classification has been suggested to be used in urban situations by Diggory\(^{(69)}\), Gilbert\(^{(67)}\) and Jones\(^{(65)}\). However, in 1977 Nelson and Piner\(^{(46)}\) published a paper on classification of vehicles acoustically for the purpose of noise predictions in urban situations. They classified vehicles...
into six groups and recommended that at least three categories
should be used for the purpose. Gilbert\(^{(67)}\) and Jones\(^{(65)}\)
suggested that the inclusion of more than two categories
may improve the accuracy of their models. The most recent
U.S.A. highway noise design guide for prediction and con­
trol\(^{(110)}\) uses three categories.

With the basic philosophy of the present simulation
model in mind it was decided to classify vehicles into three
main categories:

1. Light vehicles which include cars, car-based vans and
   2-axle commercial vehicles with an unladen weight less
   than or equal to 3000kg.
2. Medium commercial vehicles, which include commercial
   vehicles with 2 axles and an unladen weight exceeding
   3000kg and buses and coaches.
3. Heavy commercial vehicles, which include all commercial
   vehicles with three or more axles.

Motor cycles have different acoustical characteristics
from cars but they are only a small proportion of the total
flow so it was considered unnecessary to treat them separately.

It is interesting to note that the classification of
vehicles at signalised intersections for traffic engineering
purposes\(^{(119)}\) (to calculate their capacities) is as follows.

1) Light, G.V., 2) Medium or heavy G.V., 3) buses and coaches,
4) motor cycle, moped or scooter and 5) pedal cycle.

\*G.V. = Goods Vehicles
However, it has been noted that simulators of signalised intersections for traffic engineering purposes tend to classify vehicles into two categories rather than using all the categories mentioned above.

In the present model, whenever a vehicle arrives, a pseudo-random fraction between 0 and 1 is generated and compared with the percentage of heavy commercial vehicles and if the fraction is greater than the percentage it is then compared with the percentage of medium commercial vehicles if it is less than or equal this percentage the vehicle is designated as a medium commercial vehicle (and the vehicle is given the average length of medium commercial vehicles and its main characteristics, e.g. desired speed, maximum acceleration, etc. are set as explained in initial values). Otherwise the vehicle is considered to be a car and takes its length and other characteristics in the same way.

This process is illustrated in the Figure 3.1 below with the example.

![Figure 3.1 The Process of Vehicle Type Selection](image-url)
In the above, a random fraction between 0 and 0.1 would indicate heavy commercial; between 0.1 and 0.2 medium commercial vehicle and between 0.2 and 1.0 - car.

In order to avoid the problem of correlation (which would be built into the simulation model) the same random number has not been used to determine the gap length.

3.11 VEHICLE'S CHARACTERISTICS AND INITIAL VALUES

3.11.1 Vehicle Length

A survey was carried out to find cars with maximum lengths. Road tests (122) series have been used and a sample from four years is shown in Table 3.1. It must be mentioned that some of these cars are not popular on British roads (may be in London); however, they give some feeling of what overall lengths of cars is to be expected.

One way of simplifying the model without affecting its accuracy is to add the minimum spacing between two cars (which is most probable when they are queueing) and take it as the car length. This has been done and the overall length plus the absolute minimum spacing have been assumed as constant with a value of 5.8m for all cars.

A similar procedure was adopted for medium and heavy commercial vehicles. Their lengths were calculated from Appendix (3) and it was decided to use lengths including gaps of 9.8m and 13.44m for medium and heavy commercial vehicles respectively.
Table 3.1 Sample of Vehicles with Max. Lengths on British Roads

<table>
<thead>
<tr>
<th>MAKE</th>
<th>MODEL</th>
<th>YEAR</th>
<th>LENGTH (metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jensen</td>
<td>C-V8</td>
<td>1963</td>
<td>4.65</td>
</tr>
<tr>
<td>Rolls-Royce</td>
<td>Silver Cloud</td>
<td>1963</td>
<td>5.37</td>
</tr>
<tr>
<td>Jaguar</td>
<td>Mk.10</td>
<td>1963</td>
<td>5.18</td>
</tr>
<tr>
<td>Wolesely</td>
<td>6/110 Automatic</td>
<td>1964</td>
<td>4.76</td>
</tr>
<tr>
<td>Rover</td>
<td>3 Litre Coupe</td>
<td>1964</td>
<td>4.74</td>
</tr>
<tr>
<td>Iso Rivolta</td>
<td>IR300</td>
<td>1967</td>
<td>4.79</td>
</tr>
<tr>
<td>Vauxhall</td>
<td>Viscount</td>
<td>1967</td>
<td>4.78</td>
</tr>
<tr>
<td>Chrysler</td>
<td>Valiant Royal Estate</td>
<td>1967</td>
<td>4.80</td>
</tr>
<tr>
<td>Mercedes-Benz</td>
<td>250S Automatic Saloon</td>
<td>1967</td>
<td>4.91</td>
</tr>
<tr>
<td>Rambler Ambassador</td>
<td>990</td>
<td>1967</td>
<td>5.14</td>
</tr>
<tr>
<td>BMW</td>
<td>520</td>
<td>1973</td>
<td>4.52</td>
</tr>
<tr>
<td>Fiat</td>
<td>130 Coupe</td>
<td>1973</td>
<td>4.83</td>
</tr>
<tr>
<td>Ford</td>
<td>Granada Estate</td>
<td>1973</td>
<td>4.69</td>
</tr>
<tr>
<td>Rolls-Royce</td>
<td>Silver Shadow</td>
<td>1973</td>
<td>5.22</td>
</tr>
<tr>
<td>Lotus</td>
<td>Elite 503</td>
<td>1975</td>
<td>4.46</td>
</tr>
<tr>
<td>Ford</td>
<td>Granada Ghia Coupe</td>
<td>1975</td>
<td>4.57</td>
</tr>
<tr>
<td>Volvo</td>
<td>245DL</td>
<td>1975</td>
<td>4.90</td>
</tr>
<tr>
<td>Austin</td>
<td>1800 HI-line</td>
<td>1975</td>
<td>4.46</td>
</tr>
</tbody>
</table>
3.11.2 **Initial Distance**

Vehicles entering the system (segment of the road under consideration) have to be taken into account when they are some distance away from the observation point so that their effect can be included. This distance has to be specified so that:

1. Vehicles are not operating under the influence of the intersection. For this consideration, the arrival of vehicles at the point would be generally random and the headway distribution of vehicle would conform to the shifted negative exponential distribution.

2. It is longer than the maximum braking distance of any vehicle (see Table 4.1) to ensure that vehicles are not influenced by the signal operation in this respect.

3. The effect of the noise emitted by the vehicle on the overall noise level is negligible.

It will be seen that satisfying the third condition will automatically satisfy the first two.

In order to satisfy the third condition the noisiest expected vehicle has to be considered. Theoretically the noise emitted by this vehicle at the specified distance (initial distance) has to be 10dB below the background noise level; however, such a distance will become very long (as will be shown) and in practice the noise emitted by vehicles becomes negligible at much shorter distances for many reasons. The main reasons are excessive attenuation, topography shielding, shielding by buildings, road layouts
(bends and cuts) and similar factors.

Assume the noise emitted by a very noisy vehicle = 90dBA (see Table 3.9).

Considering that noise decreases by 6dBA for every doubling of distance, then by doubling the distance six times we get a noise reduction of 36dBA. The distance becomes 480M. The new noise level becomes 54dBA.

Keeping in mind that 1) a noise level emitted by a vehicle as high as 90dBA is unlikely to be encountered in urban areas (because it implies a heavy commercial vehicle travelling at speed of 100kph) and 2) the above-mentioned factors about noise attenuation due to topography and road layout. It seems quite reasonable to take the specified distance as 480M rather than 960M or 1920M, etc.

The same distance has been specified for vehicles moving away from the observation point. This makes the total segment of the road as 960M.

The main advantage of specifying this distance is that it saves computer time and storage because vehicles are not included until they reach this distance, and they are dropped from the system once they exceed this distance from the observation point.

The exact initial position of the vehicle does not necessarily equal -480.0M (negative signs have been used to signify vehicles moving towards the observation point) but it depends on the vehicle headway and the elapsed time from total measurement time because scanning is carried out at a rate of 0.25sec.
In order to find the exact position of the vehicle when it enters the system the following procedure is carried out:

1. Find the exact arrival time of the vehicle relative to the elapsed time, e.g.
   If it is the first vehicle to arrive
   Its gap = 2.20 sec.
   Time is progressing in 0.25 sec. intervals
   At time 2.0, i.e. after 8 scans
   The vehicle has not arrived
   At the next scan (time = 2.25) the vehicle has arrived
   Exact arrival time = 2.25 - 2.2 = 0.05 sec. ago
   (relative to the measuring time).

2. Multiply the difference found above (0.05 sec.) by the speed of the vehicle to find the distance travelled during this time.

3. Subtract the distance found in (2) from the specified distance to find the exact position of the vehicle on the road when it arrives.

A control device is available in the program which serves two purposes:

1. Fast vehicles as they enter the system following a slow vehicle do not collide with them (as they would have done if they entered the system with a small gap).

2. The flow running along any lane does not exceed the practical capacity of lane (which is 1500 PCU* per hour for

*Passenger car unit
both directions of flow for a standard two-lane 7.5m, two-way urban road, and 2400 PCU· per hour for a standard 7.3m one-way urban road (116).

The control is achieved by not allowing vehicles to enter the system unless a minimum specified spacing is exceeded. It is thought that this representation simulates actual life more closely.

3.11.3 Desired Speed

Once the vehicle has entered the system, and its type, length and exact position have been determined as explained earlier, its desired speed has to be specified. The vehicle while travelling in the system will always try to attain this speed.

Extensive speed measurements carried out by the TRRL (121) (formerly RRL) at 50 point traffic census, showed that under free-flowing conditions, the distribution of speeds was found to follow normal distribution with a standard deviation approximately one-fifth of the mean.

It was found that the cumulative frequency diagram was the most common method of illustrating velocity distributions. This was particularly useful when two or more distributions were being made (e.g. one for heavy commercial vehicles and one for cars).

Table 3.2 shows the mean and standard deviation values of some speed measurements carried out in Sheffield using three different methods: Venner Meter, Manual Method and Radar Meter.
Table 3.2  Measurements of Speed by Three Methods

<table>
<thead>
<tr>
<th>Venner Meter mph</th>
<th>Manual Method mph</th>
<th>Radar Meter mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.0</td>
<td>29.0</td>
<td>30.0</td>
</tr>
<tr>
<td>30.0</td>
<td>29.0</td>
<td>30.0</td>
</tr>
<tr>
<td>30.0</td>
<td>32.0</td>
<td>24.00</td>
</tr>
<tr>
<td>25.0</td>
<td>37.0</td>
<td>40.0</td>
</tr>
<tr>
<td>39.0</td>
<td>22.0</td>
<td>41.0</td>
</tr>
<tr>
<td>41.0</td>
<td>27.0</td>
<td>39.0</td>
</tr>
<tr>
<td>38.0</td>
<td>26.0</td>
<td>40.0</td>
</tr>
<tr>
<td>39.0</td>
<td>31.0</td>
<td>38.0</td>
</tr>
<tr>
<td>38.0</td>
<td>27.0</td>
<td>22.0</td>
</tr>
<tr>
<td>24.0</td>
<td>32.0</td>
<td>45.0</td>
</tr>
<tr>
<td>44.0</td>
<td>29.0</td>
<td>42.0</td>
</tr>
<tr>
<td>41.0</td>
<td>30.0</td>
<td>32.0</td>
</tr>
<tr>
<td>32.0</td>
<td>38.0</td>
<td>29.0</td>
</tr>
<tr>
<td>28.0</td>
<td>43.0</td>
<td>30.0</td>
</tr>
<tr>
<td>34.0</td>
<td>36.0</td>
<td>34.0</td>
</tr>
<tr>
<td>33.0</td>
<td>27.0</td>
<td>33.0</td>
</tr>
<tr>
<td>22.0</td>
<td>27.0</td>
<td>22.0</td>
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<tr>
<td>35.0</td>
<td>38.0</td>
<td>19.0</td>
</tr>
<tr>
<td>30.0</td>
<td>39.0</td>
<td>30.0</td>
</tr>
<tr>
<td>37.0</td>
<td>31.0</td>
<td>36.0</td>
</tr>
<tr>
<td>28.0</td>
<td>45.0</td>
<td>27.0</td>
</tr>
<tr>
<td>33.0</td>
<td>45.0</td>
<td>34.0</td>
</tr>
<tr>
<td>40.0</td>
<td>33.0</td>
<td>25.0</td>
</tr>
<tr>
<td>36.0</td>
<td>34.0</td>
<td>32.0</td>
</tr>
<tr>
<td>33.0</td>
<td>34.0</td>
<td>33.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>33.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No. of readings</th>
<th>49</th>
<th>53</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>33.10</td>
<td>34.21</td>
<td>32.26</td>
</tr>
<tr>
<td>ST.DEV.</td>
<td>5.88</td>
<td>7.03</td>
<td>7.13</td>
</tr>
<tr>
<td>Mean/S.D.</td>
<td>5.62</td>
<td>4.87</td>
<td>4.52</td>
</tr>
</tbody>
</table>
Even with a small sample it can easily be seen that the value of standard deviation is approximately one-fifth the mean, which does agree with the TRRL results.

In the present model, as the vehicle enters the system, its speed is sampled randomly from a normal distribution with a standard deviation one-fifth the mean. Different distributions are used for cars and heavy commercial vehicles. A standard Library Subroutine (NAG)\(^{(115)}\) is used for this purpose. In order to make the sample as accurate as possible, 99.5% of the expected values are included, i.e. Mean + 2xS.D; 99.73% and even 99.99% were used in some tests, i.e. (Mean + 3xS.D and Mean + 4xS.D respectively).

The value of desired speed which is sampled randomly is stored along with other vehicle's characteristics, to be used whenever required (as will be explained later).

The speed of the vehicle (\(X\)) just before it enters the system is found as follows:

\[
\dot{X} = X_{\text{des}} (1 - e^{-Ct})
\]

where \(X_{\text{des}}\) is the desired speed

\[
C = \frac{\text{maximum acceleration (} X_{\text{max}} \text{)}}{\text{desired speed (} X_{\text{des}} \text{)}},
\]

and \(t\) is time

which is the formula for a freely-flowing vehicle (see Section 4.3.2).

Time (\(t\)) is taken as the gap between the vehicle and the one ahead of it. This assumption (the vehicle is traveling freely for the last scan) seems very reasonable because the speed will depend on the gap, and will have a maximum
value which equals the desired speed (if \( \text{Gap} = \infty \)). From the next scan interval the speed will be calculated as explained in Sections 3.12 - 3.15.

3.11.4 Vehicle Maximum Acceleration

In order to have a perfect description of vehicles' performance, it is essential to have some details on maximum acceleration of the vehicle. These details should include the type of distribution, mean and standard deviation.

Data was obtained from the Road Test Series\(^{(122)}\) and Commercial Motor\(^{(123)}\) and analysed to get the starting acceleration in \( \text{m/s}^2 \). A sample of five years is given in (Appendix 4) and a summary of the mean, variance and standard deviation of the values (for cars) are shown in Table 3.3.

The values given in Road Test Series are obtained from vehicles in perfect condition, with no load except the driver, the drivers are trained for the purpose of the tests and they know exactly the optimum speed to change gear, etc., and that vehicles are tested on roads where they are free to accelerate up to their maximum speed.

However, the above-mentioned facts do not affect the purpose for which the data is to be used. As mentioned above it was needed to know the distribution of these values which has been assumed as normal, with a mean of \( 3.3 \text{m/s}^2 \) and standard deviation of \( \frac{1}{5} \)th of this mean.

Maximum acceleration is then sampled with the desired speed and stored.

The acceleration of the vehicle just before it enters the system (one scan interval before it enters) depends on its maximum acceleration, desired speed and its speed when it
Table 3.3  A Summary of Samples of Vehicles' Accelerations (m/sec.²)

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Sample</th>
<th>Mean</th>
<th>Variance</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1963</td>
<td>16</td>
<td>2.79</td>
<td>0.45</td>
<td>0.69</td>
</tr>
<tr>
<td>1964</td>
<td>26</td>
<td>2.7988</td>
<td>0.308</td>
<td>0.566</td>
</tr>
<tr>
<td>1967</td>
<td>41</td>
<td>3.07</td>
<td>0.734</td>
<td>0.867</td>
</tr>
<tr>
<td>1973</td>
<td>46</td>
<td>3.765</td>
<td>0.6886</td>
<td>0.839</td>
</tr>
<tr>
<td>1975</td>
<td>26</td>
<td>3.666</td>
<td>0.483</td>
<td>0.709</td>
</tr>
</tbody>
</table>

True Mean = 3.3  Mean S.D. = 0.73  Mean/S.D. = 4.52

enters the system and is calculated as follows:

\[ \ddot{x} = \dot{x}_{\text{max}} \left(1 - \frac{\dot{x}}{\dot{x}_{\text{des}}} \right) \]

i.e. the vehicle is travelling freely (see sec. 4.3.2), although this is not always true, it does not affect the accuracy of the model for two reasons:

1. it is calculated over one scan interval only;
2. the vehicle is still very far away from the observation point to have a major effect on the calculations.

Appendix 3 gives details of maximum accelerations for samples of medium and heavy commercial vehicles.
3.12 CAR-FOLLOWING CONSIDERATIONS

3.12.1 Introduction

Car-following theories attempt to relate the behaviour of vehicles in a dense stream of traffic to the behaviour of the vehicle immediately ahead.

The basic equation is of the form

\[ \text{Response} = \text{Sensitivity} \times \text{Stimulus} \quad 3.6 \]

The stimulus is usually taken to be the relative speed of the two vehicles and the acceleration or deceleration is the response of the following vehicle.

Thus for the \((n+1)^{th}\) vehicle in a traffic stream,

\[ x_{n+1}(t+T) = \lambda (x_n(t) - x_{n+1}(t)) \quad 3.7 \]

where \(\lambda\) is the sensitivity and \(T\) is the time lag of response.

Various possible functions have been suggested for \(\lambda\) two of which are:

a. \(\lambda = \text{constant (linear-car following model)}\)

b. \(\lambda = \frac{C}{x_n(t) - x_{n+1}(t)}\) where \(C = \text{constant} \quad \text{(reciprocal spacing car following model)}\)

b. would intuitively appear more reasonable since response is likely to be influenced by relative spacing as well as by relative speed.

Using (b) and integrating equation (3.7) gives
\[ \dot{x}_{n+1}(t+T) = \lambda (x_n(t) - x_{n+1}(t)) + \text{Constant} \]  

For steady state condition

\[ V = \lambda \left( \frac{1}{K} \right) + \text{Constant} \]

\( K = \text{Concentration,} \quad V = \text{Speed} \)

But \( V = 0 \) for \( K = K_J \) (Jam concentration)

Hence

\[ V = \lambda \left( \frac{1}{K} - \frac{1}{K_J} \right) \]

and

\[ Q = KV = \lambda \left( 1 - \frac{K}{K_J} \right) \]

Figure 3.2
Theory is obviously unsatisfactory for low values of $K$, but good agreement is not expected within that range from car-following theory since it applies only to dense traffic.

3.12.2 A Historical Resume of the Development of Car-following Theories

3.12.2.1 Constant Sensitivity

In 1953 Pipes\(^{(124)}\) attempted to describe vehicular flow in a microscopic manner. He postulated dynamic equations governing the motion of vehicles in a line by requiring that each vehicle shall be separated by a safe distance. Pipes suggested that this safe distance could be defined by the California Vehicle Code Summary as "A good rule for following another vehicle at a safe distance is to allow yourself the length of a car (about 15ft. (4.9m)) for every 10mph (16.1kph) you are travelling."

If this "traffic law" is obeyed, the co-ordinates, $X_{n+1}$ and $X_n$, of two successive vehicles in a line must satisfy the following equations

$$X_n = X_{n+1} + (b + T X_{n+1}) + L_n$$ \hspace{1cm} 3.12

for $n = 1, 2, 3, \ldots, (N-1)$

where $N =$ the number of vehicles in the line of traffic

$n =$ an index number

$X_n =$ the co-ordinate of the front of the $n^{th}$ vehicle (feet)

$L_n =$ the length of the $n^{th}$ vehicle (feet)

$b =$ the prescribed legal distance between the vehicles at standstill (feet)
$T = \text{a time constant (seconds) prescribed by the postulated "traffic law" (} T = 15.00/14.67 = 1.02 \text{sec. California Vehicle Code)}$

If these equations are differentiated with respect to time, the result is

$$\ddot{x}_n = \dot{x}_{n+1} + TX_{n+1} \quad 3.13$$

$n = 1, 2, 3, \ldots, (N-1)$

or

$$\ddot{x}_{n+1} = (\dot{x}_n - \dot{x}_{n+1}) / T \quad 3.14$$

i.e. the acceleration of the $(n+1)^{th}$ vehicle is a constant having the dimension of time$^{-1}$ multiplied by the relative velocity between the vehicle immediately in front and this vehicle.

In 1958 Chandler, Herman & Montroll$^{125}$ of the General Motors Corporation took up this theory and postulated that the applied force is proportional to the instantaneous difference in velocity of a given vehicle and its predecessor, or the case of "proportional control" in the language of servo-mechanism theory. The equation of motion of a line of "$N$" identical vehicles each of mass $M$ is

$$M\ddot{x}_{n+1} = \lambda (\dot{x}_n - \dot{x}_{n+1}) \quad 3.15$$

for $n = 1, 2, \ldots, (N-1)$
where $\lambda$ is the sensitivity of the control mechanism.

At instants in which a lead car is going faster than the following car, the follower applies an accelerating force and vice versa.

They assumed that the sensitivities for acceleration and deceleration are identical. Although this is a reasonable approximation in a properly functioning car at low speed, it is certainly not the case at high speed or when for example either the brakes are poor or an engine is not well tuned. They gave considerable thought to the stability of the system and introduced a lag in the response of the operator, pointing out that the California Vehicle Code is insensitive to lags: "Fluctuations in lead car performance would, as a result of various response lags, cause eqn. (3.12) to be violated in spite of the best intentions of followers."

The model then becomes

$$\ddot{x}_{n+1}(t+T) = b(\dot{x}_n(t) - \dot{x}_{n+1}(t))$$

where $T$ = the time lag, and

$$b = \text{a constant, } \lambda/M \text{ (sec}^{-1})$$

In order to determine the values of $b$ and $T$, experiments were carried out on the test truck at the General Motors Technical Center with two cars connected by a wire wound on to an instrumented reel which enabled $x_n-x_{n+1}$, $\dot{x}_n-\dot{x}_{n+1}$, $\ddot{x}_{n+1}$ and $\dddot{x}_{n+1}$ to be measured.

Eight male drivers drove the cars for periods of 20 to 30 minutes and the leading drivers randomly varied their speed between 10 and 80mph (16–129kph), included several braking
actions. By plotting the relative motion of the two vehicles, they found that the average values of \( T \) and \( b \) for the eight drivers were 1.55 sec. and 0.368 sec\(^{-1} \), and the values of (\( T \) and \( b \)) of the driver who obtained the best correlation coefficient (0.9) to the model were 1.0 sec. and 0.44 sec\(^{-1} \).

In 1959, Herman et al.\(^{(126)} \) further investigated the problem of stability and the propagation of disturbances down a line. Criteria were derived for local and asymptotic stability in a chain of vehicles. "Acceleration noise" was proposed as a parameter which they said "might be employed to characterize the driver-car-road complex under various conditions". They made some preliminary measurements on 'acceleration noise'.

### 3.12.2.2 Reciprocal Spacing

Gazis, Herman and Potts\(^{(127)} \) also in 1959 suggested a revised version of the car following model in which the sensitivity "\( b \)" was no longer constant as in the previous work but inversely proportional to the car spacing:

\[
M \ddot{X}_{n+1}(t+T) = b_1 \frac{\dot{X}_n(t) - \dot{X}_{n+1}(t)}{(X_n(t) - X_{n+1}(t))}
\]

where \( X_n(t) \) = the position of the \( n \)th car in the line

\( M \) = the mass of each car

\( b_1 \) = constant referred to as the sensitivity coefficient

\( T \) = the time lag

If eqn. (3.17) integrated once it gives:

\[
M \dot{X}_{n+1}(t+T) = b_1 \ln \left[ \frac{L^{-1}(X(t) - X_n(t))}{X(t+T) - X_{n+1}(t+T)} \right]
\]

3.18
where \( L \) = the length of each car
\( \ln \) = natural logarithm (\( \log_e \))

For the steady-state, the time lag can be neglected, thus yielding

\[
V = C \ln \frac{K_J}{K}
\]

where \( V \) = speed
\( C = b_1/M \) (optimum speed)
\( K = \text{Concentration} = (X_n(t) - X_{n+1}(t))^{-1} \)
\( K_J = \text{Jam concentration} = L^{-1} \)

This is the same model from the "fluid dynamic equations of motion" of Greenberg (128).

The authors then compared the experimental data obtained for the Lincoln Tunnel with the steady-state results for constant sensitivity and a sensitivity inversely proportional to the car spacing. For this purpose a least-squares fit was obtained using the flow data analysed by Greenberg (128). They found that the variable sensitivity theory fits the experimental data very much better than the theory for constant sensitivity. Using the earlier data collected by Chandler et al. (125) at General Motors, the authors plotted the values obtained for the proportionality coefficient \( \lambda /M \), versus the reciprocal of car spacing \( (1/Y \text{ ft.}^{-1}) \) of the eight drivers in order to determine whether a correlation exists. The car spacing was taken to be the average distance between the pair of cars involved in the car-following experiment even though no special
effort had been made at that time to study distance effects. They found that there is a reasonable linear trend (sensitivity decreases with increasing distance). They performed a least-squares fit through the origin and obtained

\[
\lambda/M = (40.2/Y) \text{sec}^{-1}
\]

where \(Y\) is measured in feet.

3.12.2.3 Step Function

In 1961 Herman and Potts\(^{(129)}\) gave a general discussion of a car-following theory in which the proportionality coefficient \(a\) is taken to be constant, a step function (which they suggested to be used) or inversely proportional to the car spacing. Their suggested step function in the form:

\[
a(S) = a \quad \text{if} \quad 0 < S < a_1
\]

\[
= b \quad \text{if} \quad S > a_1
\]

where \(S\) is the spacing \((X_n - X_{n+1})\) and "a", "a_1" and "b" are constants.

They stated that the step function is more realistic because it allows for two different values of the proportionality coefficient, depending on whether the two cars are close together (within a spacing \(a_1\)) or further apart. This could describe, in an extreme case, a driver whose reaction is a panic one when close to the car in front but more subdued when further away - in this case a would be chosen, say two or three times as great as b.
3.12.2.4 Visual Angle Models

In 1963 Michaels\(^{(138)}\) examined the information used by the human in the car-following situation and the nature of the responses that he may make to that information. He pointed out that the driver responds to the angular velocity of the lead vehicle.

The rate at which the angle \(\theta\) subtended by the lead vehicle is changing is:

\[
\dot{\theta} = K(\dot{x}_n - \dot{x}_{n+1}) / (x_n - x_{n+1})^2 \tag{3.21}
\]

After giving some data on the ability of the human eye to detect these changes in the angle \(\theta\), he considered three situations: (1) simple overtaking with a constant relative velocity, (2) Steady-state following and (3) responses to acceleration of a lead vehicle.

In 1967 Pipes\(^{(139)}\) postulated a car-following law in which a driver imparts to his vehicle an acceleration proportional to his perception of the rate of change of the visual angle so that:

\[
\ddot{x}_{n+1} = C (\dot{\theta}) \tag{3.22}
\]

A relation of this form implies that the following vehicle would decelerate for \(\dot{\theta}\) positive and would accelerate for \(\dot{\theta}\) negative. Then he showed that this law (which is the generalised car-following law with \(l = 2\) and \(m = 0\)) gives the original steady state law of Greenshields\(^{(135)}\).

In the same year Lee and Jones\(^{(140)}\) suggested two car-following models:
They found that the two models could be applied to a queue-releasing condition with about the same degree of goodness of fit; model (a) was found to have a slightly higher mean value of the correlation coefficient. The authors preferred this model because of its higher correlation and its sensibility in terms of the ability of a human eye to detect angular changes with the passage of time.

3.12.2.5 Generalised Form of Car-Following Theory

In 1961 Newell (130) pointed out that the existing car-following models assumed a linear relationship between spacing and speed and yet a non-linear relationship is required to explain the steady-state relation between average velocity and average headway. He suggested a generalised relation:

\[ x_{n+1}(t+T) = G(x_n(t) - x_{n+1}(t)) \]

Where \( G \) is some appropriate non-linear function and showed that it was possible to incorporate, into a single theory, all the results previously derived for linear car-following models and the non-linear phenomena derived from continuum theories (e.g. Lighthill and Witham (131), Richards (132)).

In the same year, Edie (133) proposed a car-following model in which the sensitivity was related to speed and spacing:
where $\lambda$ is the sensitivity, $a_2$ is a constant and $S$ is spacing.

"Sensitivity $\lambda$, has been referred to as $\lambda/M$ in reference (125) and as proportionality coefficient, $a$, in reference (129).

He also proposed an exponential speed/density relation for the free-flow regime (after studying curves of flow against concentration and hypothesising that there are two regimes of traffic flow: free and congested flow).

$$V = V_f \cdot e^{-k/k_o}$$

where $V = \text{speed}$

$V_f = \text{free-flow speed}$

$k = \text{concentration}$,

and $k_o = \text{optimum concentration for max. flow}$

Also in 1961 Gazis, et al (131) again discussed a variety of non-linear follow-the-leader models of traffic flow and suggested a further model in which the sensitivity

$$\lambda = a_3/S^2$$

where $a_3$ is a constant and $S$ is spacing, which yields Greenshield's (135) equation of steady-state flow of traffic:

$$V = V_f \cdot (1-K/K_j)$$
They suggested that all these known models could be accommodated in a general expression for the sensitivity in the form

\[ x_{n+1} = a \frac{x_{n+1}^m(t+T)}{(x_n(t) - x_{n+2}(t))^{1}} \]

The complete model is thus:

\[
\begin{align*}
\dot{x}_{n+1}(t+T) &= \frac{a x_{n+1}^m(t+T) \left[ \dot{x}_n(t) - \dot{x}_{n+1}(t) \right]}{\left[ x_n(t) - x_{n+1}(t) \right]^{1}} \\
\frac{\dot{x}_{n+1}(t+T)}{x_{n+1}^m(t+T)} &= \frac{a \left[ \dot{x}_n(t) - \dot{x}_{n+1}(t) \right]}{\left[ x_n(t) - x_{n+1}(t) \right]^{1}}
\end{align*}
\]

The authors then plotted a series of curves of flow "Q" against normalised concentration "K/K_j" for values of:

\[ 1 = -\frac{1}{2}, 0, \frac{1}{2}, 1, 2 \text{ and } 3 \]

and values of

\[ m = -1, 0 \text{ and } 1 \]

Curves of reasonable shape were found for

\begin{align*}
m = 0 \text{ and } & 1 = 0.5, 1, 2 \text{ and } 3 \\
m = -1 \text{ and } & 1 = -0.5, 0, 0.5, 1 \text{ and } 2 \\
m = 1 \text{ and } & 1 = 3
\end{align*}

They concluded that at the time there was insufficient data available to establish superiority of one particular model. Nevertheless it was again ascertained that a non-
linear model is necessary to account for observed flow against concentration data.

In 1963 Herman and Rothery\(^{(136)}\) carried out and analysed several experiments with two or three vehicles within the framework of the car-following model of single lane traffic flow. In particular, experiments with three vehicles were analysed in order to determine how far a driver is influenced by the vehicle two ahead of him in the traffic stream.

The following model was considered:

\[
\ddot{x}_{n+2}(t+T) = \lambda_1 (\dot{x}_{n+1}(t) - \dot{x}_{n+2}(t)) + \lambda_2 (\dot{x}_n(t) - \dot{x}_{n+2}(t))
\]

\[3.30\]

where \(\lambda_1\) and \(T\) are the sensitivity and time lag for control using the car ahead of the \((n+2)\)nd car and \(\lambda_2\) and \(T\) the corresponding sensitivity and time lag for control using the car two ahead.

Their results suggested that a driver is mainly influenced by the vehicle immediately ahead.

A second study was reported which was made to determine if any difference existed in driver response in the two cases where the relative speed was positive and negative. The results showed that small acceleration disturbances propagate more slowly than the deceleration waves.

A third study in which a light signal was displayed on the leading car indicating whether it was accelerating, coasting or braking showed that individuals used this information to drive with a smaller spacing than normal.
In 1967 Constantine and Young (137) developed a technique for obtaining the required data for car-following theory which can be used in traffic streams on the highway without any interference to normal traffic. The spacing and relative velocity were obtained photographically by time lapse kinematography, using techeometric principles, while velocity and acceleration were obtained by numerical differentiation of readings taken from an accurate distance meter. The advantage of this system over the G.M. system with cars connected by wires is that the driver behind does not know that he is under test. They gave a few results of some pilot runs of the system in which they found a good correlation with the general car-following law (1) for \( l = 0 \) and \( m = 0 \) (constant sensitivity) and (2) for \( l = 1, m = 0 \) (sensitivity = reciprocal of spacing). The differences between the two theoretical formulae were not significant in this particular experiment and the reciprocal spacing formula gave a slightly better result under certain conditions. The correlation was high throughout the period during which vehicles approach and pass through the intersection (they carried out their pilot study at a signalised intersection) but it was particularly marked during a brief period of a few seconds just prior to reaching the stop line, and during the earlier stages of acceleration.

The value of the time lag "T" which gave the best correlation coefficient was 1.0 sec.

Also in 1967 Drake, Schofer and May (141) suggested values of \( l = 3 \) and \( m = 1 \), which gives the steady-state law:

\[
V = V_{fe} - \frac{1}{4} \left( \frac{K}{KJ} \right)^2
\]
This "bell-shaped" curve gave a very good fit to data collected on the Eisenhower Expressway at Chicago; however, they concluded that it was in no respect outstanding in its predictive ability, because although a relatively low estimate of mean-free-speed was anticipated by its very formulation, the actual mean-free-speed of the facility appeared to be considerably higher than predicted by this model.

May and Keller (142) again in 1967 gave a very useful resume of microscopic and macroscopic theories of traffic flow (the generalised car-following law for m=1 to 3 and l=1 to 4), with special emphasis on their interrelationship. They also developed a comprehensive matrix which results in a set of steady-state flow equations, which includes the major macroscopic and microscopic theories (see Fig. 3.3 (a) and (b)).

They then took free speed $V_f$, jam density $K_j$, optimum speed $V_0$, optimum density $K_0$ and maximum flow as criteria for evaluation of various models. They plotted contours of each on the 1/m matrix and then combined them all on one diagram. They concluded that a car-following law which gives the best fit to all the criteria is one where:

$$m = 0.8 \quad \text{and} \quad l = 2.8.$$ 

3.13 SUMMARY OF EXISTING MODELS

Response = Sensitivity x Stimulus

$$\dot{x}_{n+1}(t+T) = \frac{c \left[ x_{n+1}(t) \right]^m}{\left[ x_n(t) - x_{n+1}(t) \right]} \left[ \dot{x}_n(t) - \dot{x}_{n+1}(t) \right], \quad 3.32$$

(The dynamic car-following equation.)
### a. Matrix of existing traffic-flow models.

<table>
<thead>
<tr>
<th>m</th>
<th>m = 0</th>
<th>m = 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(v = c \left( \frac{1}{K} - \frac{1}{K_j} \right) )</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>(v = v_o \log_e \left( \frac{K_j}{K} \right) )</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>(v = v_f \left( 1 - \frac{K}{K_j} \right) )</td>
<td>(v = v_f e^{-tk} )</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>(v = v_f e^{ck^2} )</td>
</tr>
</tbody>
</table>

### b. Existing traffic-flow models

![Diagram showing the positions of different models](#)

- Pipes, Chalder et al
- Gazis et al, Greenberg
- (Edie)
- Greenshields
- Edie
- May et al

**Fig. 3.3**

-101
m = 0, 1 = 0 gives

\[ V = C\left(\frac{1}{K} - \frac{1}{K_J}\right) \] i.e. Linear car-following model

m = 0, 1 = 1 gives

\[ V = C \log_e \left(\frac{K_J}{K}\right) \] i.e. reciprocal spacing model (Greenberg's (128) model)

m = 0, 1 = 2 gives

\[ V = C(K_J - K) = \frac{V_f}{K_J} (K_J - K) \] i.e. Greenshield's (135) model

m = 1, 1 = 2 gives

\[ V = V_f e^{-Ck} \] i.e. Edie's (133) low concentration model

m = 1, 1 = 3 gives

\[ V = V_f Ck^2 \] i.e. Drake, Schoffer and May (141) model

m = 0.8, 1 = 2.8 gives

\[ V = V_f \left[ 1 - \left(\frac{K}{K_J}\right)^{1.8}\right]^{5} \] May, Keller (142) model

General form is \[ V = V_f \left[ 1 - \left(\frac{K}{K_J}\right)^{1-1}\right]^{\frac{1}{1-m}} m<1,1>1 \]

The same equation can be derived by taking the stimulus to be the rate of change of visual angle:
where \( W \) = width of car and the sensitivity of response to be proportional to

\[
\frac{\frac{\dot{X}_{n+1}(t)}{X_{n}(t) - X_{n+1}(t)}}{\left( \frac{X_{n}(t) - X_{n+1}(t)}{X_{n}(t) - X_{n+1}(t)} \right)^{p}}
\]

i.e. inversely proportional to \((\text{time headway})^{p}\).

This gives the basic car-following equation

\[
\dot{X}_{n+1}(t+T) = C \frac{\dot{X}_{n+1}(t)}{X_{n}(t) - X_{n+1}(t)} \left( \frac{X_{n}(t) - X_{n+1}(t)}{X_{n}(t) - X_{n+1}(t)} \right)^{p} \frac{\dot{X}_{n}(t) - \dot{X}_{n+1}(t)}{(X_{n}(t) - X_{n+1}(t))^{2}} \tag{3.33}
\]

3.14 THE USE OF CAR-FOLLOWING LAWS FOR SIMULATION AND THE MODEL ADOPTED

In the U.S.A. Dart\(^{(143)}\) used the generalised car-following model with \( m=0 \) and \( m=2 \) for his simulation.

In the U.K. Sumner\(^{(144)}\) stated that the success of the work by Gazis\(^{(127)}\) in the U.S.A. and Constantine\(^{(137)}\) in the U.K. and on the basis of data published that the model gives the best fit to observed field data in both the U.K. and the U.S.A. Conditions, combined with the agreement with Greenberg's equation, made the adoption of the Reciprocal Spacing car-following model \((m=0, \ l=1)\) for his simulation the obvious choice.

Seddon\(^{(145)}\) decided to use the car-following law in its generalised form so that comparisons could be made on their
value in simulation, however, he only used one model for each site of the two sites he studied in his simulation, they were (a) $l=0, m=0$ for The Crescent and (2) $l=1, m=0$ for Birchfields Road.

For the purpose of the present simulation model it was decided to adopt the car-following law in its generalised form for the following reasons.

1. To make the model as general as it can be, so that it can be used for different purposes.
2. To study the effect of different versions of the generalised car-following laws on both the time history of noise and the distribution of noise. A facility is available in the program to change the values of $l$ and $m$ (they are used as input parameters).

In the program, distance and speed are calculated from the values of speed and acceleration at the previous scan. It is assumed that acceleration remains constant during each scan interval (0.25 sec. – see Section 3.17), i.e:

$$\ddot{x}_t = \dot{x}(t-0.25) + \ddot{x}(t-0.25) \cdot 0.25$$

$$x_t = x(t-0.25) + \dot{x}(t-0.25) \cdot 0.25 + \ddot{x}(t-0.25) \cdot \frac{0.25^2}{2}$$

where the acceleration $\ddot{x}$ for each car in the stream is obtained from the generalised car-following theory equation.
\[
\dddot{x}_{n+1}(t+T) = C \frac{\left[\dot{x}_{n+1}(t)\right]^m}{\left[x_n(t) - x_{n+1}(t)\right]^l} \left[\dot{x}_n(t) - \dot{x}_{n+1}(t)\right]
\]

3.29

Values of C, m and l have been chosen as 0.5, 1 and 1 respectively as explained in Section 4.2.2. This equation has been used to control the vehicle motions in several phases of the various flow models developed in Chapter 4.

3.15 APPLICABILITY OF CAR-FOLLOWING THEORY

It has to be pointed out that the car-following theory can be applied only to two cars in actual traffic if the second driver is deemed to be following the first car. In actual practice some drivers, even in reasonably dense traffic, will not attempt to follow the cars preceding them and hence their cars become leaders of separate groups of cars. It is to these groups of cars, moving under the close influence of each other, that the car-following theory applies.

The criterion for deciding whether or not a car is following another is difficult to formulate precisely.

In some analyses of traffic flow, the occurrence of large gaps often causes difficulties; Edie and Foote(146) for example, excluded from their analyses gaps with headways exceeding somewhat arbitrary figures of eleven seconds. In addition to time, spacing has also been chosen as a criterion for car-following theory. Herman and Potts(129) found that when the car spacing is over 200ft. (65.6m), the correlation coefficient calculated in the car-following experiment is rather small.

Seddon(145) stated that Constantine and Young(137), in private
communication, suggested that their correlations were poor above a spacing of 100ft. (32.8m). In the present model it was found easier to implement a distance criterion for car-following theory rather than a time criterion.

A distance of 50.0 meters was chosen as a compromise between the above stated figures. If the spacing between vehicles is more than this distance, vehicles travel freely (see Section 4.3.2).

3.16 BACKGROUND NOISE LEVEL

The background noise is defined as the total noise composed of all natural and man-made noise sources that can be considered as parts of the acoustical environment of the general area.

It is essential to include the background noise level in the model for the following reasons:

1. Total noise level calculated at the observation point would go below its actual level if the background noise level had not been specified.

2. When the noise level emitted by a vehicle has the same value of the background noise at the observation point, the total noise level would be 3dBA higher than any one of them, however, this would not be the case if the background noise level had not been specified. Indeed the background will contribute even when it is 10dBA below the traffic level.

In 1963, the Wilson Committee \(^{(12)}\) report presented typical measured noise values where road traffic noise was predominant.
It showed different values for day and night and represented these values as Noise Climate in dBA ($L_{80}$, the noise level exceeded for 80% of the time). Table 3.4 is a reproduction of the values.

**Table 3.4** Range of Noise Levels at Locations in Which Traffic Noise Predominates

<table>
<thead>
<tr>
<th>Group</th>
<th>Location</th>
<th>Noise Climate in dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Day - 8.0 a.m. - 6.0 p.m.</td>
</tr>
<tr>
<td>A</td>
<td>Arterial roads with many heavy vehicles and buses (kerbside)</td>
<td>80-68</td>
</tr>
<tr>
<td>B</td>
<td>(1) Major roads with heavy traffic and buses. (2) Side roads within 15-20m of roads in groups A or B (1) above.</td>
<td>75-63</td>
</tr>
<tr>
<td>C</td>
<td>(1) Main residential roads (2) Side roads within 15-20m of heavy traffic routes. (3) Courtyards of blocks of flats, screened from direct view of heavy traffic.</td>
<td>70-60</td>
</tr>
<tr>
<td>D</td>
<td>Residential roads with local traffic only.</td>
<td>65-56</td>
</tr>
<tr>
<td>E</td>
<td>(1) Minor roads (2) Gardens of houses with traffic routes more than 100m distant.</td>
<td>60-51</td>
</tr>
<tr>
<td>F</td>
<td>Parks, courtyards, gardens in residential areas well away from traffic routes.</td>
<td>55-50</td>
</tr>
<tr>
<td>G</td>
<td>Places of few local noises and only very distant traffic noise.</td>
<td>50-47</td>
</tr>
</tbody>
</table>
It has been suggested that the levels shown in Table 3.4 are likely to remain fairly static because since it is possible that they will creep upwards by a few dB as the volume of traffic increases legislation will limit the production of noise by vehicles to that which they have been producing in recent years (150).

The B.S. 4142(147), 1969, suggests a basic criterion of background noise level of 50dBA should be applied where direct measurements are impracticable.

The following corrections for type of district in the neighbourhood of the measuring position are given.

Table 3.5 Corrections for Type of District in the Neighbourhood of the Measuring Position

<table>
<thead>
<tr>
<th>Type of District</th>
<th>Add to basic Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Rural (residential)</td>
<td>-5dBA</td>
</tr>
<tr>
<td>2. Suburban, little road traffic</td>
<td>0</td>
</tr>
<tr>
<td>3. Urban (residential)</td>
<td>+5</td>
</tr>
<tr>
<td>4. Predominantly residential urban but with some light industry or main roads</td>
<td>+10</td>
</tr>
<tr>
<td>5. General industrial area intermediate between 4. &amp; 5.</td>
<td>+15</td>
</tr>
<tr>
<td>6. Predominantly industrial with few dwellings.</td>
<td>+20</td>
</tr>
</tbody>
</table>

The B.S. 4142 has been amended and the main changes are:
1. More emphasis is placed on actually measuring the background noise level.

2. The estimated background level is now referred to as a notional background rather than a corrected criterion, and

3. The preferred measurement of background level to be used is $L_{90}$.

In 1976 Attenborough and Clark (148) proposed a model that allows the prediction of background noise level, for certain combinations of area, time of day and nearest major noise source. The model was deduced from multiple regression analysis of 1353 measurements made by the Open University students. The standard error of each prediction was 10.2dBA. They suggested that the large standard error of the model indicated the difficulty of estimating background levels solely on the basis of the parameters as were suggested in BS 4142:1967. They concluded that the notional background level as calculated by using the British Standard "Method of Rating Industrial Noise Affecting Mixed Residential and Industrial Areas" will over-estimate the actual background in the great majority of situations. Their typical values compared with the B.S. are shown in Table 3.6.

For the purpose of the present work, measurements were carried out in four different sites representing commercial and residential areas in order to get a background noise level as accurate as possible.
Table 3.6 Comparison of Coefficients Found by Attenborough and Clark with Those of BS 4142.

<table>
<thead>
<tr>
<th>Time of Area Category</th>
<th>Correction BS4142</th>
<th>Correction MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notional background, rural 0900-1100</td>
<td>50*</td>
<td>44.1</td>
</tr>
<tr>
<td>12-14 Weekdays</td>
<td>0</td>
<td>0.16</td>
</tr>
<tr>
<td>16-18 Weekdays</td>
<td>0</td>
<td>0.45</td>
</tr>
<tr>
<td>20-22 Weekdays</td>
<td>-5</td>
<td>-4.07</td>
</tr>
<tr>
<td>24-07 Weekdays</td>
<td>-10</td>
<td>-10.36</td>
</tr>
<tr>
<td>14-16 Sundays</td>
<td>-5</td>
<td>-2.48</td>
</tr>
<tr>
<td>Suburban area</td>
<td>+5</td>
<td>2.27</td>
</tr>
<tr>
<td>Urban residential area</td>
<td>+10</td>
<td>7.56</td>
</tr>
<tr>
<td>Pred. urban, residential</td>
<td>+15</td>
<td>9.70</td>
</tr>
<tr>
<td>Gen. ind. int.</td>
<td>+20</td>
<td>11.18</td>
</tr>
<tr>
<td>Industrial area</td>
<td>+25</td>
<td>12.64</td>
</tr>
</tbody>
</table>

*Made up of 50 -5 (rural area para. A3) + 5(time of day para. A4). No account is taken of the correction for the type of insulation (para. A2).

The hand-held sound level meter method was adopted and the following procedure was carried out:
1. The microphone was located 1.2m above the ground, on a tripod, and about 1 meter from the facade.

2. The sound level meter was set on Fast response, A weighting.

3. In order that the operator be able to sample as rapidly as every 4 or 5 seconds, an assistant would be required to read a stop watch and record the sound level reading. To eliminate the need for an assistant, a timing light was developed that would flash for 0.5sec. in regular intervals, then intervals can be set to any time between 4 - 19sec. The operator spoke his reading which was made "on-the-fly" (i.e. without waiting for the needle to stabilize) into an inexpensive portable cassette recorder, and recopied the data at a later time on a data sheet similar to that shown in Figure 3.4. The transient meter fluctuation caused by the spoken reading died out before the next reading.

4. Most of the applicable parts of the upper portion of the data sheet were spoken into the tape recorder before any reading was taken.

5. Before taking any readings, the sound level meter was observed for a period of 30 seconds to get a feeling of the central tendency of the minimum level during this period. For the next 30 seconds the central tendency of the maximum level was noted. This helped in setting the attenuator of the sound level meter.

6. The data was analysed to estimate the statistical levels $L_{90}$ and $L_{10}$ by using the following process:
<table>
<thead>
<tr>
<th>GENERAL</th>
<th>EQUIPMENT</th>
<th>SITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator</td>
<td>Type</td>
<td>Site No.</td>
</tr>
<tr>
<td>Date</td>
<td>Serial #</td>
<td>Location</td>
</tr>
<tr>
<td>Time</td>
<td>Cal. Date</td>
<td>Site Description</td>
</tr>
<tr>
<td>Day S M T W Th F S</td>
<td>Micro. Height</td>
<td></td>
</tr>
<tr>
<td>Wind Speed</td>
<td>Micro. Distance to Wall</td>
<td></td>
</tr>
<tr>
<td>Temp.</td>
<td>SLM Setting</td>
<td></td>
</tr>
<tr>
<td>Rel. Hum.</td>
<td>Fast, Slow</td>
<td></td>
</tr>
<tr>
<td>Other Weather</td>
<td>Other</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SITE SKETCH</th>
<th>MISCELLANEOUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Count: Autos</td>
<td></td>
</tr>
<tr>
<td>Trucks</td>
<td>Other</td>
</tr>
<tr>
<td>Comments</td>
<td>Total</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NOISE LEVEL - dBA</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
</tr>
<tr>
<td>81</td>
</tr>
<tr>
<td>82</td>
</tr>
<tr>
<td>83</td>
</tr>
<tr>
<td>84</td>
</tr>
</tbody>
</table>

**NUMBER OF READINGS**

**Fig. 3.4** Noise Survey - Data Log
A. For $L_{10}$, a count down from the top of the tally sheet was made until 10 per cent of the total count was reached. Linear interpolation was employed, since the operator attempted to read the sound level meter only to an accuracy of 1dBA. This provided an estimate of $L_{10}$.

B. For $L_{90}$ a count up from the bottom of the tally sheet until 10 per cent of the total count was reached. Linear interpolation was employed to provide an estimate of $L_{90}$.

A brief description of the sites where the measurements were carried out is given in Table 3.7. The results of the measurements are shown in Table 3.8.

From some other measurements which have been carried out for this project, it can be seen that the background noise level is in the range of 52.5 - 73.5dBA for traffic flows encountered (see Chapter 9).

It was decided to choose the value of 44.5dBA as the minimum background noise level. The reason for this is that the model is designed to be used in urban traffic situations and this figure of background noise level seems quite adequate and more reasonable than choosing much smaller figures. The value is however an input under the control of the user.

Preliminary tests of the model showed that when the flow is less than 350VPH, $L_{90}$ values are mainly affected by the background noise level chosen.
### Table 3.7 Sites Description

<table>
<thead>
<tr>
<th>Site</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Church Gate</td>
<td>Narrow shopping precinct. Vehicles - access only.</td>
</tr>
<tr>
<td>2. Baxter Gate</td>
<td>One-way street. Hospital exists there.</td>
</tr>
<tr>
<td></td>
<td>Low volume of traffic. Parking is allowed on both</td>
</tr>
<tr>
<td></td>
<td>sides of the road.</td>
</tr>
<tr>
<td>4. Herbert St.</td>
<td>Residential street. Parking allowed on both sides.</td>
</tr>
<tr>
<td></td>
<td>15-20m from a main traffic road.</td>
</tr>
</tbody>
</table>

### Table 3.8 Results of noise measurements at sites of Table 3.7

<table>
<thead>
<tr>
<th>Site</th>
<th>Sampling Interval Sec.</th>
<th>Total No. of Samples</th>
<th>L₁₀ dBA</th>
<th>L₉₀ dBA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shopping</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Church Gate</td>
<td>5</td>
<td>193</td>
<td>70.0</td>
<td>56.2</td>
</tr>
<tr>
<td>Baxter Gate</td>
<td>5</td>
<td>243</td>
<td>68.2</td>
<td>52.2</td>
</tr>
<tr>
<td>Residential</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>William St.</td>
<td>5</td>
<td>242</td>
<td>63.6</td>
<td>50.4</td>
</tr>
<tr>
<td>Herbert St.</td>
<td>5</td>
<td>286</td>
<td>53.6</td>
<td>47.0</td>
</tr>
</tbody>
</table>
3.17 SCANNING

It is not possible to examine, within the digital computer, all parts of the system simultaneously; some finite scan interval is involved.

There are two general scanning methods. "Periodic Scanning" (also called epoch to epoch) which consists of scanning and updating the entire system once during each unit of time. This technique is straight-forward and is usually easy to program. In the event scan method, on the other hand, after a given event has occurred, one determines and "stores" a set of "imminent" significant events and times at which they will occur, and selects the earliest. The occurrence of this next significant event may alter the possibility or timing of other events that had been listed, so that a new set of events and times may then be calculated. Thus an event scan program is essentially asking "What happens next?" whereas the periodic scan program asks "What will the situation be one time unit from now?"

The event-scan technique is much faster and can result in an increase of computing speed by a factor of about 10 but usually requires greater program complexity. In practice, the periodic scan and event scan methods may be implemented in many ways and partially combined, in order to produce a program that is artfully suited to the problem.

In the present model, vehicle arrival is an example of event scan technique; however, periodic scan techniques have been mainly used because of the advantages mentioned above.
In deciding upon the time unit (scan interval) to be used in this model (or any other model) the following must be taken into consideration:

1. The precision of the model depends on the length of the scan interval.
2. It is important for the interval to be small enough to include vehicle actions.
3. The interval used also depends on the method of vehicle generation and must be shorter than the mean time headway (at the highest volume levels for those models which generate only one vehicle per time increment).
4. The computer time, and therefore, cost required to simulate traffic, is inversely proportional to the time interval used in scanning the system.

Values of scan intervals ranging from 0.25 to 1sec. have been used by different workers.\(^{(118),(153),(154),(145)}\). Seddon\(^{(145)}\) carried out detailed tests on simulating car-following theory using 1sec. scan interval. He found that this leads into an unstable situation and severe restraints are required in order to maintain stability.

It was strongly felt that an accurate platoon dispersion simulation is required in order to obtain a good model of a pair of intersections (see Chapter 5). This meant that as small a scan interval as possible should be used.

In noise simulation studies, Jones\(^{(65)}\) used a scan interval of 1sec. and Sparkes\(^{(61)}\) suggested that a scan interval of 1sec. should be considered as a maximum value.
It must be mentioned that one of the most important decisions which had to be made in the present simulation (or indeed any other simulation) was deciding the value of the scan interval because of the factors mentioned above.

For the above-mentioned reasons, 0.25sec. scan interval has been used throughout this model and from early runs this was found satisfactory and makes the model useable for different studies. In an experiment carried out on the campus of Loughborough University it was found unrealistic to assume that acceleration would stay constant for more than 0.25sec.

3.18 **CALCULATIONS OF NOISE LEVELS AND INDICES**

3.18.1 **Sampling**

A facility is available in the model to take a noise sample at integer multiples of the basic program scan interval. This has been made mainly to allow:

a. Checking the accuracy of the model by using different sampling times.

b. Testing the model against hand-held sound level meter measurements (which can only sample every 4sec. or more – see Section Background Noise) if required.

c. If needed, carrying out statistical testing methods on sampling such as: correlation between successive samples or the size of the sample required to give certain accuracy.

d. Saving computer time by sampling at longer intervals when the required sample size for sufficient accuracy is small, e.g. at high volumes of traffic when the
standard deviation of the noise level is small.

Sampling starts after a predetermined period has elapsed to ensure that vehicles are in the system when taking the noise sample. The predetermined period is determined as users wish and should be dependant on the flow and speed of vehicles. Values around 50 - 100sec, are suggested.

3.18.2 Noise Levels Calculations

Once the sampling time has been specified, the model will carry out noise calculations periodically.

A subroutine "NOISE" does the noise calculations by knowing the position (distance from the observation point), speed and acceleration of each vehicle on the segment of the road.

Some data was, therefore, required which gives the noise emitted by the vehicle as a function of the speed. The data chosen needed to satisfy the following criteria:

1. The sample size is sufficient and representative.
2. As many classes of vehicle to be represented as possible, to ensure that prediction accuracy can be modified when required.
3. Up to date, to make sure that changes in vehicle performance and noise emitted by them since the data were collected are negligible.

Detailed explanation on such measured data was given in Section 2.2.
Nelson and Piner\(^{(46)}\) analysed data obtained by Christie et al\(^{(48)},(49)\) and some other workers (this data set is independent\(^{(50)}\) of that from the CORTN\(^{(3)}\)) to provide an initial data set from which vehicle reference noise levels are derived for inclusion in the TRRL noise models. The analysis of the data is summarised below.

For each vehicle category the noise results obtained from the different shopping streets were plotted as cumulative percentage totals against noise level exceeded. Each line was then normalised to a reference distance of 7.5 metres from the source centre, assumed to be the centre of the road, by applying the inverse square law of spherical spreading. Then for each vehicle category the noise level exceeded by 10% of the vehicles and that exceeded by 90% were estimated for each site, assuming a Gaussian distribution, and the average 10% and 90% levels for the five sites obtained. Then average decibel levels were then used to construct for each vehicle category the average distribution, again assumed to be Gaussian, at a distance of 7.5 metres from the vehicle source centre.

It was found that unlike free-flow conditions the noise levels for the different vehicle categories fall into three rather than two distinct groups. The light vehicle group, which for free speed conditions contained all cars, car-based vans and medium vans less than 1525kg unladen weight could be extended to include all two-axle commercial vehicles with a maximum unladen weight up to 3000kg. This additional light vehicle category consists mostly of large petrol-engined
delivery vans and extends the number of vehicles presently included in the light vehicle group by less than 1.5%. The generalised reference noise levels obtained for the light vehicle group would, in consequence, be barely affected by the inclusion of this additional category. The heavy vehicle group appears, under non-free flow conditions, to divide most simply into two groups, an intermediate heavy vehicle group containing buses, coaches and two-axle commercial vehicles exceeding 3000kg unladen weight and a heavier vehicle group containing all vehicles with three or more axles.

Figure 3.5 shows the speed noise level characteristics for three different vehicle categories. The six vehicle characteristics given in Table 3.9 have been reduced in number by combining categories together to produce the most probable set of characteristics for 5, 4, 3, 2 and 1 vehicle category divisions of the total vehicle population. Table 3.10 shows the order and manner of the formation of the different vehicle categories and Table 3.9 lists the equations of all the characteristics formed, (Section 3.10).

Details on how vehicle categories have been chosen are given in Vehicle Type.

Diggory (47) found a substantial agreement between his data and that collected by Nelson and Piner (46).

The above explained data was found to be the best to fulfil the criteria set for choosing the data in this model. A choice is available in the model to use either 2 classes or 3 classes as required.

Since this simulation is mainly dealing with urban areas, it is expected to encounter a lot of acceleration and deceleration in the performance of vehicles.
Fig. 3.5 Noise Level/Speed Characteristics for the Three Classes of Vehicles Used in the Present Simulation
Table 3.9 Equations of the Noise Level Speed Characteristics Described in Table 3.10

<table>
<thead>
<tr>
<th>Characteristic Designation</th>
<th>Equation of the Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IF SPEED 26.5km/h LEVEL = 64.2dB(A) ELSE LEVEL = 21.7 + 29.9 \log_{10}(SPEED)</td>
</tr>
<tr>
<td>2</td>
<td>IF SPEED 28.1km/h LEVEL = 67.5dB(A) ELSE LEVEL = 24.2 + 29.9 \log_{10}(SPEED)</td>
</tr>
<tr>
<td>3</td>
<td>IF SPEED 37.6km/h LEVEL = 74.5dB(A) ELSE LEVEL = 27.4 + 29.9 \log_{10}(SPEED)</td>
</tr>
<tr>
<td>4</td>
<td>IF SPEED 39.4km/h LEVEL = 76.0dB(A) ELSE LEVEL = 28.3 + 29.9 \log_{10}(SPEED)</td>
</tr>
<tr>
<td>5</td>
<td>IF SPEED 44.2km/h LEVEL = 79.5dB(A) ELSE LEVEL = 30.3 + 29.9 \log_{10}(SPEED)</td>
</tr>
<tr>
<td>6</td>
<td>IF SPEED 47.0km/h LEVEL = 81.0dB(A) ELSE LEVEL = 31.0 + 29.9 \log_{10}(SPEED)</td>
</tr>
<tr>
<td>5,6</td>
<td>IF SPEED 45.8km/h LEVEL = 80.3dB(A) ELSE LEVEL = 30.7 + 29.9 \log_{10}(SPEED)</td>
</tr>
<tr>
<td>3,4</td>
<td>IF SPEED 38.6km/h LEVEL = 75.3dB(A) ELSE LEVEL = 27.9 + 29.9 \log_{10}(SPEED)</td>
</tr>
<tr>
<td>1,2</td>
<td>IF SPEED 27.1km/h LEVEL = 65.2dB(A) ELSE LEVEL = 22.4 + 29.9 \log_{10}(SPEED)</td>
</tr>
<tr>
<td>3,4,5,6</td>
<td>IF SPEED 39.4km/h LEVEL = 77.2dB(A) ELSE LEVEL = 29.5 + 29.9 \log_{10}(SPEED)</td>
</tr>
<tr>
<td>1,2,3,4,5,6</td>
<td>IF SPEED 32.7km/h LEVEL = 73.5dB(A) ELSE LEVEL = 28.2 + 29.9 \log_{10}(SPEED)</td>
</tr>
</tbody>
</table>

Table 3.10 Description and Manner of Formation of Vehicle Categories for Different Levels of Categorisation of the Total Vehicle Population

<table>
<thead>
<tr>
<th>Category Description</th>
<th>6 Cats.</th>
<th>5 Cats.</th>
<th>4 Cats.</th>
<th>3 Cats.</th>
<th>2 Cats.</th>
<th>1 Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars and light vans</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1,2</td>
<td>1,2</td>
<td></td>
</tr>
<tr>
<td>2-axle commercial vehicles</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3000kg U.W.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buses and coaches</td>
<td>3</td>
<td>3</td>
<td>3,4</td>
<td>3,4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-axle commercial vehicles 3000kg U.W.</td>
<td>4</td>
<td>4</td>
<td>3,4</td>
<td>3,4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-axle commercial vehicles</td>
<td>5</td>
<td>5,6</td>
<td>5,6</td>
<td>5,6</td>
<td></td>
<td>3,4,5,6</td>
</tr>
<tr>
<td>3-axle commercial vehicles</td>
<td>6</td>
<td>5,6</td>
<td>5,6</td>
<td>5,6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
It is well understood that acceleration has a significant effect on noise emitted by vehicles hence, it is essential to take this into consideration when simulating road traffic noise in urban areas. Therefore, some data was required for this purpose which had to satisfy the same criteria set for the data of noise vs. speed mentioned above. The best data found in this respect is that of Ringheim and Storeheie (54), (55) details of which are given in Section 2.2. Figure 3.6 shows the effect of acceleration on noise for cars and heavy commercial vehicles. Linear regression techniques have been used to drive formulae which can be utilized in the model. Table 3.11 shows the derived formulae which are incorporated into the model. Equations regarding heavy commercial vehicles are used for both classes of heavy commercial vehicles (medium and heavy) when three vehicle categories are used.

Similar data on noise vs. deceleration was not available. In all free-flowing cases decelerations have been assumed to have no effect on noise.

At each sampling time all vehicles on the segment of the road under consideration (-SPDST \leq X \leq SPDST) are taken in turn starting from the first one (at the head of the queue), and the following procedure is carried out:

1. Classify whether the vehicle is a car, a medium or a heavy commercial vehicle.
2. Calculate the noise level emitted by the vehicle due to its speed and according to its type (Table 3.9).

*See Table 3.12*
Fig. 3.6 Increase in Noise Levels Produced by Individual Vehicles During Max. Acceleration
3. Calculate the increase in noise level due to acceleration from the formulae shown in Table 3.11 and add this value to the noise level due to speed.

4. If the vehicle is decelerating, the corrected noise level is assumed to be the same level due to speed only. This will have a negligible effect on noise from free-flowing traffic because there is a minimum of deceleration manoeuvres and even when there is, it is of a very small amount.

5. Calculate the position of the vehicle according to the observation point (from the position of the vehicle on the road (see 'Car-following Theory') and from the position of the observation point) (Fig.3.7).

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Range of Acceleration m/s²</th>
<th>Noise vs. Acceleration Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars</td>
<td>$0 \leq \text{Acceleration} &lt; 2$</td>
<td>Additional Noise = 2 x Acceleration</td>
</tr>
<tr>
<td>Cars</td>
<td>$2 \leq \text{Acceleration}$</td>
<td>Additional Noise = $5.13 + 3.583 \times \text{Acc.}$</td>
</tr>
<tr>
<td>HCV</td>
<td>$0 \leq \text{Acceleration} &lt; 0.25$</td>
<td>Add.Noise = $1.6 \times \text{Acc.}$</td>
</tr>
<tr>
<td>&quot;</td>
<td>$0.25 \leq \text{Acc.} &lt; 0.75$</td>
<td>Add.Noise = $-0.6 + 4 \times \text{Acc.}$</td>
</tr>
<tr>
<td>&quot;</td>
<td>$0.75 \leq \text{Acc.} &lt; 2.0$</td>
<td>Add.Noise = $-13.38 + 21 \times \text{Acc.}$</td>
</tr>
</tbody>
</table>
6. Calculate the total attenuation due to the distance from the vehicle to the observer (as calculated in \(5.\) above) assuming that the maximum noise level occurs when the vehicle is at the closest point relative to the noise site, and that the radiated noise is uniform around any radius \(r\) from the vehicle; we have

\[
L(r) = L(h) - 10 \log_{10} \left( \frac{r}{h} \right)^K
\]

\(L(r)\) is the instantaneous noise level at the observation point caused by the vehicle at radius \(r\)

\(L(h)\) is the peak noise level caused at the observation point.

\(K\) is a propagation exponent, equal 2 for 6dB.
attenuation per distance doubling.

7. Calculate the total noise level from all the vehicles in the system, and to establish this, the procedure of the total dBA level of several uncorrelated sources is used, i.e. divide by 10 and take antilogs. Add up the resulting number for each source (vehicle in this case), log and multiply by 10. This results in a noise reading or a sample every time it is carried out. These readings are kept in an array (XT), so that they can be produced to show the actual noise history and to calculate different noise indices as explained later.

8. If there is no vehicle on the segment of road (NVS=0) "which is more likely to happen at low volumes of traffic". "NOISE" will consider the total noise level for that sample equal to the background noise level and store this reading.

3.18.3 **Calculations of Different Noise Indices**

Once the total sampling time (specified modelling time) has elapsed, noise levels calculated at each sampling interval at the observation point are reproduced and printed to show the noise history of the measurement. Noise levels are then sorted in descending order to simplify analysis (as will be shown); this sorting is carried out by a standard NAG library subroutine.

In order to obtain different noise indices, the following procedure is used:
1. Noise levels are sorted out again into 1dBA steps and printed in descending order.

2. For $L_{10}$, a count down from the top of the values is made until 10 per cent of the total count (number of total readings "KKK" made during the specified modelling time) is reached. This gives the value of $L_{10}$ because measurements are carried out in real quantities.

3. For $L_{50}$ the count down continued (from the previous step) from the top of the values until 50 per cent of the total number of measurements is reached. This gives the value of $L_{50}$.

4. For $L_{90}$, the count down continued from the top of the values until 90 per cent of the total number of measurements is reached and this gives the value of $L_{90}$.

5. Values of $L_{NP}$ and $L_{eq}$ are calculated as follows:

$$L_{eq} = 10 \log \left( \frac{10^{\frac{dBA_1}{10}} + 10^{\frac{dBA_2}{10}} + \ldots + 10^{\frac{dBA_n}{10}}}{i_1 + i_2 + \ldots + i_n} \right)$$

where $i_n$ is no. of occurrences of level dBA

$$L_{NP} = L_{eq} + (L_{10} - L_{90})$$

### 3.19 CALCULATIONS OF NOISE FROM MORE THAN ONE LANE

In order to combine noise from more than one lane, all calculations of distances, speeds, accelerations, etc., are carried out for each lane separately. In the noise calculations noises from all lanes are combined in the same way as for one lane and every sample will be the total noise reading at the observer point from all vehicles in all lanes.
The free-flowing model is able to cope with a road of up to six lanes of traffic with a central reservation. Attenuation due to the distances of the outer lanes is accounted for, and the lane width is used as an input parameter. The normal lane width in the U.K. is 3.65m.

3.20 CALCULATIONS OF ACHIEVED FLOW PARAMETERS

Since most of the variable parameters of the model are sampled randomly, and because these would not give the exact specified quantity unless the sample approaches infinity, it is better to find the exact parameters from the model rather than use the specified parameters when making reference to them. This will be very useful in checking the accuracy of the model.

3.20.1 Achieved Flow Rate

The actual flow is determined from the total number of vehicles passing the observation point during the measurement period.

If \( N \) is the total number of vehicles passed the observation point, and \( T \) is the measurement period (sec.),

then Achieved Flow = \( \frac{N}{T} \times 3600 \)

3.20.2 Percentage of Heavy Commercial Vehicles

Maximum discrepancy might be expected in this parameter, because usually the percentages are small.
Since this parameter has a significant effect on noise, it is necessary to compare the actual percentages when testing the model.

Calculations of the actual percentages are carried out in the following way:

Every time commercial vehicles are generated, their number is increased by one.

If at the end of the measurement period the total number of commercial vehicles equals \( N_{CV} \) then

\[
\text{Achieved percentage of } HCV = \frac{N_{CV}}{N} \times 100
\]

when \( N \) is the total number of vehicles passed the observation point during the measurement period.

3.20.3 **Achieved Mean Speed**

In order to find the actual mean speed of the traffic on the road, the concepts of Time-Mean Speed and Space-Mean Speed have to be introduced.

a. **Time-Mean Speed** is obtained from the distribution of vehicle speeds over a period of time at a point in space.

b. **Space-Mean Speed** from the distribution of vehicle speeds in space at a given instant.

It has been found that the time mean speed is always greater than the space mean speed (derived theoretically in References (121) and (155)).
Unfortunately it was found that it would require a major modification to the program and would have taken extra computer time if it was to be done accurately. This was due to the way in which the model was built and therefore, it was felt unjustifiable to carry it out. However, a simplified way of coarsely approximating it was devised and implemented.

In the case of the space mean speed a sample of all the vehicles on the segment was taken once, this sample is usually insufficient to give accurate results. When considering the time mean speed, ideally vehicles are sampled at a fixed point for a specified time period. Since incorporation of this procedure into the model is a major task, the procedure adopted in the model was to take a small segment of the whole road under consideration and vehicles were sampled as they entered this segment.

3.21 MODEL DESCRIPTION AND USE

3.21.1 Rules of Operation

1. It is assumed that the road is dry, level and straight.
2. The position of each vehicle in the system is referenced to its front bumper.
3. There is no pedestrian interference.
4. It is assumed that there is no accident or vehicle breakdown.
5. There is no shielding, reflection or excessive attenuation.
6. No extraneous noise, apart from specified background.
3.21.2 Flow Chart and Subroutines Description

Figure 3.8 shows the free-flow model flow chart.
The functions and subroutines incorporated in the model are:

1. Function GSNEX: This function generates random gaps according to the shifted negative exponential distribution.

2. Subroutine INITIAL: This subroutine determines whether the arriving vehicle is a light or a heavy commercial vehicle and gives it its desired speed and maximum acceleration, it also calculates its initial position, speed and acceleration.

3. Function DISTANCE: Calculates the position of each vehicle with respect to the observer. This distance is then used by "NOISE" to calculate the attenuation.

4. Subroutine NOISE: Once a noise sample is required, this subroutine calculates the noise emitted by each vehicle corrected to acceleration and distance, then takes a noise reading and stores it for the noise history and "INDICES".

5. Subroutine INDICE: It calculates \( L_{10} \), \( L_{50} \) and \( L_{90} \) from the noise history, it also calculates \( L_{eq} \) and \( L_{NP} \).

6. Subroutine CORRECT: This subroutine calculates the exact number of vehicles which have passed the observation point during the noise sampling period and from these values the achieved flow and percentage of heavies are calculated.

A detailed list of the required data input and output options are given in Appendix 5A but the main values are shown in Table 3.12.

The listing of the program is given in Appendix 5B.
START

INPUT DATA

CALL INITIAL

Update dist. & speed

Vehicle accelerating freely

Detailed Output

Print

There is a vehicle leaving the system

Last Lane

Noise Sample

CALL NOISE

Mean Time Over

CREATE OUTPUT FILE

PRINT RESULTS

END

FIG. 12 A Flow Chart for the Few-Flow Model (PFM120)

(NVS = Number of Vehicles in the System)
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>STNM</td>
<td>Time the program is allowed to run before starting noise sampling (sec.)</td>
</tr>
<tr>
<td>NTIME</td>
<td>Total Sampling time including STNM (sec.)</td>
</tr>
<tr>
<td>NOBSPT</td>
<td>Number of observation points, at which noise is to be predicted</td>
</tr>
<tr>
<td>NNL</td>
<td>Number of lanes in near stream</td>
</tr>
<tr>
<td>NFL</td>
<td>Number of lanes in far stream</td>
</tr>
<tr>
<td>W</td>
<td>Lane width (m)</td>
</tr>
<tr>
<td>WCR</td>
<td>Width of central reservation (m)</td>
</tr>
<tr>
<td>DMIC</td>
<td>Distance of microphone for individual Vehicle's noise data. 7.5m should be used in present model if no changes are made to it.</td>
</tr>
<tr>
<td>DOPT</td>
<td>Distance of observation point from the kerb in metres (up to 4 points can be specified).</td>
</tr>
<tr>
<td>A</td>
<td>The parameter A of the car-following theory.</td>
</tr>
<tr>
<td>MM</td>
<td>The parameter m of the car-following theory.</td>
</tr>
<tr>
<td>LL</td>
<td>The parameter l of the car-following theory.</td>
</tr>
<tr>
<td>MNG</td>
<td>Min. gap specified for shifted negative exponential distribution. 1sec. has been used throughout present work (sec.).</td>
</tr>
<tr>
<td>Q</td>
<td>Flow (VPH)</td>
</tr>
<tr>
<td>PCH</td>
<td>Percentage of heavy commercial vehicles</td>
</tr>
<tr>
<td>CMS</td>
<td>Light vehicles mean speed (kph)</td>
</tr>
<tr>
<td>HMC</td>
<td>Heavy commercial vehicles' mean speed (kph)</td>
</tr>
<tr>
<td>CACC</td>
<td>Light vehicles acceleration (m/sec.²)</td>
</tr>
<tr>
<td>HACC</td>
<td>Heavy vehicles acceleration (m/sec.²)</td>
</tr>
</tbody>
</table>

Values of variables A to HACC are fed for each lane.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Attenuation Constant</td>
</tr>
<tr>
<td>ST</td>
<td>Interval at which noise sample is taken</td>
</tr>
<tr>
<td>S</td>
<td>Scan interval (sec.)</td>
</tr>
<tr>
<td>SPDST</td>
<td>Specified distance at which vehicles enter and leave the system (m)</td>
</tr>
<tr>
<td>LPRT</td>
<td>A parameter to start random numbers from different initial values. If LPRT = 1 the same order of random numbers is generated.</td>
</tr>
<tr>
<td>IOUPT</td>
<td>= 0 if a short version of output is required</td>
</tr>
<tr>
<td>IBCKN</td>
<td>= 0 if background noise level is = 44.5dBA</td>
</tr>
<tr>
<td>BCKNS</td>
<td>Background noise level if IBCKN ≠ 0</td>
</tr>
</tbody>
</table>
CHAPTER 4 PRINCIPLES OF SIGNALISED INTERSECTIONS MODELS

4.1 INTRODUCTION

In the previous chapter the principles of the free-flowing model have been explained as well as its details. It was mentioned in Section 1.7 that the aim of the present work is to build models which enable the study and prediction of noise levels at signalised intersections with some emphasis on their linking. The present chapter explains in detail the principles of the signalised intersections models.

The operation of a signalised intersection model can be broken down into four elements:

a. Free Flow
b. Decelerating Flow
c. Idling Flow,
and d. Accelerating Flow.

The Free Flow case has been explained in detail in the previous chapter. The Idling Flow case does not need special treatment as it is already catered for if the rest of the cases are considered. Details of the Decelerating Flow and Accelerating Flow cases are given below.

4.2 VEHICLES BRAKING

4.2.1 Response to Amber Period

The following definitions are given for the amber period:
1. By the Highway Code \( ^{(156)} \): "AMBER means stop at the stop line. You may only go on if the AMBER appears after you have crossed the stop line or are so close to it that to pull up might cause an accident."

2. The Uniform Vehicle Code of the National Committee on Uniform Traffic Laws and Ordinances\( ^{(158)} \): "Vehicular traffic facing the signal is thereby warned that the red or "stop" signal will be exhibited immediately thereafter and such vehicular traffic shall not enter or be crossing the intersection when the red or "stop" signal is exhibited."

When the traffic signal changes from green to amber a driver may be so close to the intersection that he cannot stop within the intervening distance, and at the same time so far away that he cannot clear the intersection before the end of the amber signal when the red signal commences. The distance is then said to be within the "Critical Section\( ^{(157)} \) or "Dilemma Zone\( ^{(158)} \)."

In 1947 Greenshields\( ^{(159)} \) et al. studied the effect of the three-second amber period on the traffic flow at a signalised intersection. They selected drivers who were forced to make close decisions as follows: of the vehicles passing through an amber signal, the last would be the most likely to have stopped, while of the vehicles stopping for the red signal, the first would be the most likely to have passed through the preceding amber. They observed the two most important factors which affect the decision of the drivers of these
vehicles - (1) the distance of each vehicle from the intersection, and (2) its speed when the signal changes to amber.

Greenshields et al. introduced the idea of potential time "distance to the stop line divided by the speed of the vehicle to the intersection". They made observations on a 47 close decision cars and found that no vehicle whose potential time was greater than 3.99 sec. passed through the intersection and the majority of the vehicles passing through were less than three seconds from the intersection. Most of the vehicles which stopped were farther than three seconds from the intersection at the time the light changed to amber. For the most part these two groups were distinct with an expected overlap around the three to four second groups.

Olson & Rothery presented observations of motorists' response to the amber phase of traffic signals obtained at normal intersections. They made their observations on those drivers caught near the intersection at the moment the amber phase commences. They wished, in particular, to determine whether the behaviour of motorists in this situation actually does change with significantly different amber phase durations. The results showed that drivers do not tend to take advantage of a long amber phase by treating it as an extension of the green.

Gazis et al. found that the critical distance is independent of the duration of the amber phase, $T_a$, and depends only on the characteristics of the driver car complex (see eqn. 4.3).

*They assumed that subjective factors such as temperament and time urgency of trip to be present in the same proportions thus cancel out because they could not be measured externally in any number of large samples.
Crawford & Taylor\textsuperscript{(157)} described an experiment carried out to examine the reactions of drivers to the change of traffic lights from green to amber and then to red, and also to determine the size and position of critical sections for a range of speeds. The tests were carried out using a specially arranged vehicle-actuated traffic signal at a minor intersection on a high-speed road. For each test run the lights were green when the driver first saw them and he had no idea when, if at all, they would change; the duration of the amber period was three seconds.

The test speeds were 20, 30, 40, 50 and 60mph (32.2, 48.3, 64.4, 80.5 and 96.5kph). Only the test car was on the track during any run and the driver did not have to consider the possibility of being run into by a following vehicle if he stopped suddenly. Nevertheless, he was instructed that all stops made should be comfortable and should not inconvenience his passenger.

The distances from the intersection at which lights turned amber were chosen so that in at least two runs at each speed the driver did not stop but carried on through the intersection. In all, records of 1030 runs were obtained of which 650 were stopping runs.

For a given speed of approach, the beginning of the critical section depends on the stopping distance of the vehicle and the driver's response time. As these are not constant values the distance within which drivers can stop on a proportion of occasions was taken as the measure. In the experiment it was arranged that at some distances all drivers could stop on every occasion they approached at a particular
speed; for the same speed other distances were given which were so short that no one tried to stop. Between these two points lay a zone in which drivers sometimes stopped and sometimes did not. The 50 per cent threshold distance is defined as the distance from the intersection from which on 50 per cent of occasions drivers succeeded in stopping without entering the intersection.

The series of values of distances for successful stops on 50, 80 and 95% of the occasions were plotted and the values of distances for speeds of 20, 30, 40, 50 and 60mph (32.2, 48.3, 64.4, 80.5 and 96.5kph) were estimated and are given in Table 4.1.

Table 4.1 Beginning of critical section: distance of vehicle from the intersection when the lights turned amber for three proportions of successful stops from five speeds.

<table>
<thead>
<tr>
<th>Speed of approach mph (kph)</th>
<th>Distance of vehicle from light ft. (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proportion of Successful Stops</td>
</tr>
<tr>
<td></td>
<td>50%</td>
</tr>
<tr>
<td>---------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>20 (32.2)</td>
<td>47 (15.4)</td>
</tr>
<tr>
<td>30 (48.3)</td>
<td>90 (29.5)</td>
</tr>
<tr>
<td>40 (64.4)</td>
<td>143 (46.9)</td>
</tr>
<tr>
<td>50 (80.5)</td>
<td>204 (66.9)</td>
</tr>
<tr>
<td>60 (96.5)</td>
<td>273 (89.6)</td>
</tr>
</tbody>
</table>

Webster and Ellson\(^{161}\) carried out an experiment to find, for various speeds and distances from the stop line, the proportion of drivers approaching a green signal who were able
to stop satisfactorily when amber appeared.

The experiment was carried out at an intersection specially constructed near one end of an airfield runway about 4000 feet in length.

Five different makes of cars were used and twenty-three drivers with varying degrees of driving experience were tested. Similar instructions were given to drivers as in the previous experiment (Ref.157).

A total of 1522 test runs were made, about 10% of which were in rain or on wet roads. After rejection of all records at speeds outside the tolerance of ± 2mph and those in which the signal stayed green, the remaining 785 runs were formed into five classes by speed, namely 30, 40, 50, 60 and 70mph (48.3, 64.4, 80.5, 96.5 and 112.6kph) respectively. Figure 4.1 shows the relationship between speeds and the percentile values of amber distances for satisfactory stops found during the experiment.

Comparing the values of distances shown in Figure 4.1 with Table 4.1 it can be seen that values obtained by Webster (161) are slightly higher than those found by Crawford and Taylor (157). The reason for this could be that some of Webster's measurements were made in wet conditions.

The problem of drivers' response to amber phase of traffic signal could be summarised as follows: Vehicles approaching a traffic signal face one of two situations either to stop* (start braking) or to proceed**. This can be re-phrased to say that they either face the red or the green light. This

---

* Either the signal is amber and the driver's situation enables him to start braking or it is already red.
** Either the signal is green or it is amber and the driver's situation does not enable him to start braking (sometimes even when the signal is red).
Fig. 4.1  Percentage of Drivers Stopping Satisfactorily from Various Distances from the Stop-line When the Amber Signal Appeared

(The figures against the experimental points indicate the number of runs)
statement is applicable to vehicles approaching traffic signals while they are changing from green to amber because they have to decide either to stop or to go (which depends on many factors such as their speed, position, etc., as explained above). For this reason the amber period (which is standardized by The Ministry of Transport at 3 seconds\(^{162}\)) is added to the red period, in the present model, and drivers' responses to it are taken into account as explained above.

Table 4.1 has been chosen to be incorporated into the model for the following reasons:

1. Speed values have been measured down to 20mph as this value is important in urban areas.
2. No measurements were carried out under wet road conditions (the present model does not take such conditions into consideration because under wet conditions noise emitted by vehicles is different from that of dry conditions.

A random fraction (between 0-1) is generated whenever the signal changes from green to amber. Vehicles' positions on the road are checked in turn starting from the first one at the head of the queue until the first vehicle behind the stop line is determined. The generated random number, the distance of the determined vehicle from the stop line and its speed are compared with the values given in Table 4.1. Whether the vehicle stops or proceeds will depend on these values.
If the driver decides to go, the following vehicle (the second behind the stop line) is considered and this procedure is repeated until the first vehicle to start braking is found. However, it should be mentioned that the following vehicles have smaller chance to proceed through the amber period than those in front of them, mainly because of their positions (see Table 4.1).

Once the first vehicle to start braking is determined, it starts braking immediately (i.e. reaction time is not taken into account because (1) it is thought that it is already accounted for in the results of the experiments, (2) it only complicates the model and (3) it does not affect noise levels). Vehicle deceleration performance is explained in the next section.

4.2.2 Deceleration Performance

Braking distance may be defined as the distance required to bring a moving vehicle to a complete stop after the brakes have been fully applied.

Mathematically, braking distance on a level roadway is given by expression $\frac{X^2}{2X}$ when $X$ is the velocity of the vehicle and $X$ is the rate of deceleration$^*$. Gazis et al (158) discussed in considerable detail a problem associated with the amber signal light in traffic flow. In order to carry out a mathematical investigation of the problem they assumed a constant acceleration $X_1$ in the case of crossing the intersection, or a constant deceleration $X_2$ in the case of stopping before the intersection.

$^*$Deceleration $X = fg$, where $f = \text{coefficient of friction between vehicle and road surface, and } g \text{ the gravitational constant.}$
If the driver is to come to a complete stop before entering the intersection, they found that

\[(X - X_0 T_2) \geq \frac{X_0^2}{2X_2} \quad 4.1\]

where \(X\) is the distance of the vehicle from the intersection when the amber period commences

\(X_0\) is the constant speed at which the vehicle is travelling towards the intersection

\(T_2\) is the reaction time-lag of the driver-car complex as well as the decision-making time of the driver.

Solving eqn. 4.1 for \(X_2\) assuming the equality sign:

\[X_2 = \frac{\frac{1}{2} X_0}{(X - X_0 T_2)} \quad 4.2\]

Eqn. 4.2 gives the (constant) deceleration needed in order to bring the vehicle to a stop just before the intersection as a function of the distance of the car from the intersection at the initiation of the amber phase. For \(X = X_0 T_2\), \(X_2\) becomes infinite, however, even for values of \(X\) greater than \(X_0 T_2\), the deceleration given by (4.2) while finite, may be unsafe under the prevailing road conditions, or even physically impossible.

Assuming the existence of a maximum deceleration \(X_2^*\) by which the car can be brought to a stop before the intersection safely and comfortably, eqn. (4.1) defines a "Critical distance", namely:
If \( x > x_c \) the car can be stopped before the intersection, but if \( x < x_c \) it will be uncomfortable, unsafe, or impossible to stop.

Beakey (164) made a study to determine maximum acceleration for passenger cars and their free-wheeling and high-gear deceleration under test conditions. Investigation was also made of acceleration and deceleration under running conditions.

He found that high-gear deceleration was affected by the same forces affecting free-wheeling deceleration, but with the additional factor of friction and compression of the motor. Deceleration increased with speed at a rate greater than the first power of the speed, air resistance being the most responsible factor.

Beakey (164) suggested that it is very difficult to compute, from many observations of individual cases, values of deceleration or acceleration that would be representative of those employed by the average driver when stopping his vehicle or accelerating to normal driving speed.

A series of tests to determine average deceleration rates under several types of decelerating conditions was made by Wilson (163). The first series was made to determine the maximum average deceleration rates obtainable. The second series was made to determine deceleration rates with only engine braking, air and rolling resistance supplying the decelerating forces. The third series evaluated the decelerating effects of air and rolling resistance alone. A fourth test was made to evaluate comfort factors for passengers and the driver.
The results of deceleration where only the engine braking was used showed that the deceleration rate varies with speed where the engine was used as a brake. These deceleration rates would be the same regardless of the speed from which the deceleration starts. That is, if the test had been started at 50 or 60mph (80.5 or 96.5kph) instead of 70mph (112.6kph), the deceleration rate at 30mph (48.3kph) would be the same.

Decelerations of the order of 3.2ft/sec.\(^2\) (1.05m/sec.\(^2\)) were obtained at 70mph (112.6kph) but the values dropped to 0.8ft/sec.\(^2\) (0.26m/sec.\(^2\)) at 10mph (16.1kph). When evaluating the decelerating effects of air and rolling resistance alone, about 1.75ft/sec.\(^2\) (0.57m/sec.\(^2\)) deceleration at 70mph (112.6kph) and about 0.37ft/sec.\(^2\) (0.12m/sec.\(^2\)) at 10mph were obtained under test conditions.

Greenshields et al(159) calculated the deceleration rates by measuring the distance required to stop from high initial speeds. Fluctuations were not measured so that overall averages alone were determined. Results of their work are given in section 4.2.3.

In the traffic flow model there are two possibilities for the first vehicle to start braking when the light changes to amber:

Case 1

It is the first one behind the signal (the first vehicle to see the signal changes) and in this case it starts braking immediately as mentioned in the previous section. This means that reaction time = 0 (see eqns. 4.2 and 4.3). This has been
done because reaction time has been indirectly included by
the introduction of random process in the response to amber period.

In this case, an imaginary idling vehicle is introduced
at the stop line, i.e. a vehicle with a) distance = 0,
b) speed = 0, c) acceleration = 0. Then the car-following
theory is modified accordingly and values of deceleration for
the first vehicle to start braking are calculated from the modi­
ified car-following model whenever required until the car
stops, or proceeds if the signal changes to green.

The modified car-following model is:

\[ x_{n+1}(t+T) = A \left( \frac{x_{n+1}(t)}{x_{n+1}(t)} \right)^m \]  \hspace{1cm} (4.4)

In order to make deceleration values as accurate as
possible, it is believed that they should be a function of
\( V^2 \) and \( S (x^2 \text{ and } x) \) as explained previously.

The best way to achieve this was found by choosing appro­
priate values for \( m, l \) and \( A \) for the car-following model
(eqn. 4.4). This has been done by setting:

\[ m = 1, \quad l = 1, \quad A = 0.5 \]

These values have been used throughout this work; however,
they can be altered as required since they are used as input
parameters.
Case 2

It is not the first vehicle behind the stop line. In this case it follows the vehicle in front of it (according to the car-following theory and its limits) until it becomes the first one behind the signal and starts braking as explained in the previous case.

When the first vehicle to brake approaches very close to the stop line it will have a small value of speed and distance (to the stop line), which means dividing two very small values. The effect of this operation was found in early running tests to show some oscillation in the model. For this reason, some kind of restraint was required and this has been achieved by stopping the vehicle whose distance falls below a predetermined value. This predetermined value has to be as close as possible to reality and is therefore taken as 1 metre.

The same procedure has been adopted for following vehicles, whenever a vehicle reaches very close to its queueing position (which depends on the length and spacing of all vehicles in front of it) it is forced to stop to avoid any oscillation in the model.

4.2.3 Maximum Deceleration

Beakéy (164) found that in each group (see previous section) maximum deceleration occurred in the last few feet of the stopping manoeuvre, the greater rate being used by the higher speed drivers. However, only vehicles in the higher speed groups exceeded a rate of deceleration of 8mph/sec. (3.6m/sec.²). Indications were that 9mph/sec. (4.0m/sec.²)
might be considered the maximum rate of deceleration that can be used without discomfort to the passengers.

Wilson (163) used test speeds of 50, 60 and 70mph (80.5, 96.5 and 112.5kph) in order to determine the maximum average deceleration rates obtainable. The average deceleration rates were between 19 and 22ft/sec.\(^2\) (6.23 to 7.22m/sec.\(^2\)).

In evaluating comfort factors for passengers and driver the reactions of the observers were that about 8.55ft/sec.\(^2\) (2.81m/sec.\(^2\)) average deceleration produced a comfortable stop. Average deceleration of 11.05ft/sec.\(^2\) (3.63m/sec.\(^2\)) was undesirable and somewhat uncomfortable. The driver would rather not use this rate of deceleration. Rates of 13.90ft/sec.\(^2\) (4.56m/sec.\(^2\)) were considered very undesirable by the passengers and any loose articles resting on the seats were thrown off onto the floor. This rate becomes dangerous to the passengers. He concluded that highway design should be based on the comfort figure wherever possible; for example, sight distances should be calculated for average deceleration rates of 8.5 - 9.00ft/sec.\(^2\) (2.81-2.95m/sec.\(^2\)) rather than, say, the maximum capability figure of 19-22ft/sec.\(^2\)(6.23-7.22m/sec.\(^2\)).

Hammond (165) summarised the recommended deceleration values for different American organisations. The American Association of State Highway Officials assumed a deceleration of 12.9ft/sec.\(^2\) (4.23m/sec.\(^2\)) for all intersections (a friction factor of 0.4). Bureau of Standards tests indicated a rate of deceleration of 16.1ft/sec.\(^2\) (5.28m/sec.\(^2\)) as the maximum for comfort and the Motor Vehicle Department of New Jersey assumed as a comfortable rate of deceleration, 17.4ft/sec.\(^2\) (5.71m/sec.\(^2\)). The National Safety Council had adopted a deceleration rate of 17ft/sec. (5.58m/sec.\(^2\))
Greenshields et al (158) found that maximum average decelerations occur between 5 and 10 ft. (1.64 to 3.28 m) from stop, ranged from 6.3 ft/sec.² (2.07 m/sec.²) for buses to about 4 ft/sec.² (1.31 m/sec.²) for trucks. The maximum values for passenger cars at different locations varied from 4.6 to 5.5 ft/sec.² (1.51 to 1.80 m/sec.²).

Dart (143) allowed an independent or lead vehicle approaching the intersection with a signal indication of red initially to decelerate at no more than 3.5 ft/sec.² (1.15 m/sec.²). When vehicles were decelerating to a stop in response to yellow phase display or slowing behind much slower vehicles, deceleration rates approaching 12 ft/sec.² (3.94 m/sec.²) as a maximum were permitted.

Hobbs (166) stated that rates of deceleration usually range from 1 to 3 m/sec.² on initial slowing down with a final braking to a stop of up to 3.5 m/sec.². Rates in excess of this figure cause discomfort for standing passengers in buses and beyond 5 m/sec.² actual danger may occur due to loose objects sliding about the vehicle. Emergency stops where rates exceed 6 m/sec.² and approach 10 m/sec.² on some surfaces may cause injury to vehicle occupants.

Table 4.2 shows a summary of the results of maximum deceleration values found or reported by different workers.

A reasonable figure for deceleration had to be chosen so that safe stopping can be achieved; at the same time this figure had to be realistic in the sense that some people do use fairly high deceleration rates when the signal changes to amber.
### Table 4.2 Summary of Deceleration Studies

<table>
<thead>
<tr>
<th>Worker</th>
<th>Deceleration Value m/s²</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bealey (164)</td>
<td>4.02</td>
<td>Max. rate of deceleration can be used without discomfort to the passengers.</td>
</tr>
<tr>
<td>Wilson (163)</td>
<td>5.79 – 6.71</td>
<td>Max. av. deceleration rates obtainable (Test Speeds 50, 60 and 70mph – 80.45, 96.54 and 112.63kph).</td>
</tr>
<tr>
<td></td>
<td>2.61</td>
<td>Av. deceleration produced comfortable stop.</td>
</tr>
<tr>
<td></td>
<td>3.37</td>
<td>Undesirable and somewhat uncomfortable.</td>
</tr>
<tr>
<td></td>
<td>4.24</td>
<td>Very undesirable by passenger.</td>
</tr>
<tr>
<td>Hammond (165)</td>
<td>3.93</td>
<td>Deceleration rates for all intersections &quot;American Assoc. of State Highway Officials&quot;.</td>
</tr>
<tr>
<td></td>
<td>4.9</td>
<td>Max. deceleration for comfort &quot;Bureau of Standards&quot;.</td>
</tr>
<tr>
<td></td>
<td>5.3</td>
<td>A comfortable rate of deceleration &quot;Vehicle Dept. of New Jersey&quot;.</td>
</tr>
<tr>
<td></td>
<td>5.18</td>
<td>Adopted deceleration rate &quot;National Safety Council&quot;.</td>
</tr>
<tr>
<td>Greenshields (159)</td>
<td>1.92 – 1.68</td>
<td>For buses.</td>
</tr>
<tr>
<td>Dart (143)</td>
<td>1.07</td>
<td>Initial deceleration.</td>
</tr>
<tr>
<td></td>
<td>3.66</td>
<td>Max. deceleration</td>
</tr>
<tr>
<td>Hobbs (166)</td>
<td>1–3 m/s²</td>
<td>Initial deceleration</td>
</tr>
<tr>
<td></td>
<td>3.5</td>
<td>Final braking</td>
</tr>
<tr>
<td></td>
<td>3.5–5</td>
<td>Discomfort for standing passengers in buses.</td>
</tr>
<tr>
<td></td>
<td>5–6</td>
<td>Actual danger may occur due to loose objects sliding about in the vehicle.</td>
</tr>
<tr>
<td></td>
<td>6–10</td>
<td>Emergency stops may cause injury to vehicle occupants</td>
</tr>
</tbody>
</table>
For the above-mentioned reasons, a maximum deceleration rate of \( \frac{5 \text{m}}{\text{sec}^2} \) has been specified in the model and no vehicle can exceed this rate of deceleration. However, no restraints have been used on initial deceleration and vehicles always decelerate according to the car-following theory.

4.3 STARTING PERFORMANCE

As the signal changes from red to green, the number of waiting vehicles that can cross the intersection in a given time depends in the simple case on how soon they move after the signal has changed, and on how they accelerate. The driver of the first vehicle reacts to the signal change or the clearance of the intersection and then each driver in turn reacts until the ripple of motion has travelled to the tail car of the queue, with the progress of the wave of motion depending on individual reaction times.

4.3.1 Reaction Time

This is defined as the time which elapses between the reception of an external stimulus and the taking of an appropriate action and necessarily includes perception time*. Brake reaction time is composed of perception time, foot transfer time, and any time lag in the brake actuation.

In the U.S.A. Report of Committee on Safe Approach Speeds at Intersections from replies received from a questionnaire showed the following assumed reaction times in use at the time (165).

*In the case of a subject undergoing a simple test, where he anticipates the receipt of a signal stimulus and is required to operate a switch, the time measurement is known as response time.
Ashworth (167) states that reaction time varies within the range of 0.25 to 2 seconds for majority of drivers and he considered the latter figure as a satisfactory basis for geometric design.

Hobbs (166) states that typical brake reaction time for individuals varies from about 0.25 sec. to about 1.0 sec. in ordinary traffic conditions. The time is likely to be halved if the stimulus is expected and doubled for a weak stimulus.

In the present model, the time at which vehicles start to get into motion has been assumed to be composed of two values:

a. a constant value which has been specified as 1 sec., and

b. a variable which has been assumed as the difference between the distance of the vehicle under consideration from the one in front of it divided by the desired speed of the vehicle under consideration.
Mathematically:

\[ RT = C_r + \frac{X_n(t) - X_{n+1}(t)}{X_{\text{des.}}(n+1)} \]  

where \( RT \) = time at which vehicles get into motion (sec.), 
\( C_r \) = constant taken as 1 sec., 
\( n+1 \) = the vehicle under consideration (\( X_n(t) \) and \( X_{\text{des.}} \) as defined previously)

Eqn. 4.5 means that the vehicle at the head of the queue starts to move 1 second after the signal changes to green (no vehicle in front of it and its queueing position nominally at the stop line). The equation also means that if the vehicle is queueing behind a long vehicle, e.g. HCV, then it takes longer to get into motion than a vehicle queueing behind a small one. The higher the desired speed of the vehicle the faster it gets into motion.

The above assumption has been found quite realistic, producing results similar to those encountered in real life (see Chapter 7).

4.3.2 Starting Performance of the Vehicle at the Head of the Queue

Pipes (124) considered three types of acceleration of the leading vehicle of a line of vehicles moving from rest. These three types are:

1. Impulse acceleration
2. Exponential acceleration
3. Constant acceleration

The second type is the most realistic of the three and given as:

\[ X_1(t) = CX_{\text{des}}e^{-Ct} \]

where \( C \) is a constant having dimensions of \( \text{sec}^{-1} \). Since it is supposed that at \( t=0 \) the velocity is standing still, this leads to the following variation of velocity:

\[ X_1 = X_{\text{des}}(1 - e^{-Ct}) \]

However, the third type of acceleration of the leading vehicle given by Pipes has been used by some researchers. Davies, Grecco and Heathington used the following model for non-following vehicles (e.g. vehicles at the head of the queue being discharged from a signal).

\[ \text{Acc}(J, I+T) = K(T_{\text{vel}}(J) - \text{Vel}(J, I)) \]

where \( \text{Acc}(J, I+T) = \frac{\dot{X}}{X_{\text{des}}} \times n(t+T) \) = Acceleration of car \( J \) initiated at time \( I+T \) (acceleration of vehicle \( n \) at time \( t+T \))

\[ K = \frac{\dot{X}_\text{max}}{X_{\text{des}}} = C = \text{Proportionality coefficient} \] (\( \dot{X}_\text{max} \) is maximum acceleration, and \( X_{\text{des}} \) is desired speed)

\[ T_{\text{vel}}(J) = \dot{X}_{\text{des}}(n) = \text{Target velocity of car } J \text{ (desired velocity of vehicle } n \text{) and} \]
\( \text{Vel}(J,I) = \dot{X}_n(t) = \text{Velocity of car J at time I} \)

(velocity of vehicle n at time \( t \))

This model is the same as the second type model given by Pipes \(^{(124)}\) i.e. exponential model as will be seen.

This exponential acceleration model has been used in the present work as the free-behaviour model.

Integrating eqn. 4.7 gives the distance travelled:

\[
X(t) = \int \dot{X}_{\text{des}}(1 - e^{-Ct}) dt
\]

\[
= \dot{X}_{\text{des}}(t + e^{-Ct/C}) + K
\]

When \( t = 0 \), \( X = 0 \)

\[
K = -\frac{\dot{X}_{\text{des}}}{C}
\]

\[
X(t) = (Ct + e^{-Ct} - 1) \frac{\dot{X}_{\text{des}}}{C}
\]

When \( t = 0 \), Acceleration (\( \ddot{X} \)) = Starting Acceleration (Maximum acceleration) = \( \ddot{X}_{\text{max}} \). Substitute in eqn. 4.6 gives:

\[
\ddot{X}_{\text{max}} = \ddot{X}(0) = C \dot{X}_{\text{des}}
\]

\[
C = \frac{\ddot{X}_{\text{max}}}{\dot{X}_{\text{des}}}
\]

\[
\dddot{X}(t) = \dddot{X}_{\text{max}} e^{-Ct}
\]
Rewriting eqn. (4.7)

\[ X(t) = \dot{X}_{\text{des}} (1 - e^{-Ct}) \]  

\[ \dot{X}_{\text{des}} e^{-Ct} = \ddot{X}_{\text{des}} - \dot{X}(t) = \dddot{X}(t) / C \]

Thus

\[ \dddot{X}(t) = C \ddot{X}_{\text{des}} - C \dot{X}(t) \]

Put \( C \ddot{X}_{\text{des}} = \dddot{X}_{\max} \) and \( C = \dddot{X}_{\max} / \dddot{X}_{\text{des}} \)

Therefore

\[ \dddot{X}(t) = \dddot{X}_{\max} \left( 1 - \frac{\dot{X}(t)}{\dddot{X}_{\text{des}}} \right) \]

This model has been used to describe the acceleration of all free-flowing vehicles, whether they are ahead of queues or more than 50m away from the ones in front of them (see Section 3.15). Equations 4.7' and 4.8 have been used to describe the distance travelled and instantaneous speed of the vehicle at the head of the queue; however, if the distance between it and the one ahead of it (if there is still one in the system) becomes less than 50m, it would be governed by the car-following theory.

4.4.3 Starting Performance of Following Vehicles

Forchhammer (170) studied two different cases of starting performance:
1. When all drivers start with constant acceleration of 1.11 m/sec$^2$. The distances between stationary vehicles in the queue were assumed constant and so is the time interval between starts of successive vehicles.

2. Using the reciprocal spacing car-following model:

$$\ddot{x}_{n+1}(t+T) = A_1 \frac{x_n(t) - x_{n+1}(t)}{x_n(t) - x_{n+1}(t)}$$

He used 10 as the value of the constant $A_1$ and introduced a maximum value of acceleration as a kind of target for the driver's intentions during starting performance $\ddot{x} \leq 1.1$ m/sec$^2$.

It can be seen that eqn. 4.10 is a special case of the general car-following model adopted in the present work ($m=0$, $l=1$ and $A=10$). This model (4.10) has been adopted because it is derived from the generalised form and also because the generalised form cannot be used to start off idling vehicles with speed equal to zero ($x_{n+1}(t) = 0$) as the acceleration will be zero (see eqn. 3.29).
CHAPTER 5  SIGNALISED INTERSECTIONS MODELS

5.1 GENERAL

The control of city traffic began in London with the installation of the first traffic light, gas powered, in 1968. As a result of a gas explosion the experiment was abandoned until the advent of the first electrically-powered, manually operated, traffic signal in New York City in 1918. During the 1920's, fixed time (f.t) traffic signals (with preset green and red times) were being installed both in the U.S.A. and Britain. In 1932 the first vehicle-actuated (v.a) signals were installed in London at the junction of Gracechurch Street and Cornhill. Such signals provided a minimum green time which could be extended up to a maximum value as a function of the number of vehicles passing over a pneumatic detector pad situated in the road adjacent to the signal. These signals had become traffic-responsive and a primitive feedback system had been employed.

The total number of traffic signals installed in the U.K. is about 10000. Keeping in mind that most of these sets are concentrated in urban areas (about 6000), it must be realised that investigating their effect on the environment is a worthwhile task.

5.2 A SINGLE SIGNALISED INTERSECTION MODEL

Using the interrupted flow principles explained in the previous Chapter, a single isolated signalised intersection model has been built. The model is capable of dealing with an
intersection which has up to eight lanes running through it. The model is also capable of handling signalised 'T' inter­
sections (see Chapter 7). It is believed that the model could also be used to deal with mini-roundabouts when they are oper­
at ing at or near saturation conditions, although no work was done on this application. It is known that mini-roundabouts behave like signalised intersections when they operate under the above conditions.

The following assumptions have been made:

1. The intersection operates on a fixed time (f.t) basis. The main reasons behind this assumption are:
   a. Vehicle-actuated signalised intersections under high flow conditions operate on fixed time cycles. High and medium flow conditions are considered the prime objective of the present study.
   b. The trend in the U.K. and most other countries is to move towards Urban Traffic Control (UTC) systems wherever a number of signalised intersect­ions exist close to each other. Most intersections in UTC systems operate on f.t. basis.

2. The cycle time of the intersection is known because:
   a. The cycle is f.t.
   b. The Local Authority who would require noise levels would have predetermined the details of the cycle from flow considerations.
   c. Cycle time is a parameter, under the operator's control, which affects noise level (see Chapter 8).

3. Right and left turning traffic are accounted for by
adding them to the appropriate approach in the data input. This assumption was made for the following reasons:

a. It was realised from the beginning that some of the turning movements are very difficult to simulate and they would have required a major effort if they had been done properly. Indeed Dart (143) carried out his entire Ph.D. project on the simulation of the right turning movement "left turning for other countries". A detailed discussion was made at the start of the work, after which it was decided that adding the turning traffic to the appropriate approach would accommodate all the important noise factors such as accelerating vehicles.

b. Jones (171) made about 250 simulation runs with turning movements built into his model to investigate the problem. These runs did not show any significant difference from the ones which were made without turning movement.

c. It was aimed to extend the model for linked traffic signals for which turning traffic would have complicated the problem even further.

4. Overtaking was not built into the model for the following reasons:

a. Overtaking is not very common in urban areas especially if the approach consists of two lanes—two-way. In the case of four lanes, two-way approach, it is most likely that vehicles overtaking (usually
running in the inner lane before they overtake) will remain in the outer lane after overtaking. Noise levels are calculated for each lane separately and the above effect is already accounted for.

b. The effect of overtaking may result in a screening effect on the overtaking vehicles from those being overtaken. To investigate the possibility of such an effect, an experiment was carried out on the University campus. During the experiment two vehicles were run at constant speed parallel to each other, then each vehicle was run separately at the same speed on the same lane. Noise levels were recorded for all three cases and it was found that the screening effect was negligible.

As the above-mentioned experiment was a limited one, it is suggested that, if at some future date such screening effect be found significant, the following procedure could be adopted and used in modelling:

Assume:

The total flow on a two-lane (one-way approach) = Q
Flow on outer lane = \( q_o \)
Noise level emitted by individual vehicles = \( N_L V \)
Proportion of vehicles screened = \( P \)
Noise level reaching the observation point from screened vehicles = \( N_L S_V \)
In order to use the above in the model:

A uniform random fraction (RF) is generated and compared with P.  

IF \( \text{RF} \leq P \), the noise level from this vehicle reaching the observation point = \( NLS_v \)  

IF \( \text{RF} > P \), the noise level from this vehicle reaching the observation point = \( NL_v \)  

Flow on outer lane = \( Pq_o + (1-P)q_o \)  

When calculating noise levels \( Pq_o \) will be multiplied by \( NLS_v \) (this gives the number of calculated noise levels from screened vehicles) while \( (1-P)q_o \) is multiplied by \( NL_v \).  
The values \( NLS_v \) and \( P \) would have to be determined by controlled experiments.  

5.2.1 Rules of Operation  

1. All roads running through the intersection are dry, straight and level.  
2. There was no pedestrian interference in the intersection.  
3. The position of each vehicle in the system was referenced to its front bumper.  
4. The intersection operates on a fixed time (f.t) basis.  
5. The cycle time is known.  
6. Turning movements are added to the appropriate streams.  
7. There was no overtaking.  
8. There were no shieldings, reflections or excessive attenuation.  
9. There was no extraneous noise apart from the specified background.
5.2.2 Flow Chart and Subroutines Description

Figure 5.1 shows the flow chart of the single signalised intersection model.

The functions and subroutines incorporated in the model are:

1. Function GSNEX*: This function generates random gaps according to the shifted negative exponential distribution.
2. Subroutine INITIAL *: This subroutine determines whether the arriving vehicle is a light or an HCV, giving it its length, desired speed and maximum acceleration, it also calculates its position, speed and acceleration.
3. Subroutine RELTDIS: It calculates the relative distance between any two vehicles. This relative distance is then used to determine whether the vehicle is accelerating freely or is controlled by the car-following theory.
4. Subroutine WHICH: It finds the first vehicle behind the stop line which starts braking as the signal changes to red.
5. Subroutine STOP: This subroutine stops the vehicle if it has passed its predetermined queueing position.
6. Subroutine QUEUE: Calculates the position of each queueing vehicle behind the stop line.
7. Subroutine COUNTER: Which calculates the number of queueing vehicles at the beginning of the green. Each vehicle with speed $< 0.1 \text{m/sec.}$ and acceleration $<0.1 \text{m/sec.}^2$ is considered idling.
Fig. 5.1 Flow Chart for the SimulSised Intersection Model SCIIMOSI
8. Subroutine FIRST: This subroutine calculates the distance, speed and acceleration of each vehicle which has been at the head of the queue when the signal is showing red.

9. Subroutine START: This subroutine gives idling vehicles (not the one at the head of the queue) their initial values (distance, speed and acceleration) as they start to get into motion.

10. Subroutine DISTANCE: Calculates the position of each vehicle with respect to the observer. This distance is then used by "NOISE" to calculate the attenuation.

11. Subroutine NOISE*: Once a noise sample is required, this subroutine calculates the noise emitted by each vehicle corrected to acceleration and distance, then it takes a noise reading and stores it for the noise history and "INDICES".

12. Subroutine CORRECT: This subroutine calculates the exact number of vehicles which have passed the first observation point in each lane and from these values the achieved flow and percentages of heavies on each lane are calculated and printed.

*Subroutines developed in free flow model (Chapter 3).
A detailed list of the required data input and output options are given in Appendix 6A, but the main values are shown in Table 5.1.
The listing of the program is given in Appendix 6B.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
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<tr>
<td>B</td>
<td>Values of Table 4.1 converted into m/sec. and meters, see Appendix 6.A</td>
</tr>
<tr>
<td>STNM*</td>
<td></td>
</tr>
<tr>
<td>NTIME*</td>
<td></td>
</tr>
<tr>
<td>NOBSP</td>
<td></td>
</tr>
<tr>
<td>NCGS</td>
<td>Number of vehicles categories to be used.</td>
</tr>
<tr>
<td>NNLI</td>
<td>Number of lanes in near stream (studied approach)</td>
</tr>
<tr>
<td>NNL2</td>
<td>Number of lanes in far stream (studied approach)</td>
</tr>
<tr>
<td>NCL1</td>
<td>Number of near cross lanes</td>
</tr>
<tr>
<td>NCL2</td>
<td>Number of far cross lanes</td>
</tr>
<tr>
<td>WN</td>
<td>Width of lane (studied approach)</td>
</tr>
<tr>
<td>WC</td>
<td>Width of cross lane</td>
</tr>
<tr>
<td>DMIC*</td>
<td></td>
</tr>
<tr>
<td>DOPTN*</td>
<td>Distance of observation point from studied approach (m)</td>
</tr>
<tr>
<td>DOPTC</td>
<td>Distance of observation point from cross flow (m)</td>
</tr>
<tr>
<td>NPHASE</td>
<td>Number of phases in the cycle of the signal</td>
</tr>
<tr>
<td>INTG</td>
<td>Intergreen time (sec.) (see Ref.)</td>
</tr>
<tr>
<td>GREEN</td>
<td>Green time (sec.)</td>
</tr>
<tr>
<td>CYCLE</td>
<td>Cycle time (sec.)</td>
</tr>
<tr>
<td>RED</td>
<td>As above</td>
</tr>
<tr>
<td>Cycle</td>
<td>Red time (sec.)</td>
</tr>
<tr>
<td>NB</td>
<td>1 if signal displays green</td>
</tr>
<tr>
<td></td>
<td>2 if signal displays red</td>
</tr>
<tr>
<td>TCCS</td>
<td>Time at which the cycle has to start</td>
</tr>
</tbody>
</table>

These values are required if NPHASE = 2
Table 5.1 continued

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>MM*</td>
<td>Percent of medium vehicles</td>
</tr>
<tr>
<td>LL*</td>
<td>Standard deviation of light vehicles speed (m/sec.)</td>
</tr>
<tr>
<td>A*</td>
<td>Standard deviation of HCV speed (m/sec.)</td>
</tr>
<tr>
<td>MNG*</td>
<td>Standard deviation of light vehicles acceleration (m/sec.²)</td>
</tr>
<tr>
<td>Q*</td>
<td>Standard deviation of HCV acceleration (m/sec.²)</td>
</tr>
<tr>
<td>PCM</td>
<td>Medium vehicles mean speed (m/sec.)</td>
</tr>
<tr>
<td>PCH*</td>
<td>Standard deviation of medium vehicles speed</td>
</tr>
<tr>
<td>CMS*</td>
<td>Medium vehicles acceleration (m/sec.²)</td>
</tr>
<tr>
<td>SDCS</td>
<td>Standard deviation of medium vehicles acceleration</td>
</tr>
<tr>
<td>HMS*</td>
<td>Values of variables MM to SDMA are fed for each lane</td>
</tr>
<tr>
<td>SDHC</td>
<td></td>
</tr>
<tr>
<td>CACC*</td>
<td></td>
</tr>
<tr>
<td>SDCA</td>
<td></td>
</tr>
<tr>
<td>HACC*</td>
<td></td>
</tr>
<tr>
<td>SDHA</td>
<td></td>
</tr>
<tr>
<td>MMS</td>
<td></td>
</tr>
<tr>
<td>SDMS</td>
<td></td>
</tr>
<tr>
<td>MACC</td>
<td></td>
</tr>
<tr>
<td>SDMA</td>
<td></td>
</tr>
<tr>
<td>BT</td>
<td>Value of the constant part of the reaction time (sec.)</td>
</tr>
<tr>
<td>S*</td>
<td></td>
</tr>
<tr>
<td>FR</td>
<td>Number of scan intervals in 1 sec.</td>
</tr>
<tr>
<td>IST</td>
<td>Interval at which noise sample is required (sec.)</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>IAEFO</td>
<td>Test parameter takes the number of the policy required to be implemented (see Section 8.4)</td>
</tr>
<tr>
<td>LPRT*</td>
<td></td>
</tr>
<tr>
<td>IOUT*</td>
<td></td>
</tr>
</tbody>
</table>

* As specified in Table 3.12
5.3 LINKING OF TRAFFIC SIGNALS AND URBAN TRAFFIC CONTROL (UTC) SYSTEMS

5.3.1 Historical Introduction

Progress in signalised intersections was continued with linked systems installed in 1935 in London and Glasgow. Such systems provided an offset to the initiation of the green period of successive signals along a road in order that vehicles travelling at an optimum speed would pass unhindered through a series of traffic junctions. Some of the forms of linking of signalised intersections are: Simultaneous System (synchronised system) and Alternate System (limited progressive system).

During the late 1950's increasing concern was felt in a number of cities in various parts of the world at the mounting traffic problem. The possibility of computer control of the traffic signals of a city, or a significant fraction of a city, on a systematic basis was investigated.

The first UTC system was installed in Toronto, Canada in 1963 and has been progressively expanded so that in 1975 there were over 1000 intersections under monitoring and control. The second UTC system became operational in San Jose, U.S.A. in the mid-1960's and was the site of a number of pioneering experiments in Urban Traffic Control.

By the year 1975 there were about 70 operational UTC systems in the world. Over 100 more were being installed or in advanced stages of planning. About half of these systems were in the U.S.A. - Japan and Germany have large numbers of UTC systems (172). Some developing countries are moving towards
this direction; Baghdad's UTC system started operation early this year\(^7\). The main function of the majority of these UTC systems is to improve the flow of traffic by better control of the signalised intersections.

In Great Britain UTC systems were installed by TRRL in Glasgow in 1967 and by the (then) Ministry of Transport in West London in 1968. Both systems were designed to be used for traffic control experiments. In 1975, there were UTC systems operating in Glasgow, Central and West London, Liverpool and Leicester. Leicester became operational in 1974 and was the first system to be installed in accordance with specifications drawn up by the Department of Environment for national use. Plate 5.1 shows the control room of the Leicester UTC system. It is expected that, by 1980, UTC systems will be installed in about 15 to 20 cities of Great Britain.

5.3.2 A Pair of Signalised Intersections

When simulating a single isolated intersection it is generally assumed that vehicle arrivals follow a Poisson distribution; Negative Exponential distribution or Shifted Negative Exponential distribution. For an intersection within a network, however, vehicle arrivals are no longer random, but are dependent upon the departure pattern from the adjacent intersection. It is observed in practice that vehicles leave a signalised intersection in the form of platoons which spread out or disperse as the vehicles travel towards the neighbouring intersection.

One of the problems that arise when setting up any large-scale area network simulation is that of modelling traffic flow along link roads in the network. From the noise viewpoint
Plate 5.1  The Control Room of Leicester UTC System
a pair of intersections give all the possible changes in the traffic, i.e. random and deterministic arrivals.

A vehicle entering the system on the main road is under the control of the first intersection until it crosses over the centre-line of the first cross traffic lane, after which its movement is controlled by the second intersection as shown in Figure 5.2.

The model is capable of simulating up to four lanes on the main stream and two lanes (two-way or one-way) on each side road. Noise levels can be monitored at any point along the set-up, with up to four points at any one time (68), (185).

The pair of intersections can be linked together to test, in a controlled manner, different linking systems and can also be used to test some UTC systems as well as some traffic management schemes.
This third model which has been built is a simulation of a pair of signalised intersections in which vehicles arriving at the second intersection are related to the platoons leaving the first. Provided that the theories used to describe vehicle behaviour in the previous sections are accurate, this model will give an accurate representation of journey time and vehicle speed for a linked pair of intersections. This approach has avoided the incorporation of additional theories into the model such as platoon dispersion (173).

5.3.3 Rules of Operation

1. The main road and both side roads, which run through both intersections were dry, straight and level.
2. There was no pedestrian interference in either intersection.
3. The position of each vehicle in the system was referenced to its front bumper.
4. The intersections operate on fixed time basis.
5. Both intersections run on two phase cycles and cycle times are known.
6. A vehicle on the main approach becomes under the control of the second intersection once it has crossed over the centre-line of the first cross traffic lane.
7. There was no overtaking.
8. No shieldings, reflections of excessive attenuation exist in the system.
9. There was no extraneous noise apart from the specified background.

5.3.4 Flow Chart and Subroutines Description

Figure 5.3 shows the flow chart of the pair of intersections model.

The same subroutines developed for the single signalised intersection model (see Section 5.2.2) are used in the pair of intersections model; however, some of them required minor modifications to cope with eight lanes while others required major modifications due to the new set-up, e.g. subroutine DISTANCE.

Due to the complexity of the model it was felt necessary to split another subroutine from the main program segment. Subroutine UPDATE was developed which carried out the updating of distances, speeds and accelerations of all vehicles on all lanes.

A detailed list of the required data input and output options are given in Appendix 7A but the main values are shown in Table 5.2.

The program listing is given in Appendix 7B.
Input Data

Calculate 1st Gap

\[ T = T + 0.25 \]

Is a veh. arriving?

\[ N = N + 1 \]
\[ NVS = NVS + 1 \]

Calculate initial values, des. speed & max. accn.

\[ I = I + 1 \]
\[ I = 0 \]
Near Studied Lane?
Far Studied Lanes

Update distance, speed & acc. according to signal display for this lane

CALL NOISE

Vehicles 1,2,...I-1
Under Control of 1st Int.
In. others Under Control of 2nd Int.

\[ \text{meas. time over} \]

Print Results

End

Fig. 5.3a. A Very Simplified Flow Chart of the Pair of Signalised Intersections Model "PAIRSINS"
Flow Chart for Subroutine Update

Fig. 5.3.b
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B**</td>
<td></td>
</tr>
<tr>
<td>STNM*</td>
<td></td>
</tr>
<tr>
<td>NTIME*</td>
<td></td>
</tr>
<tr>
<td>NOBSP**</td>
<td></td>
</tr>
<tr>
<td>NCGS**</td>
<td></td>
</tr>
<tr>
<td>NNL1**</td>
<td></td>
</tr>
<tr>
<td>NNL2**</td>
<td></td>
</tr>
<tr>
<td>NCL1**</td>
<td>For the 1st intersection</td>
</tr>
<tr>
<td>NCL2**</td>
<td>For the 2nd intersection</td>
</tr>
<tr>
<td>NCL3</td>
<td>Same as NCL1 for 2nd intersection</td>
</tr>
<tr>
<td>NCL4</td>
<td>Same as NCL2 for 2nd intersection</td>
</tr>
<tr>
<td>WN**</td>
<td></td>
</tr>
<tr>
<td>WC**</td>
<td></td>
</tr>
<tr>
<td>DMIC*</td>
<td></td>
</tr>
<tr>
<td>DBINTS</td>
<td>Distance between two intersections (m)</td>
</tr>
<tr>
<td>DOPTN**</td>
<td></td>
</tr>
<tr>
<td>DOPTC**</td>
<td>Distance of observation point from cross flow of 1st intersection (m)</td>
</tr>
<tr>
<td>INTG**</td>
<td></td>
</tr>
<tr>
<td>NB**</td>
<td></td>
</tr>
<tr>
<td>GREEN**</td>
<td></td>
</tr>
<tr>
<td>CYCLE**</td>
<td></td>
</tr>
<tr>
<td>PSSTLN</td>
<td>Position of stop line (m)</td>
</tr>
<tr>
<td>SPEDIS</td>
<td>Specified distance at which vehicles enter the lane (m)</td>
</tr>
<tr>
<td>SPLDIS</td>
<td>Specified distance at which vehicles leave the lane (m)</td>
</tr>
<tr>
<td>CMS**</td>
<td>In kph</td>
</tr>
<tr>
<td>CACC**</td>
<td>In kph</td>
</tr>
<tr>
<td>MMS**</td>
<td>In kph</td>
</tr>
<tr>
<td>MACC**</td>
<td>In kph</td>
</tr>
<tr>
<td>HAC**</td>
<td>In kph</td>
</tr>
<tr>
<td>M*</td>
<td></td>
</tr>
<tr>
<td>LL*</td>
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<td>Q*</td>
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<tr>
<td>PCM**</td>
<td></td>
</tr>
<tr>
<td>PCH**</td>
<td></td>
</tr>
<tr>
<td>RT**</td>
<td></td>
</tr>
<tr>
<td>FR**</td>
<td></td>
</tr>
<tr>
<td>IST**</td>
<td></td>
</tr>
<tr>
<td>S*</td>
<td></td>
</tr>
<tr>
<td>LPRT*</td>
<td></td>
</tr>
</tbody>
</table>

* As specified in Table 3.12
** As specified in Table 5.1
CHAPTER 6  THE COLLECTION AND ANALYSIS OF DATA

6.1 GENERAL

There are several parameters to be measured in a traffic noise survey. The accuracy of such parameters has a great effect on the conclusions drawn from such studies. In the early surveys many types of equipment were used to get statistical noise indices employing manual techniques for collecting the relevant traffic data, methods which proved inefficient and time-consuming, not to mention the personal error of each individual operator. With the rapid development of electrical and electronic engineering technology, a variety of instruments have been introduced to help in the collection and analysis of the required data in the most efficient and cheap way. This could also lead to the reduction in the number of operators conducting a survey, thus reducing to a minimum any possible error.

As quoted in Chapter (1), the aim of this study is to develop models for predicting and studying road traffic noise with special reference to signalised intersections. In order to achieve this goal three models have been built, namely (1) free-flowing model, (2) a model for a single signalised intersection and (3) a model for a pair of signalised intersections.

The data required for such models was of two types:

a) Noise recordings of individual and streams of vehicles.
b) Flow and composition of traffic and cycle times of the traffic signals and synchronisations with noise recordings.
6.2 METHODS USED FOR DATA COLLECTION

Generally, methods used in the collection of the noise data are very similar in most traffic noise surveys; for this reason these methods will be left out in this section. The details of the method used in this survey are presented in Section 6.5.

Methods used for collecting the relevant traffic parameters for noise surveys however have varied considerably as attempts are made to reduce the large effort involved.

6.2.1 Manual Method

Vehicles are counted on a set of manually-operated counters. Each set consists of three counters and vehicles are placed in one of three classes, private cars and light commercial vehicles, heavy commercial and public transport vehicles, or motor cycles. The velocities of as large a sample as possible of passing vehicles are measured with a radar speed meter (39).

Lewis (42) extended this procedure by using a two-channel tape recorder, simultaneous recordings were made of the noise produced by passing vehicles and of a commentary describing their speed, type and road position. The speeds of the vehicles were again measured by means of a radar speed meter which was concealed from drivers to avoid any modification in their behaviour that frequently occurs at the sight of such a well known instrument.

A somewhat similar procedure seems to have been adopted by Bodsworth and Lawrence (174) (they called it 'Voice Commentary'), after they had found that 10 minutes of manual traffic counting
at high flow rates is close to the maximum if inaccuracies due to lapses in concentration are to be avoided. A fully-comprehensive commentary in heavy flows proved most difficult and one of the weakest aspects of their early commentaries proved to be the non-standard vocabulary.

6.2.2 Time Lapse Photography

While the manual method can be used in free-flowing noise studies with some accuracy, this method, when used in interrupted flow studies requires much greater manpower and would thus become unreliable if untrained operators are employed.

Time-lapse photography is a technique that has been used for some time in many fields of research, traffic engineering being one of them. Good quality results can be obtained by means of a commercially available 16mm or 8mm camera and a stop-action projector. For example, the Vinten Mark 3 scientific camera uses 16mm film and can be powered from a small 12volt accumulator. In addition to operating at normal cine speeds of 8, 16 or 24 frames/second, the Vinten camera is designed to operate as a time lapse camera on receipt of electric pulses at predetermined time intervals from a D.C. intervalometer with a maximum filming rate of 4 frames/second.

Time-lapse photography provides a permanent record of all data which can be re-examined if necessary. In complex traffic situations, it provides more data than is normally available by conventional means unless a large team of observers is used.

Christie et al\textsuperscript{(48),(49)} made noise recordings during
their time-lapse filming of the traffic to enable the cause of any noise to be studied in detail. Further information was recorded by an observer in the street on a separate tape recorder or on a second channel of the tape on which the traffic noise was recorded. In addition, snapshots were taken from the noise site of any vehicles thought by the observer to be particularly noisy.

Another use of time-lapse photography in environmental studies was made by Fox and Waters (27) who photographed (at hourly intervals) the counter display of their statistical distribution analyser (B&K 4420) while Gilbert (28) built a convex mirror having a horizontal viewing angle in excess of 190° into their unit which enabled them to photograph all the meters and counters readings as well as traffic conditions.

Bodsworth and Lawrence (174) attempted to photograph significant events in the traffic stream. This caused excessive interference with the commentary they were making (Section 6.2.1) and made them move on to the use of synchronised movie filming for continuous visual record of selected traffic samples. However, they suggested that videotaping may well be the optimum approach. At that time the video tape technique had been used for the present work as reported in Ref. (112). More details about video tape technique are given in the following sections.

6.2.3 Video Tape Technique

Video recordings can be used in more or less the same way as 16mm photographic techniques and appear to be finding increasing application—traffic flow studies being one such application.
Time-lapse photography and video tape recording share a number of common advantages, namely the production of a permanent record and the ability for this record to be collected by one person.

The main advantages of the video tape recording over time-lapse photography with reference to the present work are as follows:

1. Recordings can be monitored as they are made.
2. Recordings can be replayed immediately. This feature allows the operator to ensure that the equipment is functioning correctly before a recording is started and afterwards to check that a recording session has been successful before equipment is dismantled.
3. Recording tapes may be changed without disturbing the camera and so allow lengthy studies to be carried out. If two video tape recorders are used the recording can be continuous for as long as required, or to monitor complex traffic noise studies, e.g. monitoring vehicles going along a straight stretch of road and then the same vehicles as they go along an uphill gradient. This would enable a very accurate evaluation of the effect of gradient on the noise emitted by vehicles.
4. Tapes are relatively inexpensive and can be re-used many times.
5. Additional information may be recorded in a variety of ways. The sound track can be used for spoken commentary or for recording signals from vehicle detectors. Displays from instruments such as clocks, traffic counters and speed and noise meters can be viewed by additional cameras or
generated electronically, and superimposed on the traffic view or recorded in a machine-readable form so that subsequent transcription can be partially automated.

6. It can be filmed at the standard operating speed of 50 field/sec. and if a digital clock is superimposed on this, either during recording or subsequently, slow-motion analysis of the resulting tape allows events to be registered to an accuracy of the order of \( \pm 20 \text{msec} \). This is compared with 250 msec. for time-lapse photography if a speed of 4 frame/sec. is used.

The disadvantages of video tape techniques are:

1. Video picture resolution is slightly inferior to that of 16mm film.

2. Video pictures are generally in monochrome since colour video cameras are still very costly. The added detail presented by colour improves the resolution of 16mm colour film when compared with black and white video pictures.

3. Video recording systems have higher power requirements. Battery powered video tape recorders are available but one set of fully-charged will only power a recorder for about 45 minutes. These take tapes lasting about 35 minutes so that one set of batteries will provide power for one tape.

4. Video equipment is more complex and possibly less robust than photographic equipment.

The advantages of the video tape recording technique have easily outweighed its disadvantages in this application where
the short distances give adequate resolution and flexibility of operation is required.

6.3 EQUIPMENT USED ON SITE (see plate 6.1)

6.3.1 Noise Equipment

Only a brief description of the noise equipment used in the present work will be given, more details however can be found in most text books, instruction manuals or catalogues.

The noise equipment used was as follows:

1. Two B&K Impulse Precision Sound Level Meters Type 2204 each with a Condenser Microphone Type 4145, a Windscreen Type UA207 and a tripod. These are compact and portable instruments for precision sound and vibration measurements. They conform to IEC R 179 for Precision Sound Level Meters and B.S. 4197.

2. A Sound Level Calibrator 4230 or a Pistonphone 4220. These are portable, battery-driven instruments. They produce 94dB re 2x10^{-5}N/m^2 ±0.25dB at 1000Hz±1.5% which makes it independent of weighting networks or 124dB re 2x10^{-5}N/m^2 ±0.2dB at 250Hz±1% sinusoidal waveform respectively.

3. A Nagra IV-S tape recorder. This is a portable, three-speed recorder: 15, 7.5 and 3.75in/s, ¼" tape tape-recorder with two sound tracks.

6.3.2 Video Equipment

The videotape equipment used on site was as follows:
1. Portable Video Tape Camera (Sony-AVC-3450E) mounted on a tripod. This is a compact, light-weight video camera designed for use with Sony portable video tape recorders for on-the-spot recordings. The playback picture can be viewed on the viewfinder screen immediately after recording. Its other main features are:
   a. An Automatic Sensitivity Control regulates camera sensitivity to suit a wide range of lighting conditions.
   b. A high quality condenser microphone built into the camera used to comment on observations or special events.
   c. Battery condition is indicated by a Battery Check Lamp in the view-finder.
   d. Playback audio is available at the earphone jack on the recorder.
   e. Zoom lens 12.5mm wide-angle to 75mm telephoto, i.e. 1:6 zoom.

A wide angle lens was also used on some occasions.

2. Portable Video recorder (Sony AV-3420CE): This is designed to operate with the SONY AVC-3420CE Video Camera. The system records "live" action and the recorded picture can be immediately played back and viewed on the camera viewfinder screen. The main other features of the video-recorder are:
   a. The recorded material can be immediately played back and seen on a video monitor or conventional TV receiver through an RF converter.
   b. Fully automatic video and audio recording eliminates level adjustment.
c. Three-way power supply: mains 240V AC power, rechargeable internal 12V battery pack or external 12V automobile battery.
d. Commentary or background music, can be recorded on the pre-recorded picture during playback.
e. Stop-action for close examination.
f. A time counter shows the recording time minute by minute as well as indicating the amount of tape as an ordinary tape counter.
g. Automatic shut-off occurs when the tape runs out.
h. A manual tracking control corrects improper tracking in the playback picture and assures complete tape interchangeability between SONY Videocorders AV-3620CE and AV-3670CE.

The Sony equipment is high-density equipment. In the early measurements low density equipment was used. This was JVC Portable Video Camera GS-4600E and Portable Video Tape Recorder PV-4500. Features of these two systems are very similar; however, the picture quality of the high-density equipment is slightly superior.

6.3.3 Miscellaneous Equipment

Most of the following equipment was always taken to the sites:

a. Connecting cables (microphone-sound level meter-tape recorder)
b. 100 feet cable (microphone-sound level meter)
c. stop watch
d. clipboard and pencil
e. screw driver
f. batteries
g. dry/wet thermometer
h. wind speed meter

6.4 SITES DESCRIPTION

6.4.1 Criteria for Choice of Sites

1. Straight approach lanes without bends, as far behind the stop line as possible. This was required to avoid sudden changes in traffic characteristics.
2. Minimum pedestrian-traffic interference.
3. Wide footpath to minimise pedestrian interference with the equipment.
4. Absence of extraneous noise sources
5. Open site where the reflection of sound is negligible, or a site where the effect of reflection can easily be assessed
6. To cover a wide range of flow characteristics.
7. Will experience some changes when linked to the UTC system.

6.4.2 Location and Physical Characteristics of Sites

The choice of sites was based on a compliance with the above-stated criteria for choice of sites (Section 6.4.1).

In all, four sites were chosen for the study because they satisfied the conditions and Figure 6.1 shows a map of part of Loughborough on which sites chosen have been indicated by the rings. The overall appearance of the sites is illustrated by
Fig. 6.1 A Map Showing the Junctions Used in the Study
Figure 6.2 and Plates 6.1, 6.2, 6.3 and 6.4. Table 6.1 summarises the physical features.

6.5 PROCEDURE ON SITE

Noise and videotape recording were mainly carried out during the morning and evening peak hours. The morning recordings were made between the hours of 8.00a.m. and 9.15a.m. while the evening recordings were made between 4.30p.m. and 6.00p.m. A series of measurements were made at varying distances from the kerbside (2.5 - 5m) of the main flow and at a varying distance from the intersection stop-line and moving backwards away from it. These were between a point opposite the stop-line and a point as far as the site configurations allowed and where free flow conditions were clearly dominant (usually where the traffic signal is out of sight). It was proposed to take measurements at positions 0, 15, 30, 50, 100, 150, 250 and 400m away from the intersection. Site constraints such as lamp posts, parked cars, traffic light control boxes, which could have affected readings if the microphone had been too close to them, and some other practical difficulties for example the unavailability of a cable as long as 150m caused some variation from this procedure.

Noise level recordings at each of the chosen sites were generally made with two sound level meters, switched to A-weighting. The microphones were placed at two consecutive distances of the ones mentioned above (or any close to them) mounted on tripods 1.2m above the ground. The microphones were fitted with windscreens and the two sound level meters were connected by means of cables to a two-channel portable tape recorder running at a speed of 7.5 or 3.75in/sec. A
a. Belton Rd./Derby Rd. Intersection

b. Leicester Rd./King St. Intersection

c. High St./Woodgate Intersection

d. Meadow Lane/Belton Rd. Intersection

Fig. 6.7  The Overall Appearance of the Sites
Plate 6.1  Belton Rd./Derby Rd. Intersection –
The Equipment Used on Site

Plate 6.2  Leicester Rd./King St. Intersection
Plate 6.3  High St./Woodgate Intersection

Plate 6.4  Meadow Lane/Belton Rd. Intersection
Table 6.1  Summary of the Characteristics and Physical Features of the Sites Studied

<table>
<thead>
<tr>
<th>Site</th>
<th>Approach Studied</th>
<th>Site Characteristics and Some of Its Physical Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Belton Rd/Derby Rd.</td>
<td>Belton Rd.</td>
<td>4-way intersection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Straight approach lane up to about 150m from stop line</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Open site</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No parking. No pedestrian interference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No extraneous noise sources</td>
</tr>
<tr>
<td>2) Leicester Rd/King St.</td>
<td>Leicester Rd.</td>
<td>3-way intersection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Straight approach</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Semi-open site</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No parking. Little pedestrian interference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No extraneous noise sources</td>
</tr>
<tr>
<td>3) High St/Woodgate</td>
<td>High St.</td>
<td>4-way intersection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Straight approach lane up to about 100m from stop line</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The approach is flanked by buildings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Some pedestrian interference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No parking. No extraneous noise sources</td>
</tr>
<tr>
<td>4) Meadow Lane/Belton Rd.</td>
<td>Belton Rd.</td>
<td>4-way intersection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Approach lane is bend at about 100m from stop line</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Semi-open site</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Parking allowed at about 40m from stop line</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Some pedestrian interference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Children noise was experienced.</td>
</tr>
</tbody>
</table>
calibration tone was always applied before starting the traffic noise recording and sometimes at the end of it.

Video tape recording started at almost the same time as the sound level recording. Synchronisation procedure between the noise and video recording was carried out by two methods:

a. When the equipment set-up is close to the intersection and the traffic signal is in the view of the video tape: It was made by pressing the reference oscillator which is built into the tape recorder with the change of phase of the traffic signal, e.g. green to amber. Usually this was done when the operator himself was in the view of the video camera, otherwise the second operator was asked to stand in front of the camera and put his hand up with the change of the signal. To ensure accurate synchronization the reference oscillator was pressed twice, if the signal was changing from red to green it was pressed with the showing of the red/amber and with the showing of the green (2secs. later); if the signal changing to red, then it was pressed with the showing of the amber and with the showing of the red (3secs. later).

b. When the equipment set-up is far from the intersection and the traffic signal is not in the view of the video camera (usually > 100m away): In this case the operator, while in view of the video camera, simultaneously pressed the reference and banged his clipboard against his leg three times.
At least two ten-minute recordings were made each time with ten minutes interval between consecutive ones and the synchronisation process carried out at the beginning of each recording. The condition of the batteries (as indicated on the recording levels on the recorders) had to be checked constantly to make sure that the battery had not run down below the permitted level. Measurements were carried out over a period of several days for each site to cover the specified positions.

The road had to be dry and wind velocity had to be minimal. Data was obtained during the period August-September 1977 (just before the inception of the UTC scheme) and again during roughly the same weeks in 1978.

The clipboard was used to take notes on date, time, set-up and weather conditions and any other events which were thought to be relevant to the measurements. Comments were also made during the measurements using the sound track of the video tape.

6.6 EQUIPMENT USED IN THE LABORATORY

In addition to the equipment used on site, the following equipment was used in the laboratory in order to analyse the data:

1. Measuring Amplifier Type 2607: This is a precision mains/battery powered instrument with linear frequency range from 2Hz to 200KHz ± 0.5dB, measuring true RMS levels with averaging times of 0.1 to 300s on sound, vibration and voltage signals with crest factors of
up to 5 (+14dB). For peak measurements on signals with rise times as short as 20μs, positive peak, negative peak and maximum peak modes with decay times constants from 0.1 to 300s are also included. When used with a B&K microphone and pre-amplifier it conforms to the recommendation for precision sound level meters. On some occasions Type 2606 measuring amplifier was used which has slightly different characteristics.

2. Level Recorder Type 2305: This instrument produces chart recordings of AC and DC levels; AC levels from 2Hz to 200KHz and crest factor handling up to 5; facility for six dynamic ranges, two linear and four logarithmic; rectilinear and polar recording on pre-printed paper charts; writing width 50 and 100mm; RMS; average and peak levels detected and recorded using a wide range of writing speeds and paper speeds. Levels may be recorded in ink or as a finely scribed line on waxed paper.

3. Statistical Distribution Analyzer Type 4420: This is primarily an accessory for the Level Recorder 2305. It resolves measurement data (usually sound levels) into twelve class intervals and presents a numerical display which lends itself to statistical analysis. It was only used for the analysis of the early data; a CEL $L_{10}$ meter was then used for the analysis of the rest of the data.

4. Statistical Sound Level Meter Type CEL 134: This instrument can be set to calculate any level from $L_{10}$ to $L_{90}$ in decades and monitors the environment for periods of up to 31 hours. Sample durations from 5 minutes to 1 hour
may be pre-selected and the unit will then, at the end of each period, calculate the programmed level. This answer is stored and immediately another measurement period is commenced. This procedure is repeated until 31 answers are stored within the instrument. These may then be read out on demand.

5. SONY CVM-110 UK - Receiver/Monitor: This is a solid-state television monitor/receiver designed especially for use with SONY Videorecorder systems. As a monitor, it reproduces both picture and sound signals during recording and playback operation. Another video monitor was used during the laboratory procedure as will be explained in the next section.

6. SONY Videocorder AV-3670CE: This compact, portable video tape recorder provides many features, they are:
   a. Audio and video recording levels can be controlled automatically or manually by the setting of the AGC/MANUAL switch.
   b. With use of an RF unit the recorded tapes can be viewed on an ordinary TV screen.
   c. Tapes are fully interchangeable so that a tape recorded on any Sony AV-CE Series Videocorder can be played back on the AV-3670CE.
   d. A still playback picture can be obtained by simply setting the Function Selector to PAUSE/STILL. Slow motion tape speed can be varied by turning the SLOW SPEED control.
   e. A manual control corrects improper tracking in the playback picture. A meter is provided to indicate optimum tracking.
f. A SKEW control which adjusts tape tension in the playback mode.
g. External sync. switch.
h. New video and audio may be added or inserted to a previously recorded tape in the playback mode.

7. Video Timer VTG-33F: It is an all-electronic compact video display generator which superimposes digital indications for time and date on the picture in a television system. Facilities are available to superimpose the month, date, hours, minutes, seconds, 1/10 seconds and 1/100 seconds. Facilities are also available to RESET, START and HOLD the indications, adjust their position both vertically and horizontally to place it wherever required on the TV display and to change the display format to stand out from the background and change its size.

6.7 ANALYSIS PROCEDURE

6.7.1 Analysis of Noise Tapes

Early tapes were played back through either the B&K 2607 or the 2606 Measuring Amplifiers into the level recorder where the setting had been calibrated with the recorded calibration signal. The level recorder was connected to the 4420 Statistical Distribution Analyser. The analyser was used to give accumulative frequency plots of the noise sample in 5dBA groupings. From the frequency plot the $L_{10}$, $L_{50}$ and $L_{90}$ indices (see Appendix 1) were obtained.

The Statistical Sound Level Meter Type CEL 134 was used to obtain the indices $L_{10}$, $L_{50}$ and $L_{90}$ for all later measurements. The calibration signal was first run through the meter, the
sampling period was then set for the required time and the actual noise recording was run through it. The meter was interrogated just before (about 30 sec.) the end of the sampling period to get $L_{50}$ and $L_{90}$ while $L_{10}$ value was obtained at the end of the period.

The main problem encountered during the analysis of some of the tapes was the noise of children. Tapes with excessive child noise were rejected.

6.7.2 The Process of Adding the Time Base on the Video Tape

At the site recordings were made using the portable camera and videocorder (6.3.2).

In order to analyse the tapes time had to be superimposed on them to get cycle times and the required sampling time which matched the noise recording. The process of adding the time base on the video tape is shown in block diagram (Figure 6.3 and Plate 6.5). By this process both picture and sound are transferred to the new tape which had all the selected indications on e.g. month, date, hours, minutes, sec., $1/10$ sec. and $1/100$ sec.

6.7.3 Analysis of the Video Tape

The video tapes with the time-base superimposed were played back using the AV-3670CE videocorder and a monitor.

Numbers of light, medium and heavy vehicles as well as motor cycles were noted. Two legs of the intersection were analysed at a time and only the main flow if the distance from the intersection was greater than 50 m. The classification of medium vehicles was obtained as required by the present work (which is the same classification made by URBANN (82)) and as
Portable Video Tape Recorder (VTR)
Picture without time base

Monitor
Video
Audio

Timer
Video out

Monitor
Picture with time base on

VTR

Fig. 6.3 The process of adding time base
Plate 6.5 The Process of Adding the Time Base
required by the Calculation of Road Traffic Noise\(^3\). Motorcycles were noted to assess their effect, if their number was significant and sufficient samples would be available. The PAUSE/STILL facility was used to obtain cycle times and whenever things were happening too quickly for the operator to follow the events. From the counting of vehicles the total hourly flow on each approach was obtained as well as the percentages of medium and heavy vehicles.

The main problem encountered in analysing the video tapes resulted from heavy commercial vehicles blocking the view and this made it difficult to calculate the number of passing vehicles on the other approach during the HCV idling time. This situation occurred only on a few occasions and the average number of vehicles was assumed to have passed the observation point during the blocking time.

This information was then available for the validation of the signalised intersection model for testing the accuracy of the Calculation of Road Traffic Noise or URBANN prediction procedure, and in the UTC effect experiment.

6.8 INDIVIDUAL VEHICLE NOISE STUDY

Noise emitted by individual vehicles is an important factor in noise simulation models. The results from the freely flowing model (described in Chapter 3) showed from the very beginning that the data base was good and that reliable interrupted flow noise levels should be obtained\(^{112}\). This was expected due to the very large sample sizes involved and the numerous sources from which the data was derived\(^{46}\).
While the available individual vehicle noise levels cover speed and acceleration effects, no data was found to cover the effect of deceleration. To try and provide more information, a number of pilot surveys were carried out to study individual vehicles' noise levels on Loughborough University campus. During the pilot surveys, effort was constantly made to obtain more than one noise level from each vehicle by monitoring it along a segment of road. Different techniques (described below) were tried for this purpose. The experience obtained from the pilot surveys were then utilized in a later survey carried out on the TRRL test track.

6.8.1 Site and Vehicles Used

As mentioned above the site was the TRRL test track which closely complies with the ISO recommendation for the measurement of noise emitted by vehicles (57). Background noise levels were always more than 10dBA below the noise emitted by the vehicles.

Two vehicles were used, namely:

a) A car - Vauxhall Victor Estate, 3.3litre - which was described as a 'typical' car (50).

b) A heavy lorry - Foden Artic. 32 Ton, 350bhp

6.8.2 Equipment and Procedure Used on Site

The same equipment described in Section 6.3 was used in the present experiment with some modification. One channel of the Nagra IV-S tape recorder was connected to a modified traffic counter which helped in synchronizing the recorded video
picture with the noise recording. As the vehicle passes over the pneumatic counter a 1V d.c. signal was generated and recorded, therefore the position of the vehicle was identified on both the video and the noise tape (its position from the microphone). In one of the pilot surveys more than one traffic counter was used, each of which was giving a different voltage from the others to help in identifying which one was being considered. The traffic counter operates on the basis of counting each axle separately; therefore two signals were obtained as the vehicle passes over it. This enabled the calculation of the speed of the vehicle as its wheel base was known.

A grid was constructed in the region of interest by placing white adhesive tapes on the road. Five tapes were used in total at distances of 5 and 10m from each side of the microphone, the fifth one was in line with the microphone and on this tape the pneumatic detector was fastened.

Runs for both vehicles were made under the following conditions:

a. Various constant speeds
b. Acceleration from rest-starting at the 5m mark
c. Acceleration from various speeds, initiated at the 10m mark
d. Deceleration from various speeds, initiated at the 10m mark

Drivers were instructed to try and drive as they would on normal roads.
Plate 6.6 shows the site, the equipment and the car used for the tests. A few runs were also made by a Rover V-8 car.

6.8.3 Analysis Procedure

Noise recordings were played back through a B&K 2607 measuring amplifier and B&K 2035 level recorder. The output of one channel was the noise emitted by the vehicle whilst the other was that from the counter. Because the paper speed of the level recorder was known, it was possible to evaluate the vehicle speed from the signals obtained from the traffic counter. This was the first method to evaluate the speeds of the vehicle. In addition to this two other methods were employed:

1. The video tapes, after superimposing the time, were played back. The times at which the vehicle wheels crossed the tapes were noted and then the vehicle speeds were evaluated from these times.

2. A technique was devised to evaluate the position of the vehicle on the ground by knowing its co-ordinates on the photo by using the video tape equipment. The basic technique has previously been developed for use with time lapse photography (175), (176). The usual method is based on the transformation of picture co-ordinates to the ground co-ordinates, the following two equations have been derived for the purpose (175), (177):

\[
X_G = \frac{B_1 + B_2 X_p + B_3 Y_p}{B_4 X_p + B_5 Y_p + 1} \quad (6.1)
\]

\[
Y_G = \frac{B_6 + B_7 X_p + B_8 Y_p}{B_4 X_p + B_5 Y_p + 1} \quad (6.2)
\]
Plate 6.6  The TRRL Test Track, The Equipment and the Car Used for the Test
where $X_C, Y_C = X$ and $Y$ co-ordinates of any point in the ground plane

$X_P, Y_P = X$ and $Y$ co-ordinates of the same point in the film plane

$B_1 \ldots B_8$ = coefficients that remain constant as long as the oblique relationship between the two planes does not change.

By knowing the co-ordinates of four points on both the ground and the picture the eight unknown parameters can be evaluated.

In the present work an Apple II microcomputer which has the facility of low and high resolution graphics was used for the purpose of the analysis. A high resolution cross bar was generated using the computer software, the position of which was then controlled by two analog input controls (available standard with the computer) one for the x-axis and the other for the y-axis. The high resolution graphics cover 280 lines on the x and 160 on the y leaving four lines for text at the bottom. This area was used to read the co-ordinates of x and y.

As the output of the Apple II can be displayed on any home TV or on a monitor (with better quality picture) it was hoped to superimpose the generated cross bars on the recorded video picture electronically. However, this was found to be quite a task and would require major development due to the synchronisation problem involved.
Due to the problems mentioned above an alternative method was found and is briefly described as follows. The recorded video picture (with superimposed time base) was played back on a monitor and the picture of the cross bars was generated on another monitor. Two television studio cameras were then focussed on the two pictures and these two pictures were mixed and the final picture was then displayed on a third monitor. This process is shown in block diagram form in Figure 6.4.

The speed and acceleration/deceleration of the vehicles were evaluated by carrying out the following procedure:

a. The cross bars were moved until they corresponded to the position of the control points whose positions were then noted. As the positions of the control points on the ground were known these values were later used to evaluate the eight parameters (eqns. (6.1) and (6.2)). This step was repeated whenever the camera location was changed.

b. The video tape was allowed to run until the vehicle started to enter the region of interest. The tape was frozen (using the pause facility) and a certain point of the cross bars (usually the upper right hand corner of the origin) was then moved to correspond to a certain point of the vehicle usually the part of the tyre touching the ground (in one of the pilot surveys the registration plate was used). The co-ordinates of the cross bars were then noted in addition to the superimposed time (see Plate 6.7).
Fig. 6.4 The process of superimposing the cross bars on the video picture
Plate 6.7  The Cross Bars Superimposed on the Video Picture
c. The video tape was then allowed to move for a period which was varied between 0.2 - 0.5 sec. (depending on the speed of the vehicle in order to give good resolution) and step (b) above was then repeated. This procedure was continued until the vehicle left the region of interest.

d. The next vehicle run was taken and the same procedure was followed.

During the evaluation of the speeds it was found that the resolution of y co-ordinate (160) was not giving sufficiently accurate results. As the y-co-ordinate represented the distance of the vehicle from the kerb which was constant, criteria was established to maintain the y-value on the ground fairly constant (within 0.2 m). This criteria was found to be very useful and gave sensible results. The overall accuracy of the method and sources of error of the technique when used with time lapse photography is given in detail by Taylor and Carter (175) who employed a smoothing technique.

Most of the sources of errors from the technique are common to both time lapse photography and video taping. The same smoothing technique was therefore justified and was employed in the present work. The smoothing technique utilized called for replacing the speed value at any interval by a new value obtained as follows:

\[ \dot{x}_{t, \text{adj}} = \frac{\dot{x}_{t-2} + 2\dot{x}_{t-1} + 3\dot{x}_t + 2\dot{x}_{t+1} + \dot{x}_{t+2}}{9} \]  

(6.3)
where $X_{adj} = \text{adjusted value of the speed at interval } t$

$X_{t-2} = \text{initial value of the speed at 2 intervals before } t \text{ and so on.}$

All computations required for the analysis procedure were carried out on the Apple II using programs adapted and developed by the author.

Results from the analysis have shown that the most reasonable results were obtained from slow vehicle runs because they remained in the region of interest for a greater time and therefore allowed more data points to be obtained.

The technique as described above was found to give good results and has potential for future individual vehicle noise studies since it offers reduced manpower requirements and increased data collection. Room for improvement exists by superimposing the cross bars on the video picture electronically and increasing the resolution of the cross bars, and future development could employ automatic sampling of the co-ordinates under the control of the Apple II as the vehicle is tracked manually in slow motion.
7.1 INTRODUCTION

Models should only be created for a specific purpose and the adequacy or validity of the model can only be evaluated in terms of that purpose. The goal is to develop a model which creates the same problems and behaviour characteristics as the process being studied. To evaluate a model means to develop an acceptable level of confidence so that inferences drawn from the performance of the model are correct and applicable to the real world system.

The question of verification of simulation models is in reality no different from the question of verification when applied to any type of hypothesis or model, whether it be expressed as a verbal model, physical model, a mathematical equation or a computer program.

Validation and analysis of a similar study is a continuous process that begins from the start of the study. Confidence is built into the model as the study proceeds. It is not something done solely at the end. The greatest possible validity is achieved by:

1. Using common sense and logic throughout the study.
2. Taking maximum advantage of the knowledge and insight of those most familiar with the system under study.
3. Empirically testing, by the use of appropriate statistical techniques, all of the assumptions, hypotheses, etc. that can possibly be tested.
4. Paying close attention to details, checking and re-checking each step of the model building process.
5. Assuring that the model performs the way it was intended by using test cases, etc., during the debugging phase.

6. Comparing the input-output transformation of the model and the real world systems (wherever possible).

7. Running field tests or peripheral research where feasible.

8. Perform sensitivity analysis on input variables, parameters, etc.

9. Checking carefully the prediction of the model and actual results obtained from the real world system.

A constant effort was made throughout the work to comply with the nine points stated above. As it can be seen from the list above some of the tests cannot be presented even though they have been carried out, e.g. points (1), (4) and (5).

Although the present models are required to produce noise levels, the close relationship between individual vehicle noise levels, vehicle type and driver behaviour (speed, acceleration) necessitates fairly detailed modelling of the traffic flows.

Details of the tests which have been made to validate the models are presented in the following sections.

7.2 **INPUT AND OUTPUT PARAMETERS**

One of the requirements of a good model is that it should produce those parameters of random nature, very close to the specified input values.

When using the programs it is advisable (due to the random nature of the models) either to make a long sample time or make a few shorter runs of the same conditions and take the
average of these runs. This will give more accurate mean results, the latter approach being more statistically reliable.

7.2.1 Total Flow

Table 7.1 shows details of specified input and the resulting output values of total flow in vehicles per hour taken from a number of runs of around 10 minutes each. It can easily be seen from these figures that the two values are in adequate agreement, particularly as the output values can be quoted (rather than inputs).

7.2.2 Percentage of Medium and Heavy Commercial Vehicles

Table 7.2 shows the specified input and the output values of medium and heavy commercial vehicles for the interrupted flow case and those of the heavy commercial vehicles for the free-flow case. The results show that there is a tendency towards underestimating the values of the percentage of heavy vehicles and the following reasons are probably responsible.

1. Short sampling period (less than 10 minutes samples were made for runs of flows greater than 1200VPH) or low flow values. In both cases the number of HCV's is crucial.

2. The speed specified for heavy commercial vehicles is usually less than that for light and medium. This means that heavy vehicles are slower to reach the observation point where the count is made, although generated according to the specified input, may not be included in the output.
Table 7.1 Specified Input and the Output Values of Flow

<table>
<thead>
<tr>
<th>Input Value</th>
<th>Output Value</th>
<th>Difference %</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>384</td>
<td>-4.0</td>
</tr>
<tr>
<td>400</td>
<td>378</td>
<td>-5.5</td>
</tr>
<tr>
<td>700</td>
<td>624</td>
<td>-10.85</td>
</tr>
<tr>
<td>1200</td>
<td>1080</td>
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<td>+4.3</td>
</tr>
<tr>
<td>2000</td>
<td>1965</td>
<td>-1.75</td>
</tr>
<tr>
<td>2000</td>
<td>2008</td>
<td>+0.4</td>
</tr>
<tr>
<td>2000</td>
<td>2016</td>
<td>+1.85</td>
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<td>-1.92</td>
</tr>
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<td>+1.25</td>
</tr>
<tr>
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<td>2436</td>
<td>+1.5</td>
</tr>
<tr>
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<td>2808</td>
<td>+0.29</td>
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<td>+4.39</td>
</tr>
<tr>
<td>4800</td>
<td>4800</td>
<td>0.00</td>
</tr>
<tr>
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<td>5064</td>
<td>+5.50</td>
</tr>
<tr>
<td>4800</td>
<td>4824</td>
<td>+0.05</td>
</tr>
</tbody>
</table>

Table 7.2 Specified Input and the Output Values of Medium and Heavy Commercial Vehicles

<table>
<thead>
<tr>
<th>Flow</th>
<th>Input Medium % (PCH)</th>
<th>Input Heavy % (PCH)</th>
<th>Output Medium %</th>
<th>Output Heavy %</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>20*</td>
<td>20*</td>
<td>20.3</td>
<td>18.1</td>
</tr>
<tr>
<td>400</td>
<td>20*</td>
<td>20*</td>
<td>22.1</td>
<td>22.1</td>
</tr>
<tr>
<td>700</td>
<td>10</td>
<td>10</td>
<td>11.7</td>
<td>7.2</td>
</tr>
<tr>
<td>1200</td>
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<tr>
<td>1200</td>
<td>10</td>
<td>10</td>
<td>9.6</td>
<td>8.5</td>
</tr>
<tr>
<td>2000</td>
<td>10</td>
<td>10</td>
<td>10.0</td>
<td>8.4</td>
</tr>
<tr>
<td>2000</td>
<td>15</td>
<td>15</td>
<td>15.00</td>
<td>12.8</td>
</tr>
<tr>
<td>4800</td>
<td>10</td>
<td>10</td>
<td>9.5</td>
<td>9.7</td>
</tr>
</tbody>
</table>

*Free-flow model
It can be noted that these differences are small and large values are very unlikely to occur (unless the sampling time is very short).

It must be mentioned however that the output (not the input) values of flow and percentages of HCV's were compared when the noise models were validated.

7.2.3 Speed

The procedure adopted to carry out speed calculations (Section 3.20.3) in the model creates a situation whereby slow vehicles are likely to be sampled more than once and it is likely that fast vehicles would escape the sampling.

In addition the expression describing the freely-flowing vehicles is exponential, which theoretically means that vehicles do not attain their desired speed until the time reaches infinity. Both these effects tend to make the output speed low.

The following figures have been obtained from a number of runs:

<table>
<thead>
<tr>
<th>Input Speed (Time mean speed - kph)</th>
<th>Output Speed (kph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>24.3</td>
</tr>
<tr>
<td>40</td>
<td>33.3</td>
</tr>
<tr>
<td>40</td>
<td>32.6</td>
</tr>
<tr>
<td>50</td>
<td>44.0</td>
</tr>
<tr>
<td>60</td>
<td>52.7</td>
</tr>
<tr>
<td>70</td>
<td>62.0</td>
</tr>
</tbody>
</table>

It can be seen that this procedure gives a rough estimate of speed and it is believed that more accurate speed values are not necessary for the following reasons:
1. The models are intended for urban areas where the noise does not vary greatly over the range of speeds encountered (see Fig. 5.3).

2. The main models are intended for interrupted flow conditions where speed measurements present a problem, e.g. at intersections. An experiment was carried out in the Loughborough area to measure the speeds of vehicles passing through an intersection (the site chosen was Belton Rd./Derby Rd. intersection – see Plate 6.1). A radar meter was used for the purpose; however it was found that this device was not capable of detecting vehicles with speeds less than 23mph (37kph). It is probable that noise levels are largely independent of speed in the range 25-45kph(67).

It can be said with confidence that the model generates very accurate values for those specified input values which contain random processes. An argument may arise that many underestimates or overestimates can occur at one time, although this is unlikely to happen due to the fact that most of the important parameters are correlated (flow and speed). Such an effect can be minimised (as stated earlier) by either lengthening the sampling time or making more than one run and taking the average which would give a better sample.

7.3 THE TRAFFIC MODEL

Most of the validation of the traffic model was carried out when the appropriate theoretical models were chosen, e.g. the car-following theory and during the course of debugging the
model (points (1), (2) and (4) in Section 7.1). Nevertheless, some more validation steps were taken to ensure that the model was giving an accurate representation of the traffic behaviour which is the keystone of the noise prediction.

Further, the 4-sec. scan interval makes the model give a very good representation of the real-life situation.

7.3.1 Number of Queueing Vehicles

Cleveland and Capelle (179) in their queueing theory approaches to the signalised controlled intersections considered the model first postulated by Little (180).

For medium and low traffic flows, in which the carry-over of vehicles from one red interval to the next may be ignored, Little developed an equation for predicting the average queue length at a traffic signal. By using the actual red time \( R \), he approximated \( T \) and expressed the average queue length formed at a traffic signal as:

\[
q(N) = \frac{qR}{1 - qh}, \quad q \text{ is veh/sec.}
\]

In developing the above relationship Little assumed that:

1. Arriving traffic follows Poisson's distribution and in a single lane.
2. Traffic is held up for a time, \( T \), and then released.
3. Vehicles starting up leave a constant time, \( h \), between them.
4. Normal road speed is lost instantaneously on joining the queue and regained instantaneously on starting up.
5. There are no vehicles turning left or right.

The infinite acceleration and deceleration assumed is not as serious as it might appear. If a vehicle proceeds through the intersection without stopping, there is little or no delay. For those vehicles forced to stop, there will be some additional delay due to deceleration and acceleration. But this can be partially eliminated by using an effective red signal plus the average acceleration delay (179).

It can be noticed that some of the assumptions made by Little are different from those made in the present study, however, without going into a detailed examination as to what effect the differences between the two models might have on the results it is reasonable to say that provided both studies have made some realistic assumptions they should give close results.

As the present models are applicable to medium and heavy traffic the medium flow results were compared to Little's model and the details of the results are given in Table 7.3.

Despite the different assumptions made in the two models, a fair agreement is shown to exist between them.

7.3.2. Vehicles Crossing the Stop Line

Vehicles crossing the stop line can generally be described by:

\[ y = A + Bx \]

where \( y \) = time of crossing the stop line
\( x \) = position in the queue
A&B = constants
Table 7.3: Comparison Between the Number of Queueing Vehicles From the Signalised Intersection Model with that Found by Little's Formula

<table>
<thead>
<tr>
<th>Red Time (sec.)</th>
<th>Flow VPH</th>
<th>No. of Cycles Sampled</th>
<th>Mean No. of Queueing Vehicles in Cycles Considered</th>
<th>Little (180)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>E(N)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>h=2.0 sec.</td>
</tr>
<tr>
<td>70</td>
<td>264</td>
<td>16</td>
<td>5.4</td>
<td>6.0</td>
</tr>
<tr>
<td>55</td>
<td>291</td>
<td>20</td>
<td>3.6</td>
<td>5.3</td>
</tr>
<tr>
<td>45</td>
<td>302</td>
<td>24</td>
<td>3</td>
<td>4.5</td>
</tr>
<tr>
<td>40</td>
<td>270</td>
<td>18</td>
<td>2.7</td>
<td>3.5</td>
</tr>
</tbody>
</table>
Different values for A and B have been found by different researchers. The author(181) in an independent work carried out a test using the analysis of variance on four sets of data obtained from independent sources, a significant difference was found to exist between all the four sets. The results of the test led to the conclusion that the rate of discharge of vehicles from the intersection depends on the site characteristics, the town in which the junction is located and possibly the date on which the survey was carried out.

Values of B for the four sets of data are 2.162(145), 2.295(182), 2.727 and 1.668(181).

Data of vehicles crossing the stop line have been obtained from the model, vehicles were timed as they crossed the stop line, after the signal has changed to green. The average of 20 values, when the values were rounded up to the nearest 0.25sec. has been found to be 2.5sec.

This figure seems to be in very good agreement with the experimental results.

Bearing in mind that the models have mainly been built to predict noise levels, and they were not intended to give accurate data for the purpose of the above tests it is very reasonable to conclude that the model gives accurate representation of the traffic it is supposed to describe.

7.4 RESULTS OF THE INDIVIDUAL VEHICLE NOISE STUDY

Figure 7.1 is a reproduction of Fig. 3.5 with results of runs at constant speeds made by the lorry, the Vauxhall Victor and the Rover V8 vehicles shown on the same figure. The results of the lorry runs are scattered, whilst the results of the two cars show similar trends to those of the graphs.
Figs. 7.2 and 7.3 show the results of the acceleration runs of the lorry and cars respectively in addition to those for the same conditions taken from references (54) and (55). The results show similar trends and scatter to those taken from references (54) and (55). Results of the lorry generally seem to give higher noise levels than those of Ref. (55); this may be due to the fact that the lorry used in the present work was a very heavy lorry and was also loaded. The addition of the present single vehicle data to the multi-vehicle data of Refs. (54) and (55) tends to suggest that a linear relationship between noise level and acceleration might be equally valid. The driver's use of gears affects the noise level both by the choice of gear and the acceleration demanded and hence introduces a large scatter to the noise data.

Figs. 7.4 and 7.5 show the results of the deceleration runs of the two cars and the lorry respectively. The results from the cars have a definite trend of reducing the noise as the amount of deceleration increases. A regression line was fitted to the data and found to have a slope of 3.4dBA/m/s² and a correlation coefficient of 0.82. The value of the intercept was found to be 1.2dBA; this would suggest that the data was insufficient because the intercept would be expected to have a zero value, or that linear representation should not be used. During the experiment carried out on the TRRL test track, no deceleration runs were made in which deceleration values fall beyond -3.0m/s². However, in one of the pilot studies deceleration values beyond -3.0m/s² were recorded and found to have the effect of increasing noise levels by up to 4dBA. The
Fig. 7.2a Individual Vehicle Noise Study - Additional Noise vs. Acceleration - Lorry

Fig. 7.2b Increase in Noise Levels Produced by Individual Vehicles During Maximum Acceleration (Ref.55)
Fig. 7.3a Individual Vehicle Noise Study - Additional Noise vs. Acceleration - Cars

Fig. 7.3b Increase in Noise Levels Produced by Individual Vehicles During Maximum Acceleration (Ref. 54)
Fig. 7.4  Additional Noise vs. Deceleration for Cars

Coeff. of correlation = 0.82
S.E. of estimate = 1.6dBA
\[ Y = 1.2 + 3.4x \]
Additional Noise vs. Deceleration - Lorry

○ Applying brakes and/or at low gear

\[ Y = -7.8 + 16.3X \]

\[ \text{Coeff. of Corr.} = 0.85 \]

\[ x \] At high gear

\[ Y = 0.3 - 6.6X \]

\[ \text{Coeff. of Corr.} = 0.25 \]
results from the lorry deceleration runs (Fig. 7.5) have two
different trends. Noise levels seem to increase if the decel-
eration is obtained when the vehicle is running in high gear
(no brakes applied). Values of decelerations obtained for the
two cases explained above were from different speed runs.

The number of runs was very limited, hence the non-zero
intercept and the scatter, casting doubt on the linear relat-
ionship. The random choice of deceleration technique might then
lead to an average effect of zero noise increment for heavy
vehicles. No change in noise level was the assumption used
in the simulation. The noise reduction for cars would have no
effect on $L_{10}$.

7.5 THE FREE-FLOW MODEL

A number of simulation runs with an individual vehicle
distance attenuation constant of 20, i.e. (6dB per doubling
the distance "20 log $d/d_0$") were made and compared with the
standard prediction method CORTN\(^{(3)}\). Table 7.4 and Fig. 7.6
give the details of the runs and the comparison. The mean error
between predicted and simulated values was found to be 1.0dBA
and the standard error of estimate was found to be 1.8dBA (the
values of mean error and standard error of estimate were
obtained by using a standard program).

The attenuation constant was changed to 18 and a number of
simulation runs were made and compared with the predicted values
(Table 7.5 and Fig. 7.7). The mean error was reduced to 0.06dBA
and the standard error of estimate to 1.0dBA. The apparent incon-
sistency of an attenuation constant of less than 20 is explained
by the effect of "wind towards the measurement point" that is
<table>
<thead>
<tr>
<th>FLOW VPH</th>
<th>% OF HCV</th>
<th>SPEED KPH</th>
<th>SAMPLING TIME, SEC</th>
<th>10 M</th>
<th>50 M</th>
<th>100 M</th>
<th>150 M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>SIMULATED L₁₀ dBA</td>
<td>L₁₀ FROM CORTN</td>
<td>Δ L₁₀ dBA</td>
<td>SIMULATED L₁₀ dBA</td>
<td>L₁₀ FROM CORTN</td>
</tr>
<tr>
<td>220</td>
<td>30.3</td>
<td>60</td>
<td>540</td>
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<td>68.4</td>
<td>+1.56</td>
<td>59.84</td>
</tr>
<tr>
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<td>60</td>
<td>540</td>
<td>74.29</td>
<td>73.4</td>
<td>+0.89</td>
<td>62.28</td>
</tr>
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<td>540</td>
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<td>72.9</td>
<td>+0.83</td>
<td>66.21</td>
</tr>
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<td>60</td>
<td>600</td>
<td>73.73</td>
<td>72.9</td>
<td>+0.83</td>
<td>66.21</td>
</tr>
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<td>25.9</td>
<td>60</td>
<td>600</td>
<td>73.73</td>
<td>72.9</td>
<td>+0.83</td>
<td>66.21</td>
</tr>
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<td>+0.37</td>
<td>66.11</td>
</tr>
</tbody>
</table>
Fig. 7.6  Free-flow Simulated and Predicted by CORTN(3)
- Attenuation Constant = 20
Table 7.5  Simulated and Predicted $L_{10}$ Values - FREE FLOW MODEL

<table>
<thead>
<tr>
<th>FLOW VPH</th>
<th>% OF HCV</th>
<th>SPEED KPH</th>
<th>SAMPLING TIME, SEC</th>
<th>SIMULATED $L_{10}$</th>
<th>$\Delta L_{10}$</th>
<th>SIMULATED $L_{10}$</th>
<th>$\Delta L_{10}$</th>
<th>SIMULATED $L_{10}$</th>
<th>$\Delta L_{10}$</th>
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<td>+0.1</td>
<td>69.10</td>
<td>-0.68</td>
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<td>768</td>
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<td>74.64</td>
<td>+0.94</td>
<td>67.57</td>
<td>-0.13</td>
<td>64.51</td>
<td>-0.29</td>
<td>62.66</td>
<td>-0.54</td>
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<tr>
<td>870</td>
<td>35.2</td>
<td>60</td>
<td>600</td>
<td>73.92</td>
<td>+0.43</td>
<td>68.27</td>
<td>-0.43</td>
<td>65.13</td>
<td>-0.67</td>
<td>63.29</td>
<td>-0.91</td>
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<td>68.27</td>
<td>-0.43</td>
<td>65.13</td>
<td>-0.67</td>
<td>63.29</td>
<td>-0.91</td>
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<tr>
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<td>67.56</td>
<td>+0.26</td>
<td>64.24</td>
<td>-0.56</td>
<td>62.95</td>
<td>+0.15</td>
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<td>720</td>
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<td>600</td>
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<td>68.42</td>
<td>-0.68</td>
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<td>-0.88</td>
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<td>67.16</td>
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<td>-0.68</td>
<td>62.56</td>
<td>-0.84</td>
<td></td>
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</tr>
<tr>
<td>714</td>
<td>40.3</td>
<td>20</td>
<td>600</td>
<td>75.14</td>
<td>+0.04</td>
<td>68.34</td>
<td>-0.76</td>
<td>65.27</td>
<td>-0.93</td>
<td>63.35</td>
<td>-1.25</td>
<td></td>
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</tr>
<tr>
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<td>20</td>
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<td>-0.02</td>
<td>66.81</td>
<td>-0.19</td>
<td>63.79</td>
<td>-0.31</td>
<td>61.92</td>
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<tr>
<td>1386</td>
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<td>600</td>
<td>75.14</td>
<td>-0.06</td>
<td>69.49</td>
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<td>66.46</td>
<td>+0.16</td>
<td>64.27</td>
<td>-1.03</td>
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<tr>
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<td>600</td>
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<td>+1.77</td>
<td>67.69</td>
<td>+1.29</td>
<td>64.27</td>
<td>+1.03</td>
<td>62.17</td>
<td>+0.27</td>
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<td>423</td>
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<td>72</td>
<td>1200</td>
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<td>+1.77</td>
<td>67.69</td>
<td>+1.29</td>
<td>64.27</td>
<td>+1.03</td>
<td>62.17</td>
<td>+0.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>642</td>
<td>8.9</td>
<td>72</td>
<td>1200</td>
<td>73.07</td>
<td>+2.17</td>
<td>67.00</td>
<td>+2.1</td>
<td>63.96</td>
<td>+1.96</td>
<td>61.96</td>
<td>+1.54</td>
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<td></td>
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<tr>
<td>1350</td>
<td>16.4</td>
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<td>600</td>
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<td>+1.53</td>
<td>69.07</td>
<td>+1.07</td>
<td>65.91</td>
<td>+0.81</td>
<td>64.75</td>
<td>+0.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2493</td>
<td>16.97</td>
<td>20</td>
<td>600</td>
<td>77.25</td>
<td>+0.65</td>
<td>70.90</td>
<td>+0.65</td>
<td>68.25</td>
<td>+0.65</td>
<td>66.60</td>
<td>+0.65</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 7.7 Free Flow Simulated and Predicted by CORTN (3)
built into the CORTN(3).

The effect of the distance of the measurement point from the traffic stream was compared between the CORTN and the TRRL model FREL(82). Table 7.6 gives details of some runs made of the 'FREL' program; values in columns 3 and 5 are compared with -6.0 and -8.9dBA from the CORTN respectively.

It has been found that 'FREL' overestimates noise levels by values varying between 2.8 & 6.5dBA at a distance of the observation point of 10m, for the range of speeds, flows and percentage of heavy vehicles given in Table 7.6.

As it was stated in the section on car-following theory that it is applicable for dense traffic conditions, this makes the models applicable for the same conditions. A number of runs were made with low flow conditions and others with speed more than 75kph. Runs with high speed have shown similar trends to those with low flow. This is explained by the fact that vehicles travelling at high speed tend to leave longer distances between them than those when they travel at low speed, in this case the car-following theory is no longer applicable.

From the runs which were made on the low flow it was found that the model is applicable for flows greater than 300VPH and with speed equal to or less than 75kph. These conditions cover urban traffic conditions quite comfortably.

7.6 THE SIGNALISED INTERSECTION MODEL

Some of the results from the analysis of the noise and video tapes were used to test the validity of the signalised intersection model. It was tested for a four-way and a three-way intersection (T-junction). The two sites were Belton Rd./
Table 7.6  \[L_{10}\] Increment Due to Increasing Distance

<table>
<thead>
<tr>
<th>TRAFFIC CHARACTERISTICS (AVERAGE FLOW*)</th>
<th>[L_{10}] Increment Due to Increasing Distance from 10m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50m</td>
</tr>
<tr>
<td>SPEED KPH</td>
<td>PERCENT OF MCV</td>
</tr>
<tr>
<td>72</td>
<td>0.0</td>
</tr>
<tr>
<td>72</td>
<td>20.0</td>
</tr>
<tr>
<td>60</td>
<td>20.0</td>
</tr>
<tr>
<td>90</td>
<td>0.0</td>
</tr>
</tbody>
</table>

* For each sample flows of 200, 800, 1200 and 2000VPH were taken. The values shown in columns 3 and 5 are the average of the four values of the flows mentioned above.

Table 7.7  Regression Results of Measured Against Predicted Levels

<table>
<thead>
<tr>
<th>Site</th>
<th>CORTN Mean Error of Est. dBA</th>
<th>CORTN St. Error dBA</th>
<th>CORTN Correlation Coeff.</th>
<th>TRRL-Urban* Mean Error of Est. dBA</th>
<th>TRRL-Urban* St. Error dBA</th>
<th>TRRL-Urban* Correlation Coeff.</th>
<th>Present Simulation Mean Error of Est. dBA</th>
<th>Present Simulation St. Error dBA</th>
<th>Present Simulation Correlation Coeff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-way Intersection</td>
<td>0.04</td>
<td>1.04</td>
<td>0.51</td>
<td>-1.17</td>
<td>1.06</td>
<td>-0.16</td>
<td>-0.8</td>
<td>0.66</td>
<td>0.86</td>
</tr>
<tr>
<td>3-way Intersection</td>
<td>-0.87</td>
<td>1.3</td>
<td>0.4</td>
<td>-1.64</td>
<td>0.74</td>
<td>0.75</td>
<td>0.13</td>
<td>0.68</td>
<td>0.83</td>
</tr>
</tbody>
</table>

* Distances > 30m from the intersection
Derby Rd. intersection (Plate 6.1) and Leicester Rd./King St. (Plate 6.2) intersection respectively. The conditions at the chosen two sites complied closely with the criteria for choice of sites (see Section 6.5.1) and the rules of operation (Section 5.2.1).

Tables 9.1 and 9.3 give the details of the results of the analysis compared with runs of the model. Figs. 7.8 and 7.9 show the results of the comparison. The mean error and standard error of estimates were found to be $-0.8$ and $0.7\text{dBA}$ for the four-leg intersection and $0.1$ and $0.7\text{dBA}$ for the signalised T intersection.

A computer program (Appendix 2) was written to carry out the procedure of CORTN, this computer program was used to calculate the comparable noise levels for the values given in Tables 9.1 and 9.3. Figs. 7.10 and 7.11 show the results of the comparison of the measured data with the predicted data by CORTN.

Computer runs were made for the URBANN program for the results of the above-mentioned sites to compare it with the measured data. The 'URBANN' program does not have provision to include intersections and therefore only those measurements made at distances thirty metres and more from the intersection were compared.

A summary of the results of the comparisons made between measured data, CORTN, URBANN and the signalised intersection model are given in Table 7.7.

The program in Appendix 2 was also used to compare the results of the analysis of High St./Woodgate intersection with the CORTN predicted values (see Table 9.5, Fig. 7.12). Fig. 7.13 shows simulated and observed noise histories for
comparable traffic conditions which show similar patterns.
Fig. 7.8 Simulated vs. Measured Noise Levels - 4-way Intersection

Fig. 7.9 Simulated vs. Measured Noise Levels - 3-way Intersection (T-junction)
Fig. 7.10  Measured vs. Predicted $L_{10}$ dBA
for Belton Rd./Derby Rd. Intersection

Fig. 7.11  Measured vs. Predicted $L_{10}$ dBA
for Leicester Rd./King St. Intersection
Fig. 7.12 Measured vs. Predicted $L_{10}$ dBA for High St./Woodgate Intersection
Fig. 7.13 Noise histories a. simulated, b. measured
CHAPTER 8 STUDIES USING THE MODELS

8.1 GENERAL

Shannon (175) defines simulation as "the process of designing a computerised model of a system (or process) and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies for the operation of the system."

Direct experimentation on complex systems is often not practical and feasible; on the other hand, when experimenting on the computer model of a system, the experimenter has considerable ease on the control of the model structure, the parameter and the policy variations and on the measurability of the results. Insight gained from the experimentation on the model provides a basis for the improvement of the system effectiveness. By providing an opportunity for experimentation and a basis for decision making, modelling is of vital importance in the management of complex systems. This chapter is aimed at showing the potential of the models.

8.2 EFFECT OF INCLUDING THREE CLASSES OF VEHICLE RATHER THAN TWO ON THE FREE-FLOW MODEL

A number of runs have shown that using three vehicles classes rather than two would not significantly affect the noise results. Table 8.1 and Figure 8.1 give the details of these tests compared with the Calculation of Road Traffic Noise (3). The tests have covered a wide range of conditions. This finding agrees with Nelson's suggestion (46).
Table 8.1 The Effect of Including Three Classes of Vehicles on the Free-Flow Model

(a) Two Classes of Vehicle

<table>
<thead>
<tr>
<th>Flow VPH</th>
<th>% Heavy Comm. Veh. (PCH)</th>
<th>Speed KPH</th>
<th>No. of Simulation Runs</th>
<th>Average $L_{10}$ dBA Calculated</th>
<th>$L_{10}$ from Calculation of Road Traffic Noise</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>860</td>
<td>21.42</td>
<td>72.0</td>
<td>3</td>
<td>73.80</td>
<td>73.90</td>
<td>-0.1</td>
</tr>
<tr>
<td>434</td>
<td>9.64</td>
<td>72.0</td>
<td>3</td>
<td>70.70</td>
<td>69.10</td>
<td>+0.8</td>
</tr>
<tr>
<td>214</td>
<td>43.26</td>
<td>72.0</td>
<td>3</td>
<td>69.90</td>
<td>70.00</td>
<td>-0.1</td>
</tr>
<tr>
<td>868</td>
<td>43.59</td>
<td>60.0</td>
<td>3</td>
<td>75.00</td>
<td>75.50</td>
<td>-0.5</td>
</tr>
<tr>
<td>392</td>
<td>19.51</td>
<td>60.0</td>
<td>3</td>
<td>69.90</td>
<td>69.40</td>
<td>+0.5</td>
</tr>
<tr>
<td>246</td>
<td>20.89</td>
<td>60.0</td>
<td>3</td>
<td>68.00</td>
<td>67.70</td>
<td>+0.3</td>
</tr>
<tr>
<td>870</td>
<td>18.84</td>
<td>20.0</td>
<td>3</td>
<td>74.30</td>
<td>72.90</td>
<td>+1.4</td>
</tr>
<tr>
<td>436</td>
<td>7.93</td>
<td>20.0</td>
<td>3</td>
<td>67.70</td>
<td></td>
<td>+1.0</td>
</tr>
</tbody>
</table>

(b) Three Classes of Vehicle

<table>
<thead>
<tr>
<th>Flow VPH</th>
<th>% Med. Comm. Veh. (PCM)</th>
<th>% HCV</th>
<th>Speed KPH</th>
<th>No. of Simulation Runs</th>
<th>Average $L_{10}$ dBA Calculated</th>
<th>$L_{10}$ from Calculation of Road Traffic Noise</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>864</td>
<td>10.21</td>
<td>10.49</td>
<td>72</td>
<td>3</td>
<td>73.5</td>
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</tr>
<tr>
<td>452</td>
<td>6.55</td>
<td>3.74</td>
<td>72</td>
<td>3</td>
<td>70.7</td>
<td>69.4</td>
<td>+1.3</td>
</tr>
<tr>
<td>226</td>
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<td>72</td>
<td>3</td>
<td>69.4</td>
<td>69.5</td>
<td>-0.1</td>
</tr>
<tr>
<td>797</td>
<td>8.07</td>
<td>12.61</td>
<td>60</td>
<td>4</td>
<td>72.3</td>
<td>73.8</td>
<td>-1.5</td>
</tr>
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<td>402</td>
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<td>10.8</td>
<td>60</td>
<td>3</td>
<td>70.5</td>
<td>70.0</td>
<td>+0.5</td>
</tr>
<tr>
<td>196</td>
<td>14.54</td>
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<td>68.4</td>
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<td>71.5</td>
<td>69.7</td>
<td>+1.8</td>
</tr>
<tr>
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<td>13.0</td>
<td>18.79</td>
<td>20</td>
<td>3</td>
<td>69.9</td>
<td>68.6</td>
<td>+1.3</td>
</tr>
</tbody>
</table>
Fig. 8.1 Simulated vs. Predicted by CORTN, Base Line Distance (10m)
8.3 **EFFECT OF CYCLE TIME**

A number of runs of the signalised intersection model have been made with different flows, percentages of medium and heavy commercial vehicles and cycle times. The results of these runs are shown in Table 8.2. The general trend of $L_{10}$ values, when the traffic is composed of light vehicles only, indicates that noise levels decrease with the increase of cycle time. This may be due to the fact that the longer the cycle time, the less number of "first" vehicle free accelerations (when the light changes to green) which has a significant effect on individual vehicle noise (see Section 8.4). This finding supports Favre(63)'s suggestion.

$L_{eq}$ values seem to take somewhat similar pattern forms to $L_{10}$ and there might be an optimum $L_{eq}$ value associated with a specific cycle time for each condition. The trend which $L_{10}$ and $L_{eq}$ values take when the traffic is composed of light vehicles only might still hold when the percentage of heavies is small (less than 20%). No runs have been made to support this suggestion.

When the percentages of medium and heavy commercial vehicles are $> 20\%$, the patterns which $L_{10}$ and $L_{eq}$ values take are complex. The random presence of HCV accelerating or at high speeds appears to mask any effect of cycle time.

The results of the 1200VPH, with no medium or heavies, is an average of three different runs and those of the 2000VPH are the average of two runs. These different runs have given results of $L_{10}$ values within 1dBA from each other while results of $L_{eq}$ values have been within 0.5dBA. This is due to the different sample of vehicles with different maximum accelerations.
### Table 8.2 Effect of Cycle Time (Single Intersection)

<table>
<thead>
<tr>
<th>Flow VPH</th>
<th>PCM PCH</th>
<th>60 sec.</th>
<th>90 sec.</th>
<th>120 sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$L_{10}$</td>
<td>$L_{50}$</td>
<td>$L_{90}$</td>
</tr>
<tr>
<td>1200*</td>
<td></td>
<td>75.5</td>
<td>69.3</td>
<td>65.3</td>
</tr>
<tr>
<td>2000*</td>
<td></td>
<td>76.9</td>
<td>71.5</td>
<td>70.0</td>
</tr>
<tr>
<td>2800*</td>
<td></td>
<td>77.5</td>
<td>72.7</td>
<td>71.0</td>
</tr>
<tr>
<td>1200* 20*</td>
<td></td>
<td>79.9</td>
<td>74.9</td>
<td>68.9</td>
</tr>
<tr>
<td>2200* 40*</td>
<td></td>
<td>80.8</td>
<td>78.4</td>
<td>75.4</td>
</tr>
</tbody>
</table>

* Nominal input values, output vary within ±5%
and desired speeds and the relatively short sampling time (less than 10 minutes).

8.4 **THE EFFECT OF THE INTRODUCTION OF QUIETER VEHICLES**

Table 8.3 shows results of introducing four different policies:

1. Making the effect of acceleration on noise = 0.
2. Reducing the noise emitted by light vehicles by 5dBA.
3. Reducing the noise emitted by medium and heavy vehicles by 10dBA, and
4. Introducing both policies (2) and (3) together.

Three different flows with one percentage of medium and heavy vehicles of 10% each have been made (the results in the table are different from the 10% because of the randomness of the model), two runs were made with 0% of medium and heavy vehicles and one with 40% of medium and heavy commercial vehicles.

Results have shown that making the effect of acceleration on noise equal to zero have a significant effect on values of $L_{10}$ and $L_{eq}$ in all the cases considered; when the percentage of medium and heavies $\geq$ 20% (both), it gives slightly better results than quietening vehicles by 5dBA. This also shows that simulation models of interrupted traffic flow should include the acceleration parameter. Policy number 4, i.e. quietening light vehicles by 5dBA and heavy vehicles by 10dBA gives the most significant effect when the percentage of medium and heavies $\geq$ 20% as expected. Policy number 3 gives the next largest reduction.
Table 8.3  Effect of Noise Control Policies

<table>
<thead>
<tr>
<th>Flow VPH</th>
<th>PCM</th>
<th>PCH</th>
<th>Reduction in L\textsubscript{10} Policy No.</th>
<th>Reduction in L\textsubscript{eq} Policy No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1252</td>
<td>0.0</td>
<td>0.0</td>
<td>3.4</td>
<td>-</td>
</tr>
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<td>2808</td>
<td>0.0</td>
<td>0.0</td>
<td>3.6</td>
<td>-</td>
</tr>
<tr>
<td>1173</td>
<td>10.4</td>
<td>8.0</td>
<td>2.0</td>
<td>1.6</td>
</tr>
<tr>
<td>2109</td>
<td>9.6</td>
<td>8.5</td>
<td>0.9</td>
<td>0.4</td>
</tr>
<tr>
<td>2656</td>
<td>10.0</td>
<td>8.4</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>2102</td>
<td>19.2</td>
<td>18.2</td>
<td>0.9</td>
<td>0.3</td>
</tr>
</tbody>
</table>
8.5 THE EFFECT OF LINKING OF TRAFFIC SIGNALS

The effect of two forms of linking on noise have been examined:

a. Simultaneous system (synchronized system). All the signals along the controlled section display the same aspect to the same traffic stream at the same time.

b. Alternate system (limited progressive system). With this system consecutive signal installations along a given road show contrary indications. The aim is for vehicles to travel one block in half the cycle time (where more than two sets of traffic signals exist).

Table 8.4 shows the results of the noise levels monitored at three different positions along the road (Fig.5.2), for identical entry traffic samples.

Although a limited number of runs have been made, changes in values of more than 1dBA in $L_{10}$ and $L_{eq}$ have been found. This shows that this area is worth investigating in more detail. Some of the runs have been made with different speed values. Results have shown that different speed values do not seem to have affected noise levels. This agrees with Gilbert's finding. Table 8.4 also shows that the difference between free-flow and interrupted flow levels (at b compared with a) have an average value of 4.4dBA compared with the 3.2dBA found in Reference (17).
Table 8.4 Paired Traffic Signal Levels

<table>
<thead>
<tr>
<th>Flow VPH/LANE (PCM+PCH)</th>
<th>Speed of Cars* kph</th>
<th>Cycle Time d</th>
<th>Ints. 1</th>
<th>Ints. 2</th>
<th>Noise Level at a Noise Level at b+ Noise Level at c dB</th>
<th>dB</th>
<th>dB</th>
<th>dB</th>
<th>dB</th>
<th>dB</th>
<th>dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 (20)</td>
<td>65</td>
<td>660</td>
<td>100</td>
<td>Green</td>
<td>Green</td>
<td>78.5</td>
<td>75.4</td>
<td>71.7</td>
<td>75.6</td>
<td>74.2</td>
<td>69.8</td>
</tr>
<tr>
<td>400 (20)</td>
<td>65</td>
<td>660</td>
<td>100</td>
<td>Green</td>
<td>Red</td>
<td>79.4</td>
<td>77.1</td>
<td>74.8</td>
<td>76.9</td>
<td>74.8</td>
<td>70.7</td>
</tr>
<tr>
<td>400 (20)**</td>
<td>65</td>
<td>660</td>
<td>100</td>
<td>Green</td>
<td>Green</td>
<td>78.1</td>
<td>75.0</td>
<td>71.8</td>
<td>75.1</td>
<td>73.6</td>
<td>69.0</td>
</tr>
<tr>
<td>600 (20)</td>
<td>50</td>
<td>258</td>
<td>80</td>
<td>Green</td>
<td>Green</td>
<td>79.9</td>
<td>77.4</td>
<td>75.5</td>
<td>77.4</td>
<td>75.9</td>
<td>72.3</td>
</tr>
<tr>
<td>600 (20)</td>
<td>50</td>
<td>258</td>
<td>80</td>
<td>Green</td>
<td>Red</td>
<td>80.1</td>
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<td>77.3</td>
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<td>71.7</td>
</tr>
<tr>
<td>100 (20)</td>
<td>50</td>
<td>660</td>
<td>100</td>
<td>Green</td>
<td>Green</td>
<td>78.5</td>
<td>75.4</td>
<td>72.1</td>
<td>75.6</td>
<td>74.0</td>
<td>68.9</td>
</tr>
<tr>
<td>400 (20)</td>
<td>50</td>
<td>660</td>
<td>100</td>
<td>Green</td>
<td>Red</td>
<td>79.2</td>
<td>77.2</td>
<td>74.9</td>
<td>76.8</td>
<td>74.2</td>
<td>69.5</td>
</tr>
<tr>
<td>400 (20)**</td>
<td>50</td>
<td>660</td>
<td>100</td>
<td>Green</td>
<td>Green</td>
<td>78.0</td>
<td>74.9</td>
<td>71.3</td>
<td>75.0</td>
<td>72.9</td>
<td>66.8</td>
</tr>
<tr>
<td>600 (20)</td>
<td>50</td>
<td>258</td>
<td>40</td>
<td>Green</td>
<td>Green</td>
<td>79.7</td>
<td>77.2</td>
<td>74.9</td>
<td>77.2</td>
<td>75.2</td>
<td>72.1</td>
</tr>
<tr>
<td>600 (20)</td>
<td>50</td>
<td>258</td>
<td>40</td>
<td>Green</td>
<td>Red</td>
<td>79.0</td>
<td>76.3</td>
<td>73.1</td>
<td>76.3</td>
<td>74.9</td>
<td>72.0</td>
</tr>
<tr>
<td>400 (20)</td>
<td>60</td>
<td>660</td>
<td>100</td>
<td>Green</td>
<td>Green</td>
<td>78.0</td>
<td>75.9</td>
<td>72.5</td>
<td>75.7</td>
<td>73.9</td>
<td>69.7</td>
</tr>
<tr>
<td>400 (20)</td>
<td>60</td>
<td>660</td>
<td>100</td>
<td>Green</td>
<td>Red</td>
<td>79.3</td>
<td>77.2</td>
<td>74.9</td>
<td>77.0</td>
<td>74.9</td>
<td>70.2</td>
</tr>
<tr>
<td>400 (20)**</td>
<td>60</td>
<td>660</td>
<td>100</td>
<td>Green</td>
<td>Green</td>
<td>78.3</td>
<td>75.2</td>
<td>72.1</td>
<td>75.1</td>
<td>73.3</td>
<td>67.8</td>
</tr>
<tr>
<td>600 (30)</td>
<td>50</td>
<td>130</td>
<td>100</td>
<td>Green</td>
<td>Green</td>
<td>81.0</td>
<td>79.1</td>
<td>76.2</td>
<td>78.7</td>
<td>77.7</td>
<td>75.8</td>
</tr>
<tr>
<td>600 (30)**</td>
<td>50</td>
<td>130</td>
<td>100</td>
<td>Green</td>
<td>Green</td>
<td>79.9</td>
<td>78.0</td>
<td>76.2</td>
<td>77.8</td>
<td>76.4</td>
<td>74.0</td>
</tr>
</tbody>
</table>

PCM = Percentage of medium commercial vehicles
PCH = Percentage of Heavy commercial vehicles
* = Speed of medium and heavy commercial vehicles is constant = 50kph
** = with bus lane
+ = b = d/2 + 10m
8.6 **TRANSYT METHOD**

The Transport and Road Research Laboratory (TRRL) has developed a computer program called TRANSYT (*Traffic Network Study Tool*)\(^{183,184}\) to optimise the green splits of traffic signals in a road network as well as the offsets between successive signals so as to reduce the overall delay and the number of unnecessary stops. It is an off-line method of urban traffic control where the signal settings are selected according to historical data fed into the computer and is based on the assumption that traffic patterns are repeated each cycle, although a random delay component is introduced to take into consideration the fluctuation in vehicle flow.

Seven versions of the computer program that implements the TRANSYT method have been produced over the period from 1967 to 1978. In versions (5), (6) and (7), the program has the facility of optimising offsets and green settings to minimise passenger delays rather than vehicle delays. If this facility is used the TRANSYT run will be called hereafter "BUS TRANSYT" as opposed to "BASIC TRANSYT" when delays of all vehicles are weighted equally.

A copy of TRANSYT-6 program was obtained and adopted to be used on the Loughborough University computer.

The TRANSYT program was used to calculate the settings and offsets of the pair of the signalised intersections simulated in the present work (Fig. 5.2). The program was run so as to optimise the offsets and settings of both intersections.

The pair of signalised intersections model was then run to calculate noise levels at the intersections and along the road linking them when linked according to the TRANSYT output and then as linked by the simultaneous method. Results of these
runs are shown in Table 8.5.

Results of Table 8.5 show that the effect of the TRANSYT method of linking when compared with a simultaneous linking system is to reduce noise levels generally at the mid-distance point (b in Fig. 5.2) between the intersections with respect to that at the intersections themselves.

It has not been possible to use the finding reported in Chapter 9 to validate the model for several reasons, namely:

1. Different road layouts, e.g. bends, very long distances.
2. The settings and the offsets of the signals in Loughborough before the inception of the UTC system were not known and because the signals were operating in vehicle-actuated mode the offsets may well have been of a random nature.
3. Making comparisons of the noise levels at point (b) (mid-distance point) between the model and the measurements at Loughborough were not valid without having similar noise levels at point (a) (Fig. 5.2) which, in turn, was not possible without making a large number of runs. Many runs would be required to allow interpolation between the parameter values so that the model noise level at point (a) could be corrected to equal that measured at Loughborough. Alternatively a number of runs are required to allow the noise levels at intermediate points between (a) and (b) to be computed, in which case the comparison with measured data would be made between noise gradients rather than noise levels at specific points.
Table 8.5  Paired Traffic Signal Levels - Transyt Linking

<table>
<thead>
<tr>
<th>RUN No.</th>
<th>FLOW</th>
<th>VPH/LANE</th>
<th>e</th>
<th>d</th>
<th>MODE OF LINKING</th>
<th>NOISE LEVEL AT a</th>
<th>NOISE LEVEL AT b</th>
<th>NOISE LEVEL AT c</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>L_{10}</td>
<td>L_{50}</td>
<td>L_{90}</td>
</tr>
<tr>
<td>(1)</td>
<td>400</td>
<td>660</td>
<td></td>
<td></td>
<td>TRANSYT</td>
<td>83.7</td>
<td>77.6</td>
<td>72.7</td>
</tr>
<tr>
<td>(2)</td>
<td>400</td>
<td>660</td>
<td></td>
<td></td>
<td>SIMULT.</td>
<td>82.5</td>
<td>76.5</td>
<td>73.5</td>
</tr>
<tr>
<td>(3)</td>
<td>400</td>
<td>150</td>
<td></td>
<td></td>
<td>TRANSYT</td>
<td>84.4</td>
<td>78.8</td>
<td>74.3</td>
</tr>
<tr>
<td>(4)</td>
<td>400</td>
<td>150</td>
<td></td>
<td></td>
<td>SIMULT.</td>
<td>81.1</td>
<td>76.5</td>
<td>73.0</td>
</tr>
<tr>
<td>(5)</td>
<td>400</td>
<td>150</td>
<td></td>
<td></td>
<td>SIMULT.</td>
<td>83.9</td>
<td>79.0</td>
<td>74.3</td>
</tr>
<tr>
<td>(6)</td>
<td>600</td>
<td>660</td>
<td></td>
<td></td>
<td>TRANSYT</td>
<td>82.7</td>
<td>78.7</td>
<td>75.6</td>
</tr>
<tr>
<td>(7)</td>
<td>600</td>
<td>660</td>
<td></td>
<td></td>
<td>TRANSYT</td>
<td>83.3</td>
<td>79.1</td>
<td>73.0</td>
</tr>
<tr>
<td>(8)</td>
<td>600</td>
<td>660</td>
<td></td>
<td></td>
<td>SIMULT.</td>
<td>81.1</td>
<td>77.6</td>
<td>74.4</td>
</tr>
<tr>
<td>(9)</td>
<td>600</td>
<td>150</td>
<td></td>
<td></td>
<td>TRANSYT</td>
<td>82.7</td>
<td>78.9</td>
<td>76.6</td>
</tr>
<tr>
<td>(10)</td>
<td>600</td>
<td>150</td>
<td></td>
<td></td>
<td>SIMULT.</td>
<td>83.9</td>
<td>80.4</td>
<td>76.9</td>
</tr>
</tbody>
</table>

* with values of PCM and PCH < 20%
Assuming that $L_{10}$ values at the intersections (point (a)) can be adjusted to be equal by the addition of a constant noise increment to all points, the average mid-point $L_{10}$ is reduced by 6.0 and 4.6dBA for the TRANSYT method as opposed to 5.0 and 4.0 dBA to the simultaneous system for the distances of 330 and 75m respectively.

Figure 8.2 shows the value of $L_{10}$ (difference between noise level at points a and b) in dBA (obtained from Tables 8.4 and 8.5) against distance away from the intersections. TRANSYT appears to give the highest reduction in noise levels away from the intersection compared with the other methods (Alternate and Simultaneous). The Alternate method gives the next highest reduction followed by the simultaneous method. It is interesting to note that whilst the Alternate and Simultaneous methods give reductions which lie within less than 0.5dBA between one another at distances of about 300m, TRANSYT method gives reductions of more than 1.0dBA compared with the next best at the same distance.

8.7 EFFECT OF BUS LANES

It has been generally accepted that priority to public transport is essential, especially in large cities, for a more efficient transport system. Buses, which represent one form of public transport, are often delayed due to their size, slow movement and interference from other traffic (mainly cars). As a bus carries many more passengers than a private car, research has been concentrated in recent years to give buses priority whenever and wherever possible. The use of bus lanes in their two forms with-flow and contra-flow, is one outcome
Fig. 8.2 Effect of Distance
Simulated Noise Levels - Different Linking Systems
of the priorities which have been given to buses in the U.K. (and many other countries). Despite their widespread use, bus lanes have not been studied from the point of view of their effect on the environment. In the present work an attempt has been made to do so. The model has been used for this purpose and four runs with bus lanes have been made and compared with ones without. The results are illustrated in Table 8.4. Improvements of more than 1dBA in $L_{10}$ and $L_{eq}$ values have been found along the road linking the signalised intersections (this is usually the region of interest, since buses get special treatment at intersections).

8.8 **THE EFFECT OF THE SCAN INTERVAL**

Versions of the models have been used to test the effect of the scan interval on noise levels. Runs have been made with scan intervals of 0.25sec. (the value generally used in the models), 0.5sec. and 1.0sec. and the results have shown that noise levels increase with the increase of the scan interval but the effect in free-flowing conditions is minimal. Values of increases have been found to vary from 0.2dBA - more than 2dBA in $L_{10}$ values. The reason behind this trend could be due to the effect of fluctuation in acceleration which tends to happen if the scan interval is long.
CHAPTER 9 THE EFFECT OF A UTC SYSTEM ON NOISE LEVELS - 
A BEFORE AND AFTER STUDY

9.1 INTRODUCTION

In recent years there has been an emphasis on traffic management schemes in town centres. The co-ordinated control of signals over a wide area is a traffic management scheme which will produce benefits where the density of signals in an area is relatively high. Guidelines produced by the Department of the Environment indicated that Urban Traffic Control schemes could be justified if the number of signals were greater than 30, and the density of signals was not less than 10 sets/square mile (2.6km$^2$).

As early as 1963 it was suggested that smoothing the traffic flows reduces noise levels$^{(12)}$, and as the UTC system is designed to smooth flow noise reduction might be expected. Robertson$^{(172)}$ stated that "UTC systems are likely to reduce environmental effects, although evidence is somewhat limited."

This chapter gives details of a case study which is hoped to shed some light on the noise effects of UTC systems.

9.2 LEICESTER URBAN TRAFFIC CONTROL SYSTEM

It became evident that, as the number of signalised junctions in the City of Leicester increased, some form of co-ordinated control would be necessary if the maximum capacity of the road network were to be obtained.

In Leicester there are over 100 sets of signals with an average density of 15 sets per square mile (2.6km$^2$), with a maximum of double that figure in the central area. This complied with the Department of the Environment guidelines.
The scheme was conceived in 1971 and incorporated in its design the standard specification of traffic control equipment issued by the Department of the Environment. The contract was awarded to Plessey Company in 1972, the equipment was installed on site during the summer of 1974, and became fully operational during the spring of 1975.

The system operates fixed-time plans, automatically selected by the time of day. As many as 20 of these plans per junction can be held in store.

The area is split into sub-areas whose boundaries are carefully considered and should be homogeneous units with minimum interference from surrounding areas. The boundaries should intercept main traffic routes where traffic platooning is not too critical.

In Leicester, signal timing is biased in favour of buses. TRANSYT versions 6 and 7 give priority to buses.

9.2.1 Aims and Objectives

There are three major benefits from UTC systems:

1. The reduction of journey time obtained by co-ordinating the traffic signals so traffic travels along "green waves" of lights.

2. A continuous fault monitoring system which enables fault rectification to be carried out with the minimum of delay.

3. Accident reduction, pilot traffic control schemes in West London and Glasgow had also showed that the number of road accidents was reduced on implementation of area
traffic control, and a similar benefit was expected in Leicester.

9.2.2 Benefits

In May 1975 a "With and Without" survey was conducted over 2 weeks, by Leicestershire County Council, and the journey times with and without the computer controlling the signalised intersections compared.

There were three routes studied covering 35 sets of signals out of the 103 sets in the city.

Results:

<table>
<thead>
<tr>
<th></th>
<th>MORNING PEAK</th>
<th>EVENING PEAK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Journey time</td>
<td>10.0</td>
<td>5.5</td>
</tr>
<tr>
<td>No. of Vehicles hour spend on 3 routes</td>
<td>11.0</td>
<td>12.0</td>
</tr>
<tr>
<td>No. of vehicle stops</td>
<td>7.0</td>
<td>11.0</td>
</tr>
<tr>
<td>Bus journey time</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

9.2.3 Linking of Loughborough to Leicester UTC System

The most important single development has been the extension of the system to Loughborough (22km from Leicester). 14 sets of signals were connected, including 7 sets on the A6 trunk road which passes through the centre of the town. The connection was made towards the end of 1977.

Traffic plans have been developed to deal with the anticipated traffic flows throughout the day. Fixed time plans operate at peak periods when the maximum benefit can be obtained from linking. At other times and during the night the signals
revert to isolated vehicle actuated operation (as in Leicester).

9.3 THE NOISE SURVEY WITHIN THE AREA OF UTC SYSTEM

A noise survey was carried out in the few weeks just before the switching of the Loughborough system on to the computer in Leicester in 1977.

Noise and traffic data were collected using standard noise equipment and video tape recordings as described in Chapter 6. Noise and traffic samples were taken at the four sites described in Section 6.4 which were chosen because they have different flow characteristics and are representative of most other sites in Loughborough.

A similar survey was carried out during almost the same weeks a year later (1978); this was aimed at minimising the effect of the seasonal conditions which might have had an effect on the noise and/or the traffic.

Noise and traffic samples were analysed according to the procedure described in Section 6.7.

9.4 RESULTS AND DISCUSSION

Results of the analysis of the data are given in Tables 9.1 - 9.8. Tables 9.1, 9.3, 9.5 and 9.7 give the details of the results for Belton Road/Derby Road, Leicester Road/King Street, High St./Woodgate and Meadow Lane/Belton Road intersections respectively for the survey which was carried out in 1977. Tables 9.2, 9.4, 9.6 and 9.8 are the results for the same sites for the survey which was carried out in 1978.
Table 9.1: Results of the Analysis of the Data of Belton Road/Derby Road - 1977.

<table>
<thead>
<tr>
<th>Distance From Stop Line (m)</th>
<th>Distance From Kerb (m)</th>
<th>Approach</th>
<th>Measured Noise Level (dBA)</th>
<th>L10 dBA</th>
<th>L'50</th>
<th>L'90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belton Rd.</td>
<td>Derby Rd. - south</td>
<td>Alan Moss Rd. - north</td>
<td>Derby Road - north</td>
<td>FLOW</td>
<td>PCM</td>
<td>PCH</td>
</tr>
<tr>
<td>0.0</td>
<td>2.7</td>
<td>492</td>
<td>2.4 0.0</td>
<td>1044</td>
<td>6.3 2.8</td>
<td>264</td>
</tr>
<tr>
<td>15.0</td>
<td>2.7</td>
<td>378</td>
<td>0.0 3.2</td>
<td>942</td>
<td>1.3 3.9</td>
<td>396</td>
</tr>
<tr>
<td>0.0</td>
<td>2.7</td>
<td>600</td>
<td>2.0 3.0</td>
<td>960</td>
<td>5.0 0.0</td>
<td>264</td>
</tr>
<tr>
<td>15.0</td>
<td>2.7</td>
<td>408</td>
<td>0.0 2.9</td>
<td>912</td>
<td>1.3 1.3</td>
<td>402</td>
</tr>
<tr>
<td>30.0</td>
<td>2.7</td>
<td>418</td>
<td>1.3 2.6</td>
<td>888</td>
<td>2.7 2.0</td>
<td>390</td>
</tr>
<tr>
<td>45.0</td>
<td>3.0</td>
<td>318</td>
<td>5.7 9.4</td>
<td>816</td>
<td>7.4 2.9</td>
<td>348</td>
</tr>
<tr>
<td>50.0</td>
<td>3.0</td>
<td>552</td>
<td>2.2 1.1</td>
<td>906</td>
<td>7.3 4.6</td>
<td>312</td>
</tr>
<tr>
<td>50.0</td>
<td>3.0</td>
<td>326</td>
<td>3.6 7.1</td>
<td>1020</td>
<td>2.4 0.0</td>
<td>420</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>445</td>
<td>2.3 3.7</td>
<td>938</td>
<td>4.5 2.3</td>
<td>339</td>
</tr>
<tr>
<td>S.D.</td>
<td></td>
<td>104</td>
<td>2.0 3.2</td>
<td>764</td>
<td>2.5 1.6</td>
<td>62.5</td>
</tr>
<tr>
<td>N = 12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BELTON ROAD

<table>
<thead>
<tr>
<th>Approach</th>
<th>Measured Noise Level (dBA)</th>
<th>L10 dBA</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAST-W.LANE</td>
<td>EAST-W:2ND LANE WEST-E.LANE</td>
<td>74.5 68 61.0</td>
</tr>
<tr>
<td>100.0 3.0 480</td>
<td>3.8 1.3</td>
<td>374</td>
</tr>
<tr>
<td>100.0 3.0 276</td>
<td>6.5 2.2</td>
<td>372</td>
</tr>
<tr>
<td>100.0 3.0 402</td>
<td>1.5 0.0</td>
<td>456</td>
</tr>
<tr>
<td>Mean</td>
<td>386</td>
<td>3.9 1.2</td>
</tr>
<tr>
<td>S.D.</td>
<td>102.9</td>
<td>2.5 1.1</td>
</tr>
<tr>
<td>N = 3</td>
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<td></td>
</tr>
<tr>
<td>270.0 2.7 714</td>
<td>1.7 0.8</td>
<td>354</td>
</tr>
<tr>
<td>330.0 2.7 &quot;</td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>Mean</td>
<td>796</td>
<td>2.2 1.9</td>
</tr>
<tr>
<td>S.D.</td>
<td>136.4</td>
<td>0.7 1.0</td>
</tr>
</tbody>
</table>
Table 9.2  Results of the Analysis of the Data of Belton Road/Derby Road - 1978

<table>
<thead>
<tr>
<th>Distance From Stop Line (m)</th>
<th>Distance From Kerb (m)</th>
<th>Belton Road - south</th>
<th>Derby Road - north</th>
<th>Alan Moss Road</th>
<th>Mean Cycle Time (sec)</th>
<th>Measured Noise Levels - dBA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>FLOW VPH</td>
<td>PCM</td>
<td>PCH</td>
<td>FLOW VPH</td>
<td>PCM</td>
</tr>
<tr>
<td>0.0</td>
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<td>594</td>
<td>3.0</td>
<td>1.0</td>
<td>1002</td>
<td>5.4</td>
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BELTON ROAD

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EAST-WEST

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Table 9.3 Results of the Analysis of the Data of Leicester Road/King Street - 1977

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### Results of the Analysis of the Data of Leicester Road/King Street - 1978

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<th>King Street (Towards Notts.)</th>
<th>Leicester Road - Loughborough</th>
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- **Mean** values are calculated across all distances.
- **S.D.** represents the standard deviation of the calculated mean values.
- **N=** indicates the number of measurements taken at each distance.
Table 9.5  Results of the Analysis of the Data of High St./Woodgate - 1977

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<th>Distance From Kerb ( m )</th>
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<th>Leicester Road</th>
<th>Woodgate</th>
<th>Cycle Time</th>
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### Table 9.6 Results of the Analysis of the Data of High St./Woodgate - 1978

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</tr>
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|        |                        | 1347.3   | 16.2            | 529.3                      | 4.6                       | 1251.5                    | 16.0                       | 831.8 | 4.85           |
|        |                        | S.D.     | 145.6           | 152                        | 135.3                     | 1.6                       | 136.1                     | 1.5   | 111.7          |
|        |                        | N        | 12              | 12                         | 12                        | 12                        | 12                        | 12    | 12             |
|        |                        | \( \bar{x} \) | 1347.3          | 16.2                       | 529.3                     | 4.6                       | 1251.5                    | 16.0   | 831.8          |
|        |                        | S.D.     | 145.6           | 152                        | 135.3                     | 1.6                       | 136.1                     | 1.5   | 111.7          |
|        |                        | N        | 12              | 12                         | 12                        | 12                        | 12                        | 12    | 12             |

The table provides a detailed analysis of noise levels and traffic flow data at different distances from High St./Woodgate in 1978, including the measured noise levels at different distances and times, with specific values for noise levels L10, L50, and L90.
Table 9.7 Results of the Analysis of the Data of Meadow Lane/Belton Road - 1977

<table>
<thead>
<tr>
<th>Distance From Stop Line</th>
<th>Distance From Kerb m</th>
<th>Belton Road FLOW VPH</th>
<th>Belton Road PCH</th>
<th>Meadow Lane n. FLOW VPH</th>
<th>Meadow Lane n. PCH</th>
<th>Ratcliffe Road FLOW VPH</th>
<th>Ratcliffe Road PCH</th>
<th>Meadow Lane s. FLOW VPH</th>
<th>Meadow Lane s. PCH</th>
<th>Cycle Time sec.</th>
<th>Measured Noise Levels - dBA</th>
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Table 9.8 Results of the Analysis of the Data of Meadow Lane/Belton Road - 1978

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<th>Distance From Stop Line m</th>
<th>Distance From Kerb m</th>
<th>Belton Road FLOW VPH</th>
<th>PCH</th>
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<th>PCH</th>
<th>Ratcliffe Road FLOW VPH</th>
<th>PCH</th>
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<th>Cycle Time sec.</th>
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<td>130</td>
<td>68</td>
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</table>

Note: The table shows the results of the analysis of the data collected at Meadow Lane/Belton Road in 1978. The data includes measurements of flow, cycle time, and noise levels (L10, L50, L90) at various distances from the stop line and kerb. The table uses abbreviations for PCH (Peak Cycles) and VPH (Vehicle Per Hour).
A summary of the results shown in the eight tables is given in Tables 9.9 and 9.10 and Figure 9.1. It can be seen from Figure 9.1 that the introduction of the UTC system has had the effect of reducing noise levels especially at distances of more than 50m (points (5), (6), (7) and (8)) from the intersection. The trend is linear with a slope of 0.01dBA/m. The values are valid up to about 300m away from the intersections and it is believed that this trend (reduction in noise levels as the distances increase) starts to change towards less reduction at some stage. However, no data was collected to allow the exact position to be determined. As statistical tests have shown, the results are significant at three out of the four cases considered.

The reason behind the reduction in noise levels at distances at which the traffic is nearly freely-flowing due to the introduction of the UTC system could be due to the way in which the system affects platoon dispersions.

At distances up to 50m (points (1), (2), (3) and (4) in Fig. 9.1) from the intersection, the UTC system does not seem to have appreciable effect on noise levels despite the 0.5dBA shown in Fig. 9.1. This becomes clear by examining Tables 9.9 and 9.11 which show that the cycle time had been significantly increased by the introduction of the UTC system (which in turn reduces noise levels as described in Chapter 8) and that the flow had increased while decreasing the percentages of HCV (the expected effects on noise levels of the change in flow and percentage of HCV are given in Table 9.11). Taking the factors which affect noise levels (cycle time, flow and HCV %) into account with the before and after values for the
Table 9.10  Details of Fig. 9.1

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<th>Site</th>
<th>The Point No. in Fig. 9.1</th>
<th>No. of Observations Made</th>
<th>Mean $L_{10}$</th>
<th>$\Delta L_{10}$ dBA (1)-(2)</th>
<th>Range of Distances From Stop Line m</th>
<th>S.D. dBA</th>
<th>$\Delta$S.D. dBA (1)-(2)</th>
<th>T-Test</th>
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N.S.  Not significant
S  Significant at 95%
* Just failed to be significant at 95% the tabulated figure being 2.132
Fig. 9.1 The Effect of UTC System on Noise Levels

\[ Y = -0.04 + 0.01x \]

Coef. of Corr. = 0.86

S.E. of estimate = 0.64dBA
Table 9.11 Changes in Traffic Parameters, $L_{10}$ Values and Expected Changes in $L_{10}$ Values

(1) is Before, (2) is After. $\Delta PCHT = PCHT2 - PCHT1$, $\Delta Q = Q_2 - Q_1$

$PCHT = PCM + PCH$

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<td></td>
<td>(8)</td>
<td>$\Delta Q = -14 (0.98)$</td>
<td>-0.1</td>
<td>+1.8</td>
</tr>
<tr>
<td>High St./ Woodgate</td>
<td>(1)</td>
<td>$\Delta Q = 187 (1.16)$</td>
<td>+0.7</td>
<td>-2.1</td>
</tr>
<tr>
<td>Leicester Rd./ King St.</td>
<td>(2)</td>
<td>$\Delta Q = 406 (1.55)$</td>
<td>+1.85</td>
<td>-1.2</td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>$\Delta PCHT = 0.8$</td>
<td>+0.4</td>
<td>+0.2</td>
</tr>
<tr>
<td>Meadow Lane/ Belton Rd.</td>
<td>(3)</td>
<td>$\Delta Q = 383 (1.45)$</td>
<td>+1.6</td>
<td>-2.5</td>
</tr>
<tr>
<td></td>
<td>(7)</td>
<td>$\Delta PCHT = 0.37$</td>
<td>+0.37</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

"Expected $\Delta L_{10}$ Values were calculated from the CORTN"
whole four sites the total results seem to be very close, i.e. before and after are equal. This result makes it difficult to conclude whether the UTC system has improved or worsened the situation close to intersections. The results from the measurements of four sites were consistent. The test results show that no significant changes have occurred at any of the four sites (Table 9.10).

The reason behind this result (the UTC system does not have an effect on noise levels) could be the fact that at such distances (up to 50m) noise levels are dependent on individual vehicles' characteristics.

If the two sites Belton Road/Derby Road and Meadow Lane/Belton Road are considered together it can be seen that noise levels close to the intersections did not change (points nos. (3) and (4) Fig. 9.1) while those away from them (points nos. (7) and (8)) had dropped significantly (apart from point no. (5) in which noise levels had actually increased by 0.3dBA. Bearing in mind that the number of observations which were made for this point were not as many as those made for points (7), (8) and that the difference of 0.3dBA was not found to be significant (Table 9.10) this point can be regarded as a distortion to the trend. The measurements were made at Belton Road for both sites; this means that the reduction in noise levels which occurred at distances of more than 100m from the intersection do start to decrease as was suggested earlier because the levels at both intersections did not change. The length of Belton Road is about 1.2km; the measurements along it were made up to distances of
about 300m away from both intersections so the distance at which the reduction in noise levels start to decrease must lie within the remaining 600m between the two points.
10.1 CONCLUSIONS

Two models have been developed to predict road traffic noise from freely-flowing and interrupted flow traffic at signalised intersections. The models have been tested against both measurements and prediction methods and found to be in very good agreement. A third model using a similar stochastic technique to those of free-flowing and interrupted flow traffic noise models has been developed which simulates a pair of signalised intersections. This model enables the study of the effect of different traffic control strategies.

All three models have been built to be as accurate, realistic and representative of actual life as possible without undue complications. At the same time the models have been simplified to save computer time whenever this was possible and does not affect the accuracy of the noise results.

The video tape technique has been used extensively in this study and proved to be a very useful tool when used in noise studies, especially in complex situations by significantly reducing the manpower requirements for data collection and permitting detailed study of vehicle behaviour and noise relationships. Indeed, this has been well illustrated in the technique devised for studying individual vehicle noise levels in the present work.

The models have been used for the evaluation of various traffic and/or noise control strategies and found to be very useful. A variety of cases have been examined from vehicle source control to urban traffic control systems and noise level ($L_{10}$ or $L_{eq}$) can readily be altered by around 1dBA by choice of
control strategy. These evaluations reveal the potential of the models in these fields and open the door for exploring them fully and to carry out many other studies. These models would form a good basis for a comprehensive package to study and predict road traffic noise.

The effect of the implementation of the UTC system in Loughborough has been investigated and found to have had the effect of maintaining noise levels at the intersections considered and reducing the levels away from them at a rate of 1dBA/100m (up to 300m).

10.2 SUGGESTIONS FOR FURTHER RESEARCH

1. To find the optimum value of the scan interval for each model which gives accurate noise results and minimize computer time.

2. More work on the effect of acc./dec. of vehicles on noise.

3. On the equipment side, it would be very helpful if video equipment could also record noise levels simultaneously.

4. If the technique explained in Chapter 6 is developed so that the cross bars are superimposed electronically, the resolution of the cross bars is increased and automatic sampling is employed.

5. To include, in the models, the effect of barriers and non-straight segments of roads.

6. Expand the models to include other environmental effects such as air pollution and vibration.

7. Measure noise time histories from platoons of vehicles making different manoeuvres in order to build urban noise models on macroscopic principles as presently used in the Transyt method.
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A variable classified according to its magnitude or size can be arranged in a frequency distribution.

When applied to the statistical distribution of noise level with time, the type of distribution considered is as shown in Table A.1.1.

Table A.1.1

<table>
<thead>
<tr>
<th>Noise Level Class Interval (dBA)</th>
<th>Frequency (Time Spent in Each Interval in Multiples of .1 sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 - 54</td>
<td>5</td>
</tr>
<tr>
<td>55 - 59</td>
<td>10</td>
</tr>
<tr>
<td>60 - 64</td>
<td>50</td>
</tr>
<tr>
<td>65 - 69</td>
<td>170</td>
</tr>
<tr>
<td>70 - 74</td>
<td>40</td>
</tr>
<tr>
<td>75 - 79</td>
<td>20</td>
</tr>
<tr>
<td>80 - 84</td>
<td>5</td>
</tr>
</tbody>
</table>

Fig. A.1.1 Example of a Cumulative Frequency Plot
In order to calculate the percentile level $L_X$, the level exceeded for $X\%$ of the time, a cumulative frequency distribution must be calculated. Statistical distribution analysers operate on a "more than" cumulative distribution, which follows from the distribution shown in Table A.1.1 in the manner shown in Table A.1.2.

**Table A.1.2**

<table>
<thead>
<tr>
<th>Noise Level Class Interval (dBA)</th>
<th>&quot;More than&quot; Cumulative Frequency (X.1 sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 - 54</td>
<td>300</td>
</tr>
<tr>
<td>55 - 59</td>
<td>295</td>
</tr>
<tr>
<td>60 - 64</td>
<td>285</td>
</tr>
<tr>
<td>65 - 69</td>
<td>235</td>
</tr>
<tr>
<td>70 - 74</td>
<td>65</td>
</tr>
<tr>
<td>75 - 79</td>
<td>25</td>
</tr>
<tr>
<td>80 - 84</td>
<td>5</td>
</tr>
</tbody>
</table>

The cumulative distribution may then be plotted as cumulative frequency against noise level (Fig. A.1.1). The normal practice in the U.K. is to plot the frequency point at the left hand extremity of the relevant class interval and join the points in a smooth curve, $L_X$ may then be determined graphically by drawing a horizontal line from the point on the vertical axis representing $X\%$ of the total time involved (in the above case, 300 X .1 sec.), to the curve, and drawing a vertical line from where the horizontal line meets the curve to the horizontal axis. The point where this line meets the horizontal axis gives the value $L_X$. 
\[ L_{eq} = 10 \log \frac{\text{dBA}_1/10}{i_1 + 10} + \frac{\text{dBA}_2/10}{i_2 + \cdots + 10} + \cdots + \frac{\text{dBA}_n/10}{i_n} \]

where \( i_n \) is the number of occurrences of the level \( \text{dBA}_n \)

\[ L_{NP} = L_{eq} + (L_{10} - L_{eq}) \]

\[ TNI = 4(L_{10} - L_{90}) + L_{90} - 30 \]
10 REM  CALCULATION OF ROAD TRAFFIC NOISE
20 DIM FACAD(20),HSRF(20),Q18(20),QOH(20),V(20),
    P(20),G(20),D(20),DD(20),H(20),THETA(20)
28 PRINT "NO. OF SEGMENTS="
30 INPUT NSEG
40 FOR I=1 TO NSEG
50 PRINT "18 HOURS FLOW; ONE HOUR FLOW; SPEED; PERCENT
    HEAVY; GRADIENT; DISTANCE OF OBS. POINT; HEIGHT OF
    OBS. POINT; ANGLE OF VIEW"
60 INPUT Q18(I),QOH(I),V(I),P(I),G(I),D(I),H(I),THETA(I)
70 C=LOG(10)
72 PRINT "FACAD=1 IF THERE IS AN EFFECT, OTHERWISE
    =0; HSRF=1 IF THE SURFACE IS HARD; OTHERWISE HSRF=0"
75 INPUT FACAD(I),HSRF(I)
80 IF QOH(I)=0 GO TO 100
88 QA=QOH(I)
90 L10(I)=41.2+10*LOG(QA)/C
94 PRINT L10(I)
95 GO TO 110
100 L10(I)=28.1+10*(LOG(Q18(I)))/C
105 PRINT L10(I)
110 L10(I)=L10(I)+33*(LOG(V(I)+40+500/V(I)))/
    C-10*(LOG(1+5*P(I)/V(I)))/C-68.8
120 L10(I)=L10(I)+0.3*G(I)
130 DD(I)=((D(I)+3.5)^2+(H(I)-0.5)^2)^0.5
140 L10(I)=L10(I)-10*LOG(DD(I)/13.5)/C
150 L10(I)=L10(I)+10*(LOG(THETA(I)/180))/C
160 IF FACAD(I)=0 GOTO 170
165 L10(I)=L10(I)+2.5
170 IF HSRF(I)=0 GOTO 180
175 L10(I)=L10(I)+1
180 PRINT "THIS SEGMENT IS",I
185 PRINT "L10 FOR THIS SEGMENT=",L10(I),"DBA"
220 NEXT I
300 FOR L=1 TO NSEG
310 TT=TT+10*(L10(L)/10)
320 NEXT L
330 L10T=10*LOG(TT)/C
340 PRINT "TOTAL L10=",L10T,"DBA"
500 END
APPENDIX 3.A  LENGTHS AND STARTING ACCELERATIONS
MEDIUM COMMERCIAL VEHICLES

APPENDIX 3.B  LENGTHS AND STARTING ACCELERATIONS
HEAVY COMMERCIAL VEHICLES
<table>
<thead>
<tr>
<th>VEHICLE TYPE &amp; MODEL</th>
<th>TEST YEAR</th>
<th>LENGTH m</th>
<th>STARTING ACCN. m/s²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ford R226/Duple 53 - Seat Coach</td>
<td>69</td>
<td>11.30</td>
<td>0.75</td>
</tr>
<tr>
<td>Leyland/Park Royal Atlantean Double-deck Bus</td>
<td>69</td>
<td>10.03</td>
<td>0.66</td>
</tr>
<tr>
<td>Bristol VRT/ECW 75 - Seat Double Decker</td>
<td>69</td>
<td>9.22</td>
<td>0.86</td>
</tr>
<tr>
<td>Seddon RV Single-decker Bus</td>
<td>69</td>
<td>10.16</td>
<td>0.90</td>
</tr>
<tr>
<td>Bedford/Boughton Pack Horse 4x4</td>
<td>69</td>
<td>5.21</td>
<td>1.06</td>
</tr>
<tr>
<td>Bedford M 13ft.</td>
<td>70</td>
<td>6.59</td>
<td>0.72</td>
</tr>
<tr>
<td>BMC Boxer BX 14.25 tons gross truck</td>
<td>70</td>
<td>8.08</td>
<td>0.59</td>
</tr>
<tr>
<td>Leyland Red Line Terrier 8.5 ton gross four-wheeler</td>
<td>71</td>
<td>6.56</td>
<td>0.76</td>
</tr>
<tr>
<td>Leyland Red Line Boxer 16 ton gross two-axle rigid</td>
<td>71</td>
<td>8.19</td>
<td>0.48</td>
</tr>
<tr>
<td>Leyland Red Line TR650 Terrir 6.5 ton gvw four-wheeler</td>
<td>71</td>
<td>6.60</td>
<td>0.99</td>
</tr>
<tr>
<td>Scannia LB80 H50 16ton gvw four-wheeler</td>
<td>71</td>
<td>5.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Volvo F86 16ton gvw truck</td>
<td>72</td>
<td>18.00</td>
<td>0.58</td>
</tr>
<tr>
<td>Bedford YRT Plaxton Panorama Coach</td>
<td>72</td>
<td>11.23</td>
<td>0.78</td>
</tr>
<tr>
<td>Commer Commando GB675 8.5ton gcw truck</td>
<td>74</td>
<td>9.10</td>
<td>0.98</td>
</tr>
<tr>
<td>Leyland National 11.3m bus</td>
<td>74</td>
<td>11.30</td>
<td>1.09</td>
</tr>
<tr>
<td>Dodge Commando G08 at 7.5tonnes gvw</td>
<td>76</td>
<td>7.50</td>
<td>0.74</td>
</tr>
<tr>
<td>Bedford TM1700 at 16tons gvw</td>
<td>76</td>
<td>8.60</td>
<td>0.74</td>
</tr>
<tr>
<td>Mercedes-Benz L608 at 6.5 tons</td>
<td>76</td>
<td>6.94</td>
<td>1.11</td>
</tr>
<tr>
<td>Mercedes-Benz 1617 at 16 tons</td>
<td>76</td>
<td>9.00</td>
<td>0.71</td>
</tr>
<tr>
<td>Ford DA 1611 Urban artic at 16 tons gvw</td>
<td>76</td>
<td>10.80</td>
<td>0.72</td>
</tr>
<tr>
<td>Leyland Terrier TR738 at 7.5 tons gvw</td>
<td>76</td>
<td>6.5</td>
<td>2.42</td>
</tr>
<tr>
<td>Seddon Atkinson 200 at 16 tons gvw</td>
<td>76</td>
<td>9.12</td>
<td>0.69</td>
</tr>
<tr>
<td>DAF FM2000 DH 16 ton 4x2 rigid</td>
<td>77</td>
<td>7.7</td>
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</tr>
<tr>
<td>Soviern JP 13A XL</td>
<td>77</td>
<td>8.35</td>
<td>0.85</td>
</tr>
<tr>
<td>N</td>
<td></td>
<td>24</td>
<td>24</td>
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<tr>
<td>Mean</td>
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<td>8.80</td>
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<tr>
<td>S.D.</td>
<td></td>
<td>2.68</td>
<td>0.174</td>
</tr>
<tr>
<td>Variance</td>
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<td>0.0288</td>
</tr>
<tr>
<td>VEHICLE TYPE &amp; MODEL</td>
<td>TEST YEAR</td>
<td>LENGTH m</td>
<td>STARTING ACCN. m/s²</td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>-----------</td>
<td>----------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Mercedes-Benz LP 1632</td>
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<td>0.97</td>
</tr>
<tr>
<td>Foden/York 32 ton gross artic.</td>
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<td>15.00</td>
<td>0.45</td>
</tr>
<tr>
<td>Volvo F89/Parator 38ton gtw combination</td>
<td>71</td>
<td>18.12</td>
<td>0.75</td>
</tr>
<tr>
<td>Dodge KT900 6x4 22ton gross</td>
<td>71</td>
<td>9.22</td>
<td>0.57</td>
</tr>
<tr>
<td>Scammell/BRSL Crusader 32ton gross artic.</td>
<td>71</td>
<td>12.97</td>
<td>0.41</td>
</tr>
<tr>
<td>Mogirus Deutz 24ton gvw 6x4 dumper</td>
<td>71</td>
<td>7.49</td>
<td>0.65</td>
</tr>
<tr>
<td>Ford DA 2418/CRANE FRUEHAUF 24ton gross artic.</td>
<td>71</td>
<td>13.02</td>
<td>0.53</td>
</tr>
<tr>
<td>AEC Mandator Crane Fruehauf 32ton Tank Artic.</td>
<td>72</td>
<td>14.73</td>
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</tr>
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<td>DAF FT2600/Taskers 32ton gcw artic.</td>
<td>72</td>
<td>14.98</td>
<td>0.48</td>
</tr>
<tr>
<td>Seddon 34:Four/ Crane Fruehauf/32ton gcw artic.</td>
<td>72</td>
<td>14.99</td>
<td>0.48</td>
</tr>
<tr>
<td>Atkinson Borderer/Municipal 32ton gcw artic.</td>
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<td>14.96</td>
<td>0.53</td>
</tr>
<tr>
<td>Mercedes-Benz LPS 1924/Dyson 32ton gcw artic.</td>
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<td>9.53</td>
<td>0.59</td>
</tr>
<tr>
<td>Magirus-Deutz 232D 16FS/Cravens Homalloy 32ton grossartic.</td>
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<td>12.39</td>
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</tr>
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<td>DAF FT2800 DKDT</td>
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<td>Taskers 32ton gcw artic.</td>
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<td></td>
<td>0.46</td>
</tr>
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<td>Dodge K3820p/York 32ton gcw artic.</td>
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<td></td>
<td>0.54</td>
</tr>
<tr>
<td>Volvo N10-38 6x4 on/off-sik tipper</td>
<td>76</td>
<td>7.9</td>
<td>0.62</td>
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<tr>
<td>Volvo P86 6x4</td>
<td>77</td>
<td>7.21</td>
<td>0.65</td>
</tr>
<tr>
<td>Scania LB80/York 32ton gross artic.</td>
<td>70</td>
<td>13.10</td>
<td>0.41</td>
</tr>
<tr>
<td>BMC Mastiff/Pitt 26ton gross artic.</td>
<td>69</td>
<td>12.42</td>
<td>0.45</td>
</tr>
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<td>AEC Marshall 24ton gross eight-wheeler</td>
<td>69</td>
<td>7.89</td>
<td>0.43</td>
</tr>
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</table>

N
Mean
S.D.
Variance

18
12.44
3.49
11.49
APPENDIX 4

STARTING ACCELERATION (MAX. ACCELERATION)
FOR A SAMPLE OF CARS
<table>
<thead>
<tr>
<th>MAKE</th>
<th>MODEL</th>
<th>YEAR</th>
<th>STARTING ACCN</th>
<th>MAKE</th>
<th>MODEL</th>
<th>YEAR</th>
<th>STARTING ACCN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>m/sec. 2</td>
<td></td>
<td></td>
<td></td>
<td>m/sec. 2</td>
</tr>
<tr>
<td>Vauxhall</td>
<td>VX 4.90</td>
<td>1964</td>
<td>2.92</td>
<td>Jensen</td>
<td>CV.8</td>
<td>1963</td>
<td>4.06</td>
</tr>
<tr>
<td>Triumph</td>
<td>Stage Two</td>
<td>1964</td>
<td>3.62</td>
<td>Ford</td>
<td>Galaxie</td>
<td>1963</td>
<td>2.98</td>
</tr>
<tr>
<td>Citroen</td>
<td>DW</td>
<td>1964</td>
<td>2.58</td>
<td>Austin</td>
<td>MiniSuper DeLuxe</td>
<td>1963</td>
<td>2.24</td>
</tr>
<tr>
<td>Humber</td>
<td>Hawk III</td>
<td>1964</td>
<td>2.27</td>
<td>Saab</td>
<td>96</td>
<td>1963</td>
<td>2.06</td>
</tr>
<tr>
<td>Singer</td>
<td>Vogue</td>
<td>1964</td>
<td>2.13</td>
<td>Fiat</td>
<td>2300 Estate</td>
<td>1963</td>
<td>2.92</td>
</tr>
<tr>
<td>Lancia</td>
<td>Flavia Coupe</td>
<td>1964</td>
<td>2.58</td>
<td>Austin</td>
<td>1100</td>
<td>1963</td>
<td>2.06</td>
</tr>
<tr>
<td>Reliant</td>
<td>Sabre Six GT</td>
<td>1964</td>
<td>3.94</td>
<td>Sunbeam</td>
<td>Alpine III Sport Tourer</td>
<td>1963</td>
<td>2.92</td>
</tr>
<tr>
<td>Panhard</td>
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<td>1964</td>
<td>2.06</td>
<td></td>
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<td></td>
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<tr>
<td>Vauxhall</td>
<td>Cresta Estate</td>
<td>1964</td>
<td>3.12</td>
<td>Ford</td>
<td>Consul Corsair</td>
<td>1963</td>
<td>2.63</td>
</tr>
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<td>Simca</td>
<td>1500</td>
<td>1964</td>
<td>2.85</td>
<td>Rover</td>
<td>2000</td>
<td>1963</td>
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<td>Porsche</td>
<td>1600SC</td>
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<td>Viva</td>
<td>1963</td>
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<td>Ford</td>
<td>Cortina Super Est.</td>
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<td>2.06</td>
<td>Jaguar</td>
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**Mean** | **Variance** | **Total of Scores**
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**Total Cumulative Time:** 180.37
**Gap:** 0.78
**GT:** -0.13

**Vehicle Arrival:**

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**Starting Position:** -479.20
**Starting Speed:** 5.64 m/s
**Starting Acceleration:** 0.97 m/s²
**Vehicle Length:** 5.80 m
Normal output would only give details of vehicles' arrivals

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Both outputs give

- **Total Number of Vehicles on All Lanes** = 75
- **Total Percentage of Queues** = 17.5%
- **Total Flow** = 450,000 veh
- **Time Mean Speed of all Lanes** = 48.52 km/h
- **Space Mean Speed of all Lanes** = 37.44 km/h

Both outputs also give noise history (see fig. 7.13)
Appendix 5. B  Listing of FFNOISE

MASTER FFNOISE

*** FREE FLOWING NOISE SIMULATION ***

THIS PROGRAM IS CAPABLE OF SIMULATING NOISE FROM DIFFERENT ROAD CONFIGURATIONS USING STOCHASTIC TECHNIQUE

*****

NLN=NUMBER OF NEAR SIDE LANES  NFL=NUMBER OF FARSIDE LANES
W=LANE WIDTH  WCR=THE WIDTH OF CENT. RESERVATION
DMIC=DISTANCE OF MICROPHONE  DOPT=DISTANCE OF OBS. POINT
FROM THE KERB
STN=IS THE SPECIFIED TIME AT WHICH NOISE SAMPLING IS TO START
NTIME=IS THE TOTAL SAMPLING TIME
NT=IS THE TOTAL NUMBER OF VEHs, IN ALL LANES
NLBS=NUMBER LEFT BEFORE STARTING NOISE MEASUREMENT

*****

REAL MNG,LEQ,LNP
DIMENSION F(6),AVG(6),RD(6),NVS(6),NLBS(6),YXT(1300)
DIMENSION N(6),N1(6),N3(6),N4(6),N11(6),N12(6),NVC(6),NN(6)
DIMENSION G(6),ST(6),TT(6),C(6,120),G1(6)
DIMENSION LA(6),SPD1(6,400),TSPD1(6),TM1(6),SPD2(6,400),
& TSPD2(6),TM2(6),TXT(1300),DSFSS(6)
COMMON/BLOCK 1/PCH(6),V(6,120),D(6,120)
COMMON/BLOCK 2/LEQ,LNP,XT10,XT50,XT90
COMMON/BLOCK 3/CMS(6),SDCS(6),HMS(6),SDHS(6)
COMMON/BLOCK 4/CACC(6),SDCA(6),HACC(6),SDHA(6)
COMMON/BLOCK 5/NNL,NFL,W,WCR,DMIC,DOPT(4)
COMMON/BLOCK 6/NVC,KA
COMMON/BLOCK 7/V(6,120,16)
COMMON/BLOCK 8/ADNL(6,120),CNL(5,120),ANL(6,120),XT(4,1300),NOBSP
COMMON/BLOCK 9/NCL(6),NLH(6),NCN(6),NHNA(6)
COMMON/BLOCK 10/BCKNS
COMMON/BLOCK 11/SPDST,1,PRT

*****

INPUT DATA

*****

READ(1,405)STN,NTIME
405 FORMAT(405)
READ(1,400)NOBSP,NNL,NFL,W,WCR,DMIC,(DOPT(LE);LE=1,NOBSP)
400 FORMAT(310,7F0.0)
KA=NNL+NFL
DO 700 IA=1,KA
READ(1,410)A(IA),HM(IA),LL(IA),MNG(IA),Q(IA),PCH(IA)
READ(1,420)CMS(IA),HMS(IA),CACC(IA),HACC(IA)
CMS(I,A) = CMS(I,A) / 3.6
SDCS(I,A) = CMS(I,A) / 5.0
HMS(I,A) = HMS(I,A) / 3.6
SDHS(I,A) = HMS(I,A) / 5.0
SDCA(I,A) = CACC(I,A) / 5.0
SDHA(I,A) = HACC(I,A) / 5.0
DSFSS(I,A) = (CMS(I,A) + 2.0 * SDCS(I,A)) * 0.25

700 CONTINUE
410 FORMAT(F0.0, 210, 3F0.0)
420 FORMAT(4F0.0)
   READ(1,430) AC, ST, S, SPDST, LPRT
430 FORMAT(4F0.0, 10)
   READ(1,432) IOUTP, IBCKN
432 FORMAT(210)
   IF (IBCKN.EQ.0) GO TO 434
   READ(1,436) BCKNS
434 FORMAT(F0.0)
   GO TO 437
437 CONTINUE
   ST=ST*100
   IST=IFIX(ST)
   WRITE(2,450)
450 FORMAT(I1, 'TIME', 9X, 'CUMULATIVE TIME', 12X, 'GAP', 13X, 'GT',
   1 13X, 'N1', 11X, 'FLOW', 4X, 'NO. OF VEH.', 1X/100(' -'))

****
TO CHECK IF THERE IS AN ARRIVAL
****
   IF (TT(IC) - T) 0.0, 230
   N20=NVS(IC)
IF(N20.EQ.0)GO TO 200
IF(V(IC,N20,1J1)-V(IC,N20,2).LT.-480.0)GO TO 220

200

GT(IC)=TT(IC)*TT
G(IC)=G(IC)
G(IC)=GSNEX(MNG.AVG.IC)
TZZ=TT(IC)
TT(IC)=TT(IC)+G(IC)
N(IC)=N(IC)+1

NVS(IC)=NVS(IC)+1

C
****
C THERE IS AN ARRIVAL
C CALCULATE INITIAL VALUES OF DISTANCES, SPEEDS & ACC.
C
*****
C
N30=NVS(IC)
CALL INITIAL (.N30 ,G1,GT,M1,42,43,C,IC)
WRITE(2,570)T,TZZ,G(IC),GT(IC),NVS(IC),IC,N(IC)
570

FORMAT(1X,TIME='F7.2',3X,'TOTAL CUMULATIVE TIME =','F7.2,'
1 3X,'GAP='F6.2',3X,'GT='F7.2',3X/NO. OF VEH. IN THE SYSTEM
2 =','I4',3X,'FLOW =','I5',3X,'TOTAL NO. OF VEH. ENTER THE SYSTEM
3 SYST =','I4)
WRITE(2,460)V(IC,N30,3),IC,N30,4),C(IC,N30),V(IC,N30,4)
1 V(IC,N30,4),V(IC,N30,4),V(IC,N30,2)
460

FORMAT(1X,'DESIRED SPEED='F6.2,4X,'MAXIMUM ACC. =','F6.2,4X,'C=
1,F5.2/1X,'STARTING POSITION =','F6.2','M',3X,'STARTING SPEED =','F6.
2 ,1/5',3X,'STARTING ACCELERATION =','F6.2,1/5',3X,'VEH. LENGTH
3 =','F6.2,1/5',3X)
GO TO 230

220

G(IC)=G(IC)+S

TT(IC)=TT(IC)+S

230 IF(NVS(IC).EQ.0)GO TO 820

C

****
C UPDATE DISTANCES, SPEEDS, ACCS.
C
*****
C
MM1=M4(IC)
LL1=LL(IC)
A1=A(IC)
N30=NVS(IC)
DO 833 J=1,N30
V(IC,J,1J1)=V(IC,J,1)+V(IC,J,2)*S+0.5*V(IC,J,3)*S**2
V(IC,J,1J2)=V(IC,J,2)+V(IC,J,3)*S
IF(V(IC,J,1J1).LT.,0.5V(IC,J,1J2))GO TO 833
LA(IC)=LA(IC)+1
LL1=LA(IC)

835

SPD1(IC,L1)=V(IC,J,1J2)

IF(J.EQ.1)GO TO 100
RDBTV=ABS(ABS(V(IC,J-1,J1)-V(IC,J,J1))-V(IC,J-1,2))
IF(RD3TV.GT.50.0)GO TO 100
V(IC,J,J3)=A1*((V(IC,J,J12))*MM1)*(V(IC,J-1,42)-V(IC,J,M2))/
1 RDBTV+LL1
IF(V(IC,J,J3).LT.-5.00)V(IC,J,J3)=-5.00
IF(V(IC,J,J3).GT.V(IC,J,4))V(IC,J,J3)=V(IC,J,4)
GO TO 830
V(IC,J,13) = V(IC,J,4) * (1.0 - V(IC,J,12) / V(IC,J,3))

CONTINUE

PRINT CURRENT VALUES OF DISTANCES, SPEEDS & ACCS OF ALL VEHS.

N4U = NVS(IC)
IF(ITOUP, EQ, 0) GO TO 911
J1 = (N40 - 1) / 4 + 1
N50 = NVS(IC)
IF(N45, NE, 1) GO TO 825
IF(N50, EQ, 0) GO TO 860
DO 870 J1 = 1, N50
DO 870 JMM = 1, 16
V(IC,J, JMM) = V(IC,J+1, JMM)
860
DO 890 JMM = 1, 16
V(IC,J, N50 + 1, JMM) = 0.0
890
CONTINUE
IF(abs(CT - 0.5 * (NGTIME - STNM)).GT.0.1E-5) GO TO 820
N74 = NVS(IC)
DO 940 LG = 1, N49
IF(T, EQ, 0.1E-5) GO TO 810

TSPD2(IC) = TSPD2(IC) + SPD2(IC, LG)
T4S2(IC) = TSPD2(IC) / NVS(IC)
N92 = N92 + NVS(IC)
TTSPD2 = TTSPD2 + TSPD2(IC)
TTM2 = TTM2 + 3.6
820
CONTINUE

******
SAMPLING & CALLING NOISE
******

IF(T, LT, STNM) GO TO 810
IF(T, GE, STNM, AND, NCSNM, NE, 1) CALL CORRECT(N, NVS, N3, N4, NCSNM, & NCEND, M1, KA)
IF(T, GE, NTIME - 1, AND, NCEND, NE, 1) CALL CORRECT(N, NVS, N3, N4, NCSNM, & NCEND, M1, KA)
IF(I11, EQ, 1) GO TO 855
I11 = 1:
DO 1001 IC = 1, KA
1001 WRITE(2, 1000) N3(IC), N4(IC)
1000 FORMAT(1X, 3F7.2, 2X)
855 IF(IST, EQ, 25) GO TO 856
IF(IT/I810, 0, 810)
CALL NOISE (NVS, IJ1, IJ2, IJ3, KKK, AC)

FORMAT (1X, 'NOISE FROM INDIVIDUAL VEHS. ADJUSTED TO DIS' /
1 45 (* - *) / 1X, 10F10.2)

CONTINUE

CONTINUE

CALL & PRINT ACHIEVED PARAMETERS

****

DO 730 IL = 1, KA
   L25 = LA (IL)  
   DO 920 LD = 1, N25
         TSPD1 (IL) = TSPD1 (IL) + SPD1 (IL, LD)
         TMS1 (IL) = TMS1 (IL) / LA (IL)
         LAT = LAT + LA (IL)
         TMS2 (IL) = TMS2 (IL) / 3.6
         NLBS (IL) = NLBS (IL) + NCL (IL) + NHL (IL) + NCNA (IL) + NHNA (IL)
         N1 (IL) = N1 (IL) + NCNA (IL)
         A2 (IL) = (N1 (IL) - N1 (IL)) * 3600.0 / (T - STNM)
      END
      WRITE (2, 510) IL, N (IL), NLC (IL), NCL (IL), NHL (IL), NCNA (IL),
      NHNA (IL), PCHV (IL), A2 (IL)
      730  CONTINUE

      ********

      WRITE (2, 580) LA (IL), TSPD1 (IL), TSPD2 (IL), TMS1 (IL), TMS2 (IL)

      CONTINUE


      PRINT ACHIEVED PARAMETERS

      730  CONTINUE

      FORMAT (1X, 'TOTAL SUM OF TIME MEAN SPEED SAMPLE = ', F8.2//1X, 'TOTAL SUM OF SPACE MEAN SPEED SAMPLE = ', F8.2//1X, 'TIME MEAN SPEED = ', F8.2//50 (', '))

      CONTINUE

      AT = AT + 3600.0 / (T - STNM)
      TPCH = PCT * 100.0 / AT
      TTMS1 = TMS1 / LAT
      TTMS1 = TTMS1 / 3.6
      WRITE (2, 520) AT, TPCH, AT, TTMS1, TTMS2

      CONTINUE

      FORMAT (1X, 'TOTAL NUMBER OF VEHS. ON ALL LANES = ', I10//1X, 'TOTAL PER CENT OF HCV. 11X = ', F6.2//1X, 'ACHIEVED TOTAL FLO= ', I9X, 'TIME MEAN SPEED OF ALL LANES = ', F8.2//1X, 'KPH')
3  SPACE MEAN SPEED OF ALL LANES = "F8.2,1KPH"/760(*1))
   CALL LP120
   DO 950 LH=1,N0BSPT
   WRITE(2,450)
  480   FORMAT(1x,'NOISE HISTORY')
   WRITE(2,540)(XT(LH,IK),IK=1,KKK)
  540   FORMAT(1x,10F10.2)
   CALL LP120
   ---- DRAWING THE HISTGRAM
   #######
   DRAW NOISE HISTORY
   #######
   DO 960 LI=1,KKK
  960   XTT(LI)=XT(LH,LI)
   CALL GRAF(YXT,XTT,KKK,0)
   CALL PICCLE
   CALL UTS4(KKK,XTT(1))
   WRITE(2,490)(XTT(IL),IL=1,KKK)
  490   FORMAT(1X,'SORTED OUT NOISE LEVELS'/10(2X,F10.2))
   CALL INDICES
   ****
   ****
   ****
   CALL INDICES (XTT,F,KKK)
   >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
   CALL HISCHA (F,50,0.1,0.95,5,44,5)
   CALL PICCLE
   WRITE (2,500)XT10,XT50,XT90,LEQ,LNP,D0PT(LH)
  500   FORMAT(7X,'L10',7X,'L50',7X,'L90',7X,'LEQ',7X,'LNP',50(1E1))
   & 5F10.2//1X,* DISTANCE OF OBS, POINT = "F6.2,1M"
   CONTINUE
   CALL DEVEN
   STOP
   END

*****
THIS FUNCTION GENERATES GAPS RANDOMLY ACCORDING TO THE
SHIFTED NEGATIVE EXPONENTIAL DISTRIBUTION

*****
FUNCTION GSNEK(NG,AVG,1)
REAL NG
DIMENSION NG(6),AVG(6),P(6)
COMMON/BLOCK 11/SPDST,LPRT
IF(LPRT.EQ.1)GO TO 10
CALL G05BBF
R=G054AF(W)
P(I)=MNG(I)+(AVG(I)-MNG(I))*ALOG(I/R)
RETURN
END

**** SUBROUTINE INDICES ****

THIS SUBROUTINE CALCULATES NOISE INDICES

SUBROUTINE INDICES (XT,F,KKK)
REAL MNG,LEQ,LNP
DIMENSION XT(1300),F(60),XX(60),JJ(60)
COMM/VRLOCK 2/LEQ,LNP,XT10,XT50,XT90
LNP=0.0
LEQ=0.0
DLEQ=0.0
ULEQ=0.0
K=0
J=0
DO 70 IA=1,60
XX(IA)=0.0
JJ(IA)=0.0
F(IA)=0.0
ISUM10=KKK*0.1+0.5
ISUM50=KKK*0.5+0.5
ISUM90=KKK*0.9+0.5
XT10=XT(ISUM10)
XT50=XT(ISUM50)
XT90=XT(ISUM90)
L=0
JN=1
IKKK=1
X1=95.5
WRITE(2,80)
FORMAT(2,80)
70 X1=X1-1.0
K=K+1
XX(K)=X1/10.0
DO 20 J=JN,KKK
IF(XT(J),LT,X1)GO TO 30
CONTINUE
IKKK=2.
30 L=L+1
JI=J-JN
JJ(K)=J
F(L)=1.0*JI/IKKK
IF(J,J4E,JN)WRITE(2,40),J,(XT(J1),J1=JN,J=1)
40 FORMAT(5X,'(F10.2)',10(F10.2))
JN=J
GO TO (10,0)IKKK
WRITE(2,50),(F(L),L=1,60)
50 FORMAT(1X,'PER CENT NOISE LEVEL IN EACH CLASS/32(1-1)/
3(10F10.2)//40(1*))
DO 60 I=1,K
ULEQ=JLEQ*(100*XX(I))JJ(I)
DLEQ=DLEQ+JJ(I)
CONTINUE
LEQ=10*ALOG10(ULEQ/DLEQ)
**SUBROUTINE INITIAL**

This segment calculates the desired speed max, acc, & type of vehicle for each new arrival. Also calculates the starting position, speed & acceleration.

```
SUBROUTINE INITIAL (J,G,GT,M1,M2,M3,C,IC)
DIMENSION C(6,120),N(6),NVS(6),RD(6),G(6),TT(6)
COMMON/BLOCK 1/PCH(6),Y(6,120),D(6,120)
COMMON/BLOCK 3/CHS(6),SDCS(6),HHS(6),SDH(6)
COMMON/BLOCK 4/CACC(6),SDCA(6),HACC(6),SDHA(6)
COMMON/BLOCK 7/V(6,120,16)
COMMON/BLOCK 11/SPDST,LPRT
IF(LPRT.EQ.1)GO TO 100
CALL G05BBF
100 Y(J,J) = G05AAF(W)
   IF(Y(J,J) .GT. PCH(1C)) GO TO 10
   N(1C) = N(1C) + 1
   V(J,J,2) = 9.8
25 V(J,J,3) = G05AFC(HMS(1C),SDH(1C))
   IF(V(J,J,3) .GT. (HMS(1C) + 2.0*SDH(1C))) OR.
   V(J,J,3) = G05AFF(HACC(1C),SDHA(1C))
   IF(V(J,J,4) .GT. (HACC(1C) + 2.0*SDHA(1C))) OR.
   V(J,J,4) = G05AFF(CACC(1C),SDCA(1C))
   IF(V(J,J,4) .LT. (CACC(1C) + 2.0*SDCA(1C))) OR.
   GO TO 20
10 V(J,J,2) = 5.8
5 V(J,J,3) = G05AFC(CMS(1C),SDCS(1C))
   IF(V(J,J,3) .GT. (CMS(1C) + 2.0*SDCS(1C))) OR.
   V(J,J,3) = G05AFF(CACC(1C),SDCA(1C))
   IF(V(J,J,4) .GT. (CACC(1C) + 2.0*SDCA(1C))) OR.
   V(J,J,4) = G05AFF(C(1C),J,J3)/V(J,J,3)
   EC = C(J,J)*G(1C)
   V(J,J,H2) = V(J,J,3)*(1.0-EXP(EC))
   V(J,J,H1) = -SPDST*GT(1C)*V(J,J,M2)
   V(J,J,H3) = V(J,J,4)*(1.0-V(J,J,M2)/V(J,J,3))
RETURN
END
```

**SUBROUTINE NOISE**

This subroutine calculates the noise emitted by each vehicle and calculates the total attenuation due to its position on the road, then takes a noise sample.

```
SUBROUTINE NOISE(N,1J1,1J2,1J3,4KC,AC)
DIMENSION NVS(6),N(6),N(1C) .RD(6)
```
COMMON/BLOCK 1/CHC(6),V(6,120),D(6,120)
COMMON/BLOCK 3/CHS(6),SDCS(6),HMS(6),SDHS(6)
COMMON/BLOCK 5/NVL,FNL,W,WC,DMIC,DOPT(4)
COMMON/BLOCK 6/VCV,KA
COMMON/BLOCK 7/V(6,120,16)
COMMON/BLOCK/ADNL(6,120),CNL(6,120),ANL(6,120),XT(4,1300),NOBSPT
COMMON/BLOCK 10/BCNS
DO 120 IT=1,NOBSPT
   XT(IT,KKK)=BCNS
   DO 90 I=1,KA
      N41=N(I)
      IF(N(I).EQ.0)GO TO 90
      DO 10 J=1,N41
         IF(ABS(V(I,J,2)-5.8),LT,0.1E-6)GO TO 5
         IF(V(I,J,1J2),GE,10.94)GO TO 25
         V(I,J,1)=77.2
         GO TO 35
         V(I,J,1)=27.5+29.9*ALOG10(V(I,J,1J2)+3.6)
         IF(V(I,J,1J3),GE,0.00,AND,V(I,J,1J3),LT,0.25)GO TO 45
         IF(V(I,J,1J3),GE,0.25,AND,V(I,J,1J3),LT,0.75)GO TO 55
         IF(V(I,J,1J3),GE,0.75,AND,V(I,J,1J3),LT,2.20)GO TO 65
         IF(V(I,J,1J3),GE,2.20)GO TO 75
         IF(V(I,J,1J3),LT,0.0)ADNL(I,J)=0.0
         GO TO 70
         ADNL(I,J)=1.6*V(I,J,1J3)
         GO TO 70
         ADNL(I,J)=-0.6+4.0*V(I,J,1J3)
         GO TO 70
         WRITE(2,400)V(I,J,1J2),V(I,J,1J3)
         IF(V(I,J,1J2),GE,7.53)GO TO 30
         V(I,J,1)=65.2
         GO TO 40
         V(I,J,1)=27.4+29.9*ALOG10(V(I,J,1J2)+3.6)
         IF(V(I,J,1J3),GE,0.0,AND,V(I,J,1J3),LT,2.0)GOTO 50
         IF(V(I,J,1J3),GE,2.0,AND,V(I,J,1J3),LT,5.5)GOTO 60
         IF(V(I,J,1J3),GE,5.5)GO TO 85
         IF(V(I,J,1J3),LT,0.0)ADNL(I,J)=0.0
         GO TO 70
         WRITE(2,410)V(I,J,1J1),V(I,J,1J2),V(I,J,1J3)
         400 FORMAT('NOISE DUE TO ACC. OF A HCV IS NOT CALCULATED!',F8.2)
         GO TO 70
         ADNL(I,J)=-13.38+21.0*V(I,J,1J3)
         GO TO 70
         IF(V(I,J,1J2),GE,7.53)GO TO 30
         V(I,J,1)=65.2
         GO TO 40
         V(I,J,1)=27.4+29.9*ALOG10(V(I,J,1J2)+3.6)
         IF(V(I,J,1J3),GE,0.0,AND,V(I,J,1J3),LT,2.0)GOTO 50
         IF(V(I,J,1J3),GE,2.0,AND,V(I,J,1J3),LT,5.5)GOTO 60
         IF(V(I,J,1J3),GE,5.5)GO TO 85
         IF(V(I,J,1J3),LT,0.0)ADNL(I,J)=0.0
         GO TO 70
         WRITE(2,410)V(I,J,1J1),V(I,J,1J2),V(I,J,1J3)
         400 FORMAT('NOISE DUE TO ACC. OF A CAR IS NOT CALCULATED!',
         10 FORMA(3F8.2)
         ADNL(I,J)=0.0
         GO TO 70
         ADNL(I,J)=2.0*V(I,J,1J3)
         GO TO 70
         WRITE(2,410)V(I,J,1J1),V(I,J,1J2),V(I,J,1J3)
         85 FORMAT(3F8.2)
         ADNL(I,J)=5.13+3.583*V(KJ,J,1J3)
         70 CNL(I,J)=V(I,J,1)+ADNL(I,J)
         CALL DISTANCE(I,J,I1,J2,J3,IR)
         ADNL(I,J)=CNL(I,J)*AC*ALOG10(D(I,J)/DMIC)
         XT(IR,KKK)=XT(IR,KKK)+10***(ANL(I,J)/10.0)
         CONTINUE
         10 CONTINUE
         90 CONTINUE
         DO 100 IS=1,NOBSPT
**SUBROUTINE DISTANCE ****

**SUBROUTINE DISTANCE**

**COMMON BLOCK 7/PCH(6),V(6,120),D(6,120)**

**IF (KST.NN1).GO TO 10**

**D(K,J)=SQRT((V(K,J,11)-V(K,J,2)/2)**2+(DOP(1)+W/2+(K-1)*W)**2)**

**RETURN**

**END**

**SUBROUTINE CORRECT**

**COMMON BLOCK 9/NCL(6),NH(6),NCNA(6),NHNA(6)**

**IF (NCNM,EQ,1).GO TO 10**

**DO 20 I=1,K**

**N3(I)=NVS(I)**

**N4(I)=N(I)**

**WRITE(2,1000)N3(I),N4(I)**

1000

**FORMAT('//'50('I'),216)**

**N10=NVS(I)**

**DO 20 J=1,N10**

**IF (V(I,J,41).GT.0.0.AND.ABS(V(I,J,2)-5.8).LT.0.1E-6).NCL(I)=NCL(I)+1**

**& IF (V(I,J,41).GT.0.0.AND.ABS(V(I,J,2)-9.80).LT.0.1E-6).NH(I)=NH(I)+1**

20

**CONTINUE**

**NCNM=1**

**RETURN**

**NCEND=1**

**DO 30 I=1,K**

**N10=NVS(I)**

**DO 30 J=1,N10**

**IF (V(I,J,41).LT.0.0.AND.ABS(V(I,J,2)-5.8).LT.0.1E-6).NCNA(I)=NCNA(I)+1**

**& IF (V(I,J,41).LT.0.0.AND.ABS(V(I,J,2)-9.80).LT.0.1E-6).NHNA(I)=NHNA(I)+1**

30

**CONTINUE**

**RETURN**

**END**

**FINISH**

**END**
<table>
<thead>
<tr>
<th>Line No.</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-9</td>
<td>B</td>
</tr>
<tr>
<td>10</td>
<td>STNM,NTIME</td>
</tr>
<tr>
<td>11</td>
<td>NOBSP.NCGS,NNL1,NNL2,NCL1,NCL2,WN,WC,DMIC,DIPTN,DOPTC,</td>
</tr>
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<td>12</td>
<td>NPHASS</td>
</tr>
<tr>
<td>13,16</td>
<td>INTG,GRH,NCYCLE</td>
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<tr>
<td>14,17,19,21</td>
<td>MM,LL,A,MNG,Q,PCM,PCH</td>
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<td>15,18,20,22</td>
<td>CMS,SDCS,HMS,SDHS,CACC,SDCA,HACC,SDHA,MMS,SDMS,MACC,SDMA</td>
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<tr>
<td>23</td>
<td>S,RT,FR,IST,IASFO</td>
</tr>
<tr>
<td>24</td>
<td>IOUT</td>
</tr>
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<table>
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<th>Format</th>
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<tr>
<td>5F0.0</td>
</tr>
<tr>
<td>F0.0,10</td>
</tr>
<tr>
<td>6I0.0,11FO.0</td>
</tr>
<tr>
<td>I0</td>
</tr>
<tr>
<td>10,2FO.0</td>
</tr>
<tr>
<td>2I0,5FO.0</td>
</tr>
<tr>
<td>12F0.0</td>
</tr>
<tr>
<td>3F0.0,3I0</td>
</tr>
<tr>
<td>I0</td>
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</table>
Normal output

<table>
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<tr>
<th>Time</th>
<th>37.25</th>
<th>Total Cycles: 37.12</th>
<th>Last Gap: 2.62</th>
<th>New Gap: 15.57</th>
<th>GT: 0.04</th>
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<td>Lane</td>
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<td>First Veh. to Start Braking: 3</td>
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</table>

<table>
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<tr>
<th>Time</th>
<th>37.80</th>
<th>Total Cycles: 37.67</th>
<th>Last Gap: 3.89</th>
<th>New Gap: 7.80</th>
<th>GT: 0.80</th>
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</thead>
<tbody>
<tr>
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</table>

<table>
<thead>
<tr>
<th>Time</th>
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<th>Total Cycles: 38.13</th>
<th>Last Gap: 3.49</th>
<th>New Gap: 10.56</th>
<th>GT: 0.26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane</td>
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<td>First Veh. to Start Braking: 3</td>
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</table>

<table>
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<th>Last Gap: 3.09</th>
<th>New Gap: 11.30</th>
<th>GT: 0.04</th>
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</thead>
<tbody>
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</table>

<table>
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<tr>
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<th>Last Gap: 2.65</th>
<th>New Gap: 15.80</th>
<th>GT: 0.51</th>
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</thead>
<tbody>
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<table>
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<th>Last Gap: 3.40</th>
<th>New Gap: 11.80</th>
<th>GT: 0.04</th>
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</thead>
<tbody>
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<td>Lane</td>
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<td>First Veh. to Start Braking: 3</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

**NQ** = Number of queuing vehicles; **GT** = Time difference between the veh. exact arrival time and the instantaneous time.

<table>
<thead>
<tr>
<th>Lane</th>
<th>L10</th>
<th>L50</th>
<th>L90</th>
<th>LEQ</th>
<th>LNP</th>
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<tr>
<td></td>
<td>7.77</td>
<td>75.11</td>
<td>67.91</td>
<td>74.32</td>
<td>82.20</td>
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<tr>
<td></td>
<td>Distance of Obs. Point from Veh. Lanes</td>
<td>10.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Distance of Observation Point from Cross Lanes</td>
<td>10.00</td>
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<td></td>
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</tbody>
</table>

Noise history and details of achieved parameters are also given.
Appendix 6. B Listing of SGINNS

MASTER SGINNS

<<<<<<<<<<< >>>>>>>>>>>

H NL1B:4L2—NUMBER OF NEAR SIDE LANES
H NL1B:CL2—NUMBER OF CROSS LANES
D HNC—DISTANCE OF MICROPHONE
D DOPTN,DOPTCH—DISTANCE OF OBSERVATION POINTS FROM NEAR LANE & CROSS LANE
N NOBSP—NUMBER OF OBSERVATION POINTS
N NCGS—NUMBER OF VEHICLE CATEGORIES
W W—WIDTH OF NEAR SIDE LANES
W NC—WIDTH OF CROSS LANES
W NPHASE—NUMBER OF PHASES IN THE CYCLE
R RD—REFERENCE DISTANCE

<<<<<<<<<<< >>>>>>>>>>>

REAL H K,LEQ,LUP
REAL H LHS(3),VACC(8)
DIMENSION R K(3,20)
DIMENSION IV(50),F(60),AI(8),PCNV(8),HNG(8),Q(8),AVG(8),PC4V(8)
DIMENSION S(6),ST(6),XTT(800),C(8,100),E(8),XTT(800);
H N(6),NCV(6),RPI(3),VLS(8),NLBS(5),XYS(800),NYV(8)
DIMENSION KLSDD(8)
DIMENSION B(3),TCCS(8),GREENS(8),REDN(8),N16(8),N17(8)
H NAVE(8),STT(8),XVE(8),XVC(8),N7(8),JB(8),AT(8,40),INC(8)
DIMENSION XTPRS(400),XTPRS(400)
DIMENSION MVH(8,40),S:ME(3,40)
COMMON/BLCK 1/CH(8),PC4(8),VH(8,100),D(8,100)
COMMON/BLCK 2/LEQ,LUP,XTT,XTT0,XT0
COMMON/BLCK 3/CVE(8),SACS(8),HMS(3),SDHS(8),MYS,SDMS(8)
COMMON/BLCK 4/CACE(8),SDCA(8),HACC(8),SDHA(8),MACC,SDHA(8)
COMMON/BLCK 5/NCVS,NNL1,NNL2,NNL1,NNL2,NNL1,NNL2,NNL1,NNL2

, DOPTC(4)
COMMON/BLCK 6/NCV,NMV,KA
COMMON/BLCK 7/IVC(8)
COMMON/BLCK 8/AD,LL(4,100),CHL(4,100),ANL(4,100),XT(4,800),NOBSP
COMMON/BLCK 9/IV(8),LL(8),A(8)
COMMON/BLCK 10/1I0(8,100)
COMMON/BLCK 11/H,1M,H3
COMMON/BLCK 12/RDTV,RAAA
COMMON/BLCK 13/NMLHC(8)
COMMON/BLCK 14/IJ1,1IJ2,1I3
COMMON/BLCK 15/I5(15,3)
COMMON/BLCK 16/TV(6,100,16)
COMMON/BLCK 17/NVS
COMMON/BLCK 18/NC(8),NHL(8),NNL(8),CNNA(8),NNMA(8),NNMA(8)
COMMON/BLCK 19/NVCF0
COMMON/BLCK 20/LPRT
CALL LP120
READ(10,435,16)(IS,IT,IS=1,15),IT=1,3)
435 FORMAT(5F9.0)
READ(10,405)STHR,ftime
405 FORMAT(10,F0.0)
READ(10,405)NOBSP,NCGS,NNL1,NNL2,NNL1,NNL2,NNL1,NNL2
WRITE(6,110,F0.0)
100 FORMAT(40)
K=NNL1+NNL2+NNL1+NNL2
READ(10,401)NPHASE
401 FORMAT(IO)
402 DO 70 IA=1,KA
403 IF(NP=IA,ST.2)GO TO 404
404 IF(NP=IE,IA,ST.1NL1+NL2))GO TO 406
405 READ(10,433)I,TS,GREEN(IA),CYCLE
406 FORMAT(IO,2F9.0)
407 N3(IA)=1
408 TCCS(IA)=3.0
409 RED(IA)=CYCLE-GREEN(IA)
410 GO TO 407
411 RED(IA)=GREN(IA-NL1-NL2)+2*INTG
412 GREN(IA)=RED(IA-NL1-NL2)-2*INTG
413 TCCS(IA)=(GREN(IA)+INTG)
414 IA=2
415 GO TO 407
416 READ(10,415)GREN(IA),RED(IA),CYCLE,NB(IA),TCCS(IA)
417 READ(10,416)I,TA,LL(IA),A(IA),MDG(IA),O(IA),PCH(IA),PCH(IA)
418 READ(10,416)I,TA,SDCS(IA),HMS(IA),SDHS(IA),CACC(IA),
419 1 SDCS(IA),HMS(IA),SDHS(IA),CACC(IA),SDHS(IA)
420 FORMAT(1F9.0,160.0)
421 PCH(IA)=PCH(IA)/160.0
422 PCH(IA)=PCH(IA)/160.0
423 WRITE(2,430)IA,GREN(IA),RED(IA),TCCS(IA)
424 FORMAT(' LANE=',I6,' GREEN=',F8.2,' RED=',F8.2,' TCCS=',F8.2)
425 CONTINUE
426 FORMAT(3F9.0,160.0)
427 FORMART(2I0,5F9.0)
428 FORMAT(12F9.0)

**********************************************************************
IAEF0 = A PARAMETER TO TEST THE EFFECT OF ACC, & DIFFERENT POLICIES
IAEF0 = 0 NO CHANGES
IAEF0 = 1 ACC. EFFECT = 0
IAEF0 = 2 CARS NOI5E REDUCED BY SDBA
IAEF0 = 3 HCV NI5E REDUCED BY 10 DBA
IAEF0 = 4 ALL VEH. NOISE REDUCED BY 5

LPRT = 1 IF THE SAME ORDER OF RANDOM NUMBERS IS TO BE GENERATED

**********************************************************************
READ(10,425)SRT,FR,IST,IAEF0,LPRT
READ(10,426)IOUT
READ(10,426)IOUT
WRITE(2,430)
FORMAT(1X,'TIME',5X,'CUMULATIVE TIME',12X,'GAP',13X,'GT',

13X,'NO. OF VEH.',1X,1500(1,-1))
** GENERATION OF FIRST GAP FOR EACH FLOW(LANE) **

**********************************************************************

GAP: INTERVAL BETWEEN VEHICLES
GT: GAP-TIME
13X: NARROW GAP
11X: LOSS OF SPACE
4X: INTERVAL BETWEEN VEHICLES
1X: 1000 (1,-1)
DO 750 IN=1, KA
AVG(IN)=3500.0/Q(IN)
G(IN)=GSNE(X(IN), AVG, IN)
TT(IN)=G(IN)
750 WRITE(2,530)TT(IN), G(IN), IN
530 FORMAT(' CUMULATIVE TIME','F8.2,'FIRST GAP','F8.2,'FLOW','I5)
DO 810 JJ=1,4
T=T+S
IT=FIXX(100*T)
11J1=2+JJ*3
11J2=3+JJ*3
11J3=4+JJ*3
11J4=5+JJ*3
11=1/JJ-3+(1/JJ)*12
12=1/JJ-3+(1/JJ)*12
13=1/JJ-3+(1/JJ)*12
DO 620 IC=1, KA

-----
TO CHECK IF THERE IS AN ARRIVAL
-----
IF(TT(IC)=T)GOTO, 210
620 = NVS(IC)

INPUT CONTROLE

IF(V(IC;H20,41) - V(IC;N20,2) - 3.0.LT.-480.0) GO TO 200
220 GT(IC)=TT(IC)-T
61 IC)= G(IC)
G(IC)=GSNEX(IN, AVG, IC)
TTZ=TT(IC)
TT(IC)=TT(IC)+G(IC)
NVS(IC)=NVS(IC)+1
V erratic values of distances, speeds & ACC.

460 INPUT CONTROLE
GOTO 210
210  IF(NB(IC).EQ.2)GO TO 250

210  IF((TCCS(IC)+CYCLE).GT.T)GO TO 260

211  FORMAT(1 SIGNAL IS RED NOW ?????? ????? STOP '5X' TIME NOW IS =',
          F8.2/40('-'))

212  FORMAT(' SIGNAL IS GREEN NOW ******** YOU MAY GO '5X' TIME NOW
          1 IS =',F8.2/40('-'))

550  FORMAT(1 LANE = ',16,4X,'CYCLE NO. = ',16,5X,'NO = ',16,5X,
          1'TIME OF COMPLETED CYCLES = ',5X,F8.2,5X,'TIME = ',F8.2)

260  IF(NQ(IC).EQ.0)GO TO 600

N7(IC)=N6(IC)
AT(IC, 1) = 0.0
N24 = NQ(IC)

VEHICLES GET INTO MOTION

IF(KLSNDD(IC), EQ, 1) GO TO 993
KLSNDD(IC) = 1
N2D = JS(IC)
CALL QUEUE(NP99, N999+N24, IC)
N99A = 0
N99B = N999+N24
IF(N995, GT, NVS(IC)) N99A = NVS(IC)
RATN(IC, N999) = 1.0
DO 998 LN = N999+1, N988
RATN(IC, LN-1) = RATN(IC, LN-1) + ABS(QD(IC, LN-1)-QD(IC, LN))
1 /V(IC, LN-1) = RT
998 CONTINUE

IF(STT(IC), GE, PATH(IC, LN-1) .AND. STT(IC), LT, RATN(IC, LN-1)) GO TO 270

270 CONTINUE

GO TO 500

IF(LAN(IC), EQ, 1) GO TO 600
N6(IC) = NAV(IC)
NA = IC - 17(IC)
N26 = 0
N26 = JB(IC) + NAV(IC) - 1
IF(NA, GT, 0) CALL START(N26, IC, S+IC)

UPDATE DISTANCES, SPEEDS, ACCEls.

CAR FOLLOWING THEORY PARAMETERS

M1 = M4(IC)
LL1 = LL(IC)
A1 = A4(IC)

---

H32 = NVS(IC)
H34 = JB(IC)
H36 = NAV(IC)
838 N33=ND(IC)
839 IF(J.GE.N34) GO TO 840
840 DO 830 J=1,N32
841 IF(CIC(IC).EQ.0) GO TO 831
842 V(IC,J,1J2)=V(IC,J,1J2)+S0.5*V(IC,J,M3)*S**2
843 IF(V(IC,J,1J2).LT.0.0) GO TO 832
844 IF(V(IC,J,1J2).LT.0.0) GO TO 833
845 CALL RELTDS(J,IC)
846 IF(ND(IC).EQ.2) GO TO 839
847 IF(CRDTV.LT.5.0) AND.V(IC,J-1,1J2).LT.0.01.
848 1 AND.V(IC,J,1J2).LT.0.01) GO TO 835
849 IF(CRDTV.LT.2.0) AND.V(IC,J-1,1J2).LT.
850 1 0.01. AND.V(IC,J,1J2).GT.0.01) GO TO 832
851 IF(V(IC,N34+1J3).AND.GT.0) GO TO 833
852 1 J.LT.(N34+1J3) GO TO 835
853 GO TO 836
854 IF(V(IC,J,1J2).LT.0.0) GO TO 834
855 V(IC,J,1J2)=1.0*(V(IC,J,1J2)***1H1)*V(IC,J,1J2)+1
856 IF(V(IC,J,1J2).LT.-5.0)V(IC,J,1J3)=5.0
857 IF(V(IC,J,1J3).LT.5.0)V(IC,J,1J3)=V(IC,J,1J3)
858 GO TO 830
859 QD(VIC,N34)=0.0
860 IF(VIC,N34,J,J) GT.QD(VIC,N34)=1) GO TO 832
861 V(IC,JM4,J1J3)=A1*(V(IC,N34,J1J2)***1M1)*V(IC,J1J2)+V(IC,JM4,
862 1M1)*V(IC,N34,J1J2)***111
863 V(IC,N34,J1J3)=**123*V(IC,N34,J1J3)
864 IF(VIC,N34,J1J3).LT.-5.0)V(IC,N34,J1J3)=5.0
865 GO TO 830
866 CALL STOPI(J,IC)
867 GO TO 830
868 V(IC,J,1J3)=V(IC,J,1J3)+(1.0-V(IC,J,1J2)/V(IC,J,1J3))
869 GO TO 830
870 V(IC,J,1J2)=0.0
871 V(IC,J,1J3)=0.0
872 GO TO 830
873 CALL FIRST(N34,C,STT,IC)
874 CONTINUE
C
C********
CWRITE IN BLOCKS
C********
C840 N40=NVS(IC)
CIF(N40.EQ.0) GO TO 620
C  IOUT#1 FOR VERY DETAILED OUTPUT
C
C   IF(IOUT,HE,1)GO TO 920
J1=(NI60-1)/4+1
11=3
DO 970 I=1,J1
11=11+4
12=11+3
IF(I(12,GF,N40))12=NI60
970 WRITE(IC,550) V(IC,J,1J1),V(IC,J,1J2),V(IC,J,1J3),V(IC,J,1J2)
   V(IC,J,1J2),J=11,12)
530  FORMAT(1X,4(4F7.2,2X))
C
C  CHECK IF THE VEH. IS STILL ON THE SEGMENT
C
C  ::::: :::::::::
C
C  920 IF(V(IC,1,J1,GT,480,.96 VVS(IC)=NVS(IC)=1
N50=NVS(IC)
N45=N40-150
IF(H45,NE,1)GO TO 520
JB(IC)=JB(IC)=1
IF(H50,NE,0)GO TO 560
DO 870 J=1,N50
DO 870 J=1,N50
870 V(IC,J,J11)=V(IC,J+1,J1M)
860 DO 890 JM1=1,16
890 V(IC,JM6+1,JM1)=0.0
820 CONTINUE
C
C  850 IF(T,LT,ST,49)50 TO 810
   IF(T,GT,ST,LT,0.01,AND.NCNSHM,NE,1,OR.T,NTIME,LT,0.01,AND.NCNSHM,NE,1)
   CALL CORRECT(H10,N17,NCSN4,NCNDC,KA)
C
C  855 IF(T/IST*IST-17)810,0,810
   KKK=KKK+1
   YXT(KKK)=KKK
   IF(KKK,GE,300)GO TO 877
   YXTPRS(KKK)=KKK
   KKPRS=KKKPRS+1
   CALL NOISE(NVS,KKKPRS)
   CALL NOISE(NVS,KKK)
   GO TO 810
   DO 875 IP=1,KA
   NS2=NVS(IP)
   WRITE(IP,475)
475  FORMAT(1X,NOISE FROM INDIVIDUAL VEH. ADJUSTED TO DIS'/45('')
475  WRITE(IP,477)CNL(IP,1Q),ANL(IP,1Q),ANL(IP,1Q),1Q=1,NS2)
470  FORMAT(1X,12F9.2)
810  CONTINUE
CALL DEVICE(4,0)
DO 250 IV=1,4000
WRITE(4,480)
480 FORMAT(1X,'NOISE HISTORY')
WRITE(4,540)(XT(IV,IK),IK=1,100)
540 FORMAT(1X;13F10.2)
C
C ---- DRAWING THE HISTOGRAM
C
DO 940 IX=1,100
IF(IX.GT.300)GO TO 940
XTTPRS(IX)=XT(IV,IX)
940 WRITE(4,4000)(XTTPRS(JA),JXTPRS(JA),JA=1,300)
C
C CALL PICCLE
C
C CALL JTS4(KK,KK,XTT(1))
WRITE(4,490)(XTT(IL),IL=1,KK)
490 FORMAT(1X,'SORTED OUT NOISE LEVELS'/1X,10(2X,F10.2))
C
C CALL INDICES(XXT,F,KK)
C
C CALL HSCAV(1,F,10,1,95.5,64.5)
WRITE(4,500)(XTT0,XTQ,XT0,LEQ,LPN)
500 FORMAT(7X,'L10',7X,'L50',7X,'L90',7X,'LE0',7X,'LNP')/50(-1)'//
& 5F10.2)
WRITE(4,445)(DPTH(1V),NPTC(1V)
445 FORMAT(1X,'DISTANCE OF OBS. POINT FROM NEAR LINES = ',F10.2/)
1 1 'DISTANCE OF OBSERVATION POINT FROM CROSS LINES = ',F10.2)
C
C CONTINUE
C
DO 750 IL=1,KA
NLBS(IL)=CLC(IL)*MIL(IL)+NHL(IL)+(N16(IL)-N17(IL))
NNAE(IL)=CNXA(IL)+MNAE(IL)+NNAE(IL)
PCHV(IL)=(CNV(IL)-NHL(IL)+NNAE(IL))*100/(N(IL)-NLBS(IL)-NNAE(IL))
PCHV(IL)=(CNV(IL)-NHL(IL)+NNAE(IL))*100/(N(IL)-NLBS(IL)-NNAE(IL))
AR2(IL)=C(V)/NLBS(IL)-NNAE(IL)*3600,00/(T-STM)
WRITE(11,750)M17(IL)+M17(IL)+M17(IL)+NCL(IL)+NML(IL)+NHL(IL)+NLBS(IL),
& NNAE(IL)+MNAE(IL)+NNAE(IL)+MNAE(IL)
750 Format(1X,'AT START OF NOISE MEASUREMENT TIME'/)
1 7X,'V = ',15,SX,'VMS = ',16,5X,'NCL = ',16,5X,'NML = ',16,
2 5X,'NHL = ',15,SX,'NLBS = ',16,16,'AT THE END OF NOISE MEASURMENTS'/
3 7X,'NHNA = ',15,5X,'NNAE = ',16,5X,'NNAE = ',16)
730 WRITE(4,510)IL,AR2(IL),PCHV(IL),PCHV(IL),PCHV(IL)
510 FORMAT(20(''))/1 LANE NUMBER = ',16,
& 'FLOW = ',F6.2,'VPH = ',5X,'NO. OF COMM. VEH. = ',16,
1 5X,'ACHIEVED PERCENT OF HV = ',F6.2,5X/' NO. OF MEDIUM VEH. = ',
2 16,5X,'ACHIEVED PERCENT OF MED. COMM. VEH. = ',F6.2/'
C
C NT IS THE TOTAL NUMEBR OF VEHS. IN ALL LANES
C NLBS NUMBER LEFT BEFORE STARTING NOISE MEASUREMENT
C
C
DO 740 II=1,KA
NT=NT*11+NLBS(II)-NNAE(II)
NT=NT+IV(II)-NML(II)-NNAE(II)
740 NCT=NCT+HCV(II)-NHL(II)-NNAE(II)
AT=NT/3600,00/(T-STM)
TPCHM=NT*100,0/NT
TPCH=4CT*100.0/VT
WRITE(4,520)TPCH,TPC1,TPCH,ATQ
520 FORMAT(1X, 'TOTAL NO. OF VEHS. = ', I6, 5X, 'PERCENT MED. = ', F8.2/
'PERCENTAGE OF HCV. = ', F2.5X, 'ACTUAL TOTAL FLOW = ', F8.2, 'VPH')
CALL DEVOID
STOP
END

FUNCTION GSNEX(MNG, AVG, I)

REAL MNG
DIMENSION MNG(8), AVG(8), P(8)
COMM/BLOCK 20/LPRT

LPRT IS A PARAMETER TO INITIALISE THE RANDOM NOS.

IF(LPRT.EQ.1) G0 TO 10
CALL GSBBF
10 R=GSBAF(J)
P(I)=MNG(I)+(AVG(I)-MNG(I))* ALOG(1/R)
RETURN
END

SUBROUTINE INICES(XT, F, KKK)

REAL MNG, LEP, LNP
DIMENSION XX(300), JJ(300)
DIMENSION XT(300), F(300)
COMM/BLOCK 2/LEQ, LNP, XTI0, XT50, XT90
LEN=0.0
LEQ=0.0
DLEQ=0.0
ULEQ=0.0
K=0
JJ=0
DO 70 IA=1, 60
XX(IA)=0.0
JJ(IA)=0.0
70 F(IA)=0.0
ISUM10=KKK*0.1+0.5
ISUM50=KKK*0.5+0.5
ISUM90=KKK*0.9+0.5
XT10=XT(ISUM10)
XT50=XT(ISUM50)
XT90=XT(ISUM90)
L=0
J4=1
IKKK=1
XI=0.5
10 XI=XI-1.0
K=KK+1
XX(K)=XI/10.0
DO 20 J=JN,JJK
IF(CT(J),LT,X1>GD TO 30
20 CONTINUE
JJKK=2

CJ<TISUE

1KKK=2

L=L+1

JI=J-JN

JJ(J)=J

F(L)=1.0+J1/JKK

1 IF(J1,NE,JN)WRITE(4,40)J1,XT(J1),J1=JN,J1=1

40 FORMAT(5X,'(I7,I7) ',10(F10.2))

JN=J

GO TO (10,0,JJKK)

WRITE(4,50)(F(L),L=1,60)

10 FORMAT(3/PERCENT UNISF LEVEL IN EACH CLASS'

3/60(1*12)

DO 60 I=1,K

ULE0=JLEN+10-XX(I)*J(J)

DLE0=JLEN+JJ(I)

60 CONTINUE

LEN=10*ALOG10(ULEQ/DLEQ)

LVP=LEQ+XT10-XT90)

RETURN

END

C SUBROUTINE INITIAL (J,G,GT,C,IC)

C

REAL YMS(3),MACC(8)

DIMENSION C(8,170),HCV(8),G(8),GT(8),NMV(8)

COMMON/ROKE/LOCK 1/PCH(8),PCM(8),V(8,100),D(8,100)

COMMON/ROKE/LOCK 5/CMS(8),SDMS(8),MMS(8),SDHA(8)

COMMON/ROKE/LOCK 4/CAAC(8),SCDA(8),HACC(8),SDHA(8),MACC,SDMA(8)

COMMON/ROKE/LOCK 2/YCV,VMV,KA

COMMON/ROKE/LOCK 11/UI,M2,13

COMMON/ROKE/LOCK 16/V(6,100,16)

COMMON/ROKE/LOCK 20/LPRT

IF(LPRT,EQ.1)GO TO 100

CALL 305BBF

V(C,IC,J)=G05A5F(J)

IF(V(C,IC,J),GT,PCH(IC)+PCM(IC))GO TO 10

IF(V(C,IC,J),GT,PCH(IC))GO TO 40

HCV(IC)=HCV(IC)+1

V(C,IC,J)=13.44

25 V(C,IC,J)=G05A6F(HMS(IC),SDH(IC))

IF(V(C,IC,J),GT,SMS(1)+2.0*SDH(1),OR.

1 V(C,IC,J),LT,HMS(1)-2.0*SDH(1))GO TO 25

35 V(C,IC,J)=G05A6F(HACC(1),SDMA(1))

IF(V(C,IC,J),GT,HACC(1)+2.0*SDMA(1),OR.

1 V(C,IC,J),LT,HACC(1)-2.0*SDMA(1))GO TO 35

GO TO 20

40 NMV(1)=NMV(1)+1

V(C,IC,J)=2.8

45 V(C,IC,J)=G05A6F(HMS(1),SDH(1))

IF(V(C,IC,J),GT,HMS(1)+2.0*SDH(1),OR.

1 V(C,IC,J),LT,HMS(1)-2.0*SDH(1))GO TO 45

50 V(C,IC,J)=G05A6F(HACC(1),SDMA(1))

IF(V(C,IC,J),GT,HACC(1)+2.0*SDMA(1),OR.

...
V(I,J,1) = 27.9 + 2.9 * ALOG10(V(I,J,IJ2)*3.6)
IF (IAEF0.E2,3) V(I,J,1) = V(I,J,1) - 10.0
IF (IAEF0.E2,4) V(I,J,1) = V(I,J,1) - 5.0
35 IF (IAEF0.E2,1) GO TO 95
IF (V(I,J,IJ3),GE,0.0,AND.V(I,J,IJ3),LT,0.25) GO TO 65
IF (V(I,J,IJ3),GE,0.75,AND.V(I,J,IJ3),LT,2.0) GO TO 65
IF (V(I,J,IJ3),GE,2.0) GO TO 75
IF (V(I,J,IJ3),LT,0.0) ADNL(I,J) = 0.0
GO TO 70
95 ADNL(I,J) = 0.0
GO TO 70
45 ADNL(I,J) = 1.6 * V(I,J,IJ3)
GO TO 70
55 ADNL(I,J) = 0.6 * 4.0 * V(I,J,IJ3)
GO TO 70
75 WRITE(1,400) V(I,J,1), V(I,J,IJ2), V(I,J,IJ3)
400 FORMAT('NOISE DUE TO ACC. OF A HCV IS NOT CALCULATED',3FB,2)
GO TO 70
65 ADNL(I,J) = -13.3 + 2.1 * V(I,J,IJ3)
GO TO 70
5 IF (V(I,J,IJ2),GE,7.53) GO TO 30
V(I,J,1) = 65.2
IF (IAEF0.E2,2,11,IAEF0.E2,4) V(I,J,1) = V(I,J,1) - 5
GO TO 40
30 V(I,J,1) = 22.4 + 27.9 * ALOG10(V(I,J,IJ2)*3.6)
IF (IAEF0.E2,2,11,IAEF0.E2,4) V(I,J,1) = V(I,J,1) - 5
GO TO 40
40 IF (IAEF0.E2,1) GO TO 125
IF (V(I,J,IJ3),GE,0.0,AND.V(I,J,IJ3),LT,2.0) GO TO 50
IF (V(I,J,IJ3),GE,0.0,AND.V(I,J,IJ3),LT,5.5) GO TO 60
IF (V(I,J,IJ3),GE,5.5) GO TO 85
IF (V(I,J,IJ3),LT,0.0) ADNL(I,J) = 0.0
GO TO 70
125 ADNL(I,J) = 0.0
GO TO 70
50 ADNL(I,J) = 2.0 * V(I,J,IJ3)
GO TO 70
85 WRITE(1,400) V(I,J,1), V(I,J,IJ2), V(I,J,IJ3)
400 FORMAT('NOISE DUE TO ACC. OF A CAR IS NOT CALCULATED',3FB,2)
ADNL(I,J) = 0.0
GO TO 70
60 ADNL(I,J) = 5.13 + 3.593 * V(I,J,IJ3)
70 C4L(I,J) = V(I,J,1) + ADNL(I,J)
DJ 140 IR = 1, IHRSIP
CALL DISTANCE(I,J,IR)
ADNL(I,J) = C4L(I,J) - 20.0 * ALOG10(D(I,J)/D41C)
140 XT(IR,KK) = XT(IR,KK) + 10 ** (ADNL(I,J)/10.0)
10 CONTINUE
90 CONTINUE
DJ 100 TS = 1, IHRSIP
100 XT(IS,KK) = 10.0 * ALOG10(XT(IS,KK))
RETURN
END
C
C SUBROUTINE DISTANCE(KJ, JJ, I)
C
C COMMON/ALOCK 1/PCH(8), PCY(3), Y(8,100), D(R,100)
COMMON/ BLOCK 5/CGS, NNL1, NNL2, VCL1, NCL2, UN/ WC, DMIC, DOPTC(4)

COMMON/ BLOCK 14/J1, J2, J3
COMMON/ BLOCK 16/ V(5, 100, 16)
IF(KJ, GT. (NNL1 + NNL2 + NCL1)) GO TO 10
IF(KJ, GT. (NNL1 + NNL2)) GO TO 20
IF(KJ, GT. NNL1 ) GO TO 30
D(KJ, J) = SORT((DOPTC(I) + V(KJ, J, J1) - V(KJ, J, 2)/2)*2 + (DOPTC(I) + UN/2)
1 W - (KJ-1) )**2
RETURN
30
D(KJ, J) = SORT((DOPTC(I) + V(KJ, J, J1) - V(KJ, J, 2)/2 + (NNL1 + NNL2) * JC)**2
1 (DOPTC(I) + V(KJ, J, J1) - W)**2
RETURN
10
D(KJ, J) = SORT((DOPTC(I) + V(KJ, J, 2)/2)**2 + (DOPTC(I) + WC/2)
1 (KJ - NNL1 - NNL2 - 1)**2
RETURN
RETURN
20
D(KJ, J) = SORT((DOPTC(I) + V(KJ, J, 1) - V(KJ, J, 2)/2)**2 + (DOPTC(I) + WC/2)
1 **2 + (DOPTC(I) + V(KJ, J, 1) - V(KJ, J, 2)/2)**2
RETURN
END

SUBROUTINE COUNTER (NVS, JB, IC)

DIMENSION JA(3), NVS(5)
COMMON/ BLOCK 7/V2(5)
COMMON/ BLOCK 17/V1, M2, V3
COMMON/ BLOCK 16/V(5, 100, 16)
NQ(1C) = 0
30
1 N = JB(IC)
2 N = NVS(1C)
DO 10 I = N1, N2
IF (V (IC, I, M2), LT, 0, 10, AND, ABS(V(IC, I, M3)) . LT, 0, 10) NQ(1C) = NQ(1C) + 1
10 CONTINUE
RETURN
END

SUBROUTINE WHICH (NVS, JB, IC)

DIMENSION JA(3), NVS(5)
COMMON/ BLOCK 11/V1, M2, V3
COMMON/ BLOCK 15/ WHICH(8)
COMMON/ BLOCK 16/V(5, 100, 16)
WHICH(1C) = 1
R = Q5AASF(4)
N = NVS(1C)
DO 10 I = 1, N
DO 10 II = 1, 15
IF (V(IC, I, 11) . LE, B(II, 1), AND, V(IC, I, M2) . LE, B(II, 2),
1 AND, R . LE, B(II, 5)) GO TO 20
IF (V(IC, I, 11) . LT, -130, 0) GO TO 20
10 CONTINUE
WRITE(IC, 2000)
2000 FORMAT (1X, 'ROAD IS CLEAR', 10, 2)
JB(1C) = N + 1
WRITE (IC, J) IC, JB (IC)
RETURN
20 J3 (IC) = 1
WRITE (IC, J) IC, JB (IC)
700 FORMAT (1X, LAME = '1', 16, 5X, 'FIRST VEH. TO START BRAKING = ', 16)
30 RETURN

END

C SUBROUTINE START (V, C, S, IC)

C

DIMENSION NVS (A), JB (B), NAV (B), C (B, 100)
COMMON / BLOCK 11 / M1, M2, M3
COMMON / BLOCK 14 / J1, J2, J3
COMMON / BLOCK 16 / V (4, 100, 16)
V (IC, 1, 1) = V (IC, 1, 1)
V (IC, 1, 3) = 1.0 * (V (IC, (N - 1), M2) = V (IC, N, M2)) / (V (IC, (N - 1), M2)
IF (V (IC, N, 1) = V (IC, N, 1))
V (IC, N, 1) = A BS (V (IC, N, 1))
RETURN
END

C SUBROUTINE FIRST (J, C, T, IC)

C

DIMENSION C (6, 100), T (B)
COMMON / BLOCK 9 / M1 (B), N (B), A (B)
COMMON / BLOCK 11 / M1, M2, M3
COMMON / BLOCK 12 / M1V, RNBTV
COMMON / BLOCK 14 / J1, J2, J3
COMMON / BLOCK 16 / V (4, 100, 16)
IF (J.EQ.1) GO TO 10
CALL RELTDIS (J, IC)
IF (RNBTV, LT, 50.0) GO TO 10
5 V (IC, J, J1) = (C (IC, J) T (IC)) EXP (C (IC, J) T (IC)) - 1.0) * (V (IC, J, 3)
V (IC, J, J2) = V (IC, J, 3) * (1.0 EXP (C (IC, J) T (IC))
V (IC, J, J3) = V (IC, J, 3) (1.0 - V (IC, J, J2)) / V (IC, J, 3)
RETURN
10 V (IC, J, J1) = V (IC, J, 4) + V (IC, J, 4) S > 0.5 * V (IC, J, 3) S > 2
V (IC, J, J2) = V (IC, J, 4) S > V (IC, J, M3) S
160 V (IC, J, J3) = (IC) * (V (IC, J, J2) ** 2) * MM (IC) * (V (IC, J, 4) S
V (IC, J, 4) / (A 3 S (RNBTV . 5.0)) ** LL (IC)
RETURN
END

C SUBROUTINE STOP (I, IC)

C

COMMON / BLOCK 7 / Q (B)
COMMON / BLOCK 10 / 2D (B, 100)
COMMON / BLOCK 14 / J1, J2, J3
COMMON / BLOCK 16 / V (4, 100, 16)
V (IC, I, J1) = V (IC, I, J1)
V (IC, I, J2) = 0.0
V (IC, I, J3) = 0.0
RETURN
END

C SUBROUTINE QUEUE (I, J, IC)

C

COMMON / BLOCK 10 / 2D (B, 100)
COMMON/BLOCK 16/V(5,10,16)
DO 20 IN=1,1
QC(IN,IN)=0.0
20 CONTINUE
DO 10 IN=1,1
QC(IN,1)=-(ABS(QC(IN,1))+V(IN,1,2))
10 CONTINUE
RETURN
END

SUBROUTINE RELTHIS(J,IC)
COMMON/BLOCK 11/41,42,43
COMMON/BLOCK 12/RDTV,RBTV.
COMMON/BLOCK 14/IV1,IV2,IV3
COMMON/BLOCK 15/V(5,10,16)
RDTVARS(V(IC,(J-1),11)-V(IC,J,1))
RETURN
END

SUBROUTINE CORRECT (N6,N7,NCSN4,NCEND,K)

DIMENSION N6(8),N7(8),N8(8),NVS(8)
COMMON/BLOCK 5/NCGS,NN1,NNL2,NCL1,NCL2,UN,WC,DMIC,DOPTN(4)
1,DOPTC(4)
COMMON/BLOCK 11/M1,M2,43
COMMON/BLOCK 14/V(5,10,16)
COMMON/BLOCK 15/N,NVS
COMMON/BLOCK 16/NCL(8),NHL(8),NHL(8),NCNA(8),NMNA(8),NMNA(8)
IF(NCSN4.EQ.2,1)GO TO 10
DO 20 J=1,K
OBS=DOPTC(2)
IF(V(I,J,1).LE.OBS)GO TO 11
H6(I)=N6(I)
H7(I)=N7(I)
H10=NCNA(I)
DO 20 J=1,K
IF(V(I,J,1).GT.OBS.AND.ABS(V(I,J,2)>.8).LT.0.1E-6)
1 NCL(I)=NCL(I)+1
IF(V(I,J,1).GT.OBS.AND.ABS(V(I,J,2)-9.8).LT.0.1E-6)
1 NCL(I)=NCL(I)+1
IF(V(I,J,1).GT.OBS.AND.ABS(V(I,J,2)-13.44).LT.0.1E-6)
1 NHL(I)=NHL(I)+1
20 CONTINUE
NCSN4=1
RETURN
10 NCEND=1
DO 30 J=1,K
OBS=DOPTC(2)
IF(V(I,J,1).LE.OBS.AND.ABS(V(I,J,2)-5.8).LT.0.1E-6)
1 NCNA(I)=NCNA(I)+1
IF(V(I,J,1).LT.OBS.AND.ABS(V(I,J,2)-9.8).LT.0.1E-6)
1 NCNA(I)=NCNA(I)+1
30 CONTINUE
RETURN
END
NHA(I) = NHA(I) + 1
IF (V(I, J, 11) .LT. OBS. AND. ABS(V(I, J, 2) - 13.44) .LT. 0.1E-6)
30 CONTINUE
RETURN
END
FINISH
END
Normal output

SIGNAL IS GREEN NOW $ S S $ YOU MAY GO TIME NOW IS = 200.00

INTERSECTION = 1 LANE = 2

Lane = 2 Cycle No. = 2 No. = 7 Time of completed cycles = 200.00 Time = 200.00

INTERSECTION = 1 No.31 = 7 No.32 = 24 No.33 = 148 = 1

INTERSECTION = 2 LANE = 2

Lane = 2 Cycle No. = 2 No. = 10 Time of completed cycles = 200.00 Time = 200.00

INTERSECTION = 2 No.31 = 7 No.32 = 24 No.33 = 408 = 8

N31, N32 and JB provide continuous checking on the results.

Noise output is similar to that of SGINNS.

Listing of subroutines which are similar to those of SGINNS is not given.
Appendix 7.B Listing of PAIRSINSE

MASTER PAIRSINSE

THIS PROGRAM SIMULATES NOISE LEVELS AT A PAIR OF SIGNALISED INTERSECTIONS USING SIMILAR PRINCIPLES TO THOSE OF FFNOISESINSE

PSSTLN -- POSITION OF THE STOP LINE
SPDIS -- SPECIFIED LEAVING DIS.
SPEEDIS -- SPECIFIED ENTERING DIS.
RED -- REDTIME IN SEC.
GREEN -- GREEN TIME IN SEC

REAL HIG, LEQ, LNP
REAL HNS(3), HACC(8)
DIMENSION IV(50), F(60), AQ(R), PCHV(8), HNG(8), Q(R), AVG(8), PCWV(8)
DIMENSION IG(50), GT(R), TT(8), C(8,100), G1(1), XT(900)
1 H(8), NC(8), RD(8), NN(8), NLRS(8), YXT(800), NNS(8), INTG(2)
DIMENSION NA(2,8), TCCS(2,8), GREEN(2,8), RED(2,8), N16(8), N17(8)
1 HAV(2,8), SST(2,8), NC(2,8), N6(2,8), N17(2,8), NNAE(8)
2 AT(2,8,20), PSSTLN(2,8), SPDIS(8), CYCLE(2), TSPSNS(2,8), NS(2,8)
COMMON /LOCK 1/PCK(8), PC(4R), Y(R,100), D(R,100), SEDIS(8)
COMMON /LOCK 2/LEQ, LNP, XT10, XT50, XT90
COMMON /LOCK 3/C1S(8), SDCS(8), HM5(8), STHM(8), MNS7, SDHS(8)
COMMON /LOCK 4/CACC(8), SDCA(8), HACC(8), SDHA(8), HACC, SDHA(8)
COMMON /LOCK 5/NGS(8), NL1, NL2, NL1, NCL2, NCL3, NCL4, NW, WC, DMIC
COMMON /LOCK 6/NV, NV, KA
COMMON /LOCK 7/IV(2,8)
COMMON /LOCK R/ADHL(4,100), CNL(4,100), ANL(4,100), XT(4,800), NOBS
COMMON /LOCK 9/UM(8), LL(8), A(8)
COMMON /LOCK 10/RD(8,100)
COMMON /LOCK 11/V1, H2, 43
COMMON /LOCK 12/RDTV, RDOVTV
COMMON /LOCK 13/N11ICH(2,8), 1OPS, 1IJB(2,8)
COMMON /LOCK 14/I1, 1I2, 1I3
COMMON /LOCK 15/V(8,15), 16
COMMON /LOCK 17/VN, NVS
COMMON /LOCK 18/NCL(8), NNL(8), NNL2, NCL1, NCL2, NCL3, NCL4, NW, WC, DMIC
COMMON /LOCK 19/DOPTN(4), DOPTC(4), DBINTS
COMMON /LOCK 20/LPRT
CALL LP120
READ(10,435) ((B(IS, IT), IS=1,15), IT=1,3)
FORMAT(F0.0)
READ(10,405) STHMTIME
FORMAT(F0.0,10)
READ(10,400) NOHSP, NCGS, NNL1, NNL2, NCL1, NCL2, NCL3, NCL4, WN, WC, DMIC
FORMAT(B10,3F0.0)
READ(10,402) DOINTS, (D(DOPTH(1), DOPTC(1)), IT=1,7), NOBSP
FORMAT(F0.0,0)
KC=NL1+NNL2
KB=NNL1+NL2+NCL1+NCL2
KA=NNL2+NCL1+NCL2+NCL3+NCL4
DO 705 IX=1, KB
NB(1,IX)=1
IF(X, GTC>60) GO TO 417

435
405
400
402
TO CHECK IF THERE IS AN ARRIVAL

IF(TT(IC)=T)0,0,210
N20=NVS(IC)
IF(N20,EQ,0)GO TO 220
IF(V(IC,N20,2)-4.0,LT,SPEED(IC))GO TO 200

GT(IC)=TT(IC)+T
G1(IC)=G(IC)
G(IC)=GS*EX(N,AVG,IC)
TZZ=TT(IC)
TT(IC)=TT(IC)+G(IC)
N(IC)=V(IC)+1
NVS(IC)=NVS(IC)+1

THERE IS AN ARRIVAL
CALCULATE INITIAL VALUES OF DISTANCES,SPEEDS & ACC.

N30=NVS(IC)
CALL INITIAL(N30,G1,GT,C,IC)
WRITE(IC,570)T,TZZ,G1(IC),G(IC),GT(IC),NVS(IC),IC,N(IC)

FORMAT(1X,'TIME =',F7.2,' TOTAL CUM. TIME =',F7.2,' LAST GAP
1 =',F7.2,' NEW GAP =',F7.2,' GT =',F7.2/1X,' NUMBER OF VEH. IN
2 THE SYSTEM =',I4,' FLOW =',I4,' TOTAL NO. OF VEH. ENTERED THE
3 SYSTEM =',I4)
WRITE(1C,650)V(IC,N30,3),V(IC,N30,4),C(IC,N30),V(IC,N30,41),
1 V(IC,N30,42),V(IC,N30,43),V(IC,N30,43)

FORMAT(1X,'DESIRED SPEED=',F6.2,' STARTING ACC. =',F6.2/4X,'C=',F
1 ,F6.2,4X,10.2)
GOTO 210

GOTO 210
CONTINUE

CARRY OUT CALCULATIONS FOR THE INTERSECTIONS

DO 815 I=1,2
N32=NVS(IC)
IF(I.EQ.1) IOPS=2
IF(I.EQ.2) IOPS=1
IF(I.EQ.1.AND.IC.GT.KB.OR.I.EQ.2.AND.IC.GT.KC.AND.IC.LE.KB)
1 GO TO 845
IF(NVS(IC).EQ.0) GO TO 869
IF(IC.GT.KC) GO TO 869
IF(IC.LE.:NNL1) GO TO 846

C
C +++++++++++++++++++++++++++++
C
C FIND THE FIRST VEHICLE TO BE UNDER THE CONTROL OF THE NEXT INTS.
C
C +++++++++++++++++++++++++++++
C
DO 845 JA=1,N32
B45 IF(VIC(JA,1)).LT.,PSSTLN(1,IC)+0.5*UC) GO TO 865
N31=0
GO TO 869
B65 N31=JA-1
GO TO 869
B46 DO 847 JAA=1,N32
B47 IF(VIC(JAA,1)).LT.,PSSTLN(2,IC)+0.5*UC) GO TO 848
N31=0
GO TO 869
B48 N31=JAA-1
869 IF(NB(A,IC),EQ.2.AND.NVS(IC),EQ.0) GO TO 251
IF(NB(A,IC),EQ.0) GO TO 250
IF(TCCS(1,IC)+GREEN(I,IC)),GT,T) GO TO 260
N2(1,IC)=0

231 WRITE(IIC/505),T,1,IC
505 FORMAT' SIGNAL IS RED NOW ???. STOP',10X,'TIME NOW IS = ' 
     1,'F3.2/4/0(''-''// INTERSECTION = ',16,6X,': LANE = ',160// )
N3(1,IC)=2
IF(IC.LE.KC) GO TO 230
CALL WHICH(104,J1,PSSTLN,IC,1)
GO TO 600
230 IF(I.EQ.1.AND.IC.GT.NNL1.OR.I.EQ.2.AND.IC.LE.NNL1)
    1 CALL WHICH(31+1,32,J1,PSSTLN,IC,1)
IF(I.EQ.1.AND.IC.LE.NNL1.OR.I.EQ.2.AND.IC.GT.NNL1)
    1 CALL WHICH(104,J1,PSSTLN,IC,1)
GO TO 600
250 IF(NWHICH(I,IC),EQ.0.AND.I.EQ.1.AND.IC.GT.NNL1.AND.IC.LE.KC.OR.
    1 WHICH(I,IC),EQ.0.AND.I.EQ.2.AND.IC.LE.NNL1) CALL WHICH(N31+1,N32
    2 JB,PSSTLN,IC,1)
IF(NWHICH(I,IC),EQ.0.AND.I.EQ.1.AND.IC.LE.NNL1.OR.NWHICH(I,IC).
    1 EQ.0.AND.I.EQ.2.AND.IC.GT.NNL1.AND.IC.LE.KC) CALL WHICH(1,N31
    2 JB,PSSTLN,IC,1)
IF(NWHICH(I,IC),EQ.0.AND.IC.GT.KC) CALL WHICH(1,N32,JB,PSSTLN,IC,1)
251 IF(TCCS(1,IC)+CYCLE(I,GT,T.AND.NVS(IC),EQ.0) GO TO 815
IF (TCCS(1,IC)+CYCLE(I,GT,T) GO TO 600
C
C CYCLE IS GREEN
C
NWHICH(I,IC)=0
STY(I,IC)=0.0
NAV(I,IC)=0
NL(1,IC)=0
NZ(1,IC)=0
NC(1,IC)=1
NC(1,IC)=NC(1,IC)+1
TCCS(1, IC) = TCCS(1, IC) + CYCLE(1)
WRITE(1, 515), 1, IC

515 FORMAT(1, SIGNAL IS GREEN NOW: YOU MAY GO)
1 TIME NOW IS = "FR. 2/46('-')": INTERSECTION = "1, 15": LANE 2 = "1", 15/1/1
IF(1, EQ. 1, AND. IC, LE. NNL1 . OR. 1, EQ. 2, AND. IC, GT. NNL1, AND. IC, LE. KCS)
1 GO TO 255
CALL COUNTER(N33, JB, 1, IC)

255 N33(1, IC) = JB(1, IC)
IF(JB(1, IC), EQ. 1) N33(1, IC) = JB(1, IC) + 1
CALL COUNTER("31, N33, 1, IC, 1")

551 WRITE(1, 550), 1, IC, N2(1, IC), NQ(1, IC), TCCS(1, IC), T = 7; N31, N32
1 N33(1, IC) = JB(1, IC)

550 FORMAT(1, LANE = "1", IC, "CYCLE NO. = "16, 5X, "NO. = "16, 5X:"
1 TIME OF COMPLETED CYCLES = "5X, FR. 2, 5X, "TIME = "5X, 8, 2, 1"
1 INTERSECTION = "16, 10X, " N31 = "13, "N32 = "13, "N33 = "13, "JB = "13"

N22 = VB(1, IC)
STPPos(1, IC) = V(1, IC, N22, 1)
260 IF(NVS(1, IC). EQ. 0) GO TO 815
IF(NQ(1, IC). EQ. 0) GO TO 600
STT(1, IC) = T - TCCS(1, IC)
N7(1, IC) = N6(1, IC)
AT(1, IC, 1) = 0, 0
N24 = N3(1, IC)
1 DO 270 IN = 2, N24 + 1
AT(1, IC, IN) = RT + (1.0 + RT/FR) + RT + (1.0 + RT/FR)*IN
IF(STT(1, IC), EQ. 1, AND. STT(1, IC), LT. AT(1, IC, IN))
1 GO TO 270

900 CONTINUE
GO TO 500

270 NAV(1, IC) = IN - 1
IF(NAV(1, IC). EQ. 1) GO TO 600
N5(1, IC) = NAV(1, IC)
N4 = N5(1, IC) - N7(1, IC)
N26 = 0
N26 = JB(1, IC) + NAV(1, IC) + 1
IF(NA(. GT. 0) CALL START(N26, C, S, IC)

C UPDATE DISTANCES, SPEEDS & ACFS, ACCORDING TO THE POSITION OF THE VEHICLE, I.E., WHETHER IT IS UNDER THE FIRST INTERSECTION OR THE SECOND ONE. CROSS LANES NOT INCLUDED.

C

600 HM1 = HM(1, IC)
LL1 = LL(1, IC)
A1 = AK(1, IC)
N34 = J3(1, IC)
N36 = NAV(1, IC)
N38 = NQ(1, IC)
IF(1, IC, LE, KCS) GO TO 867
CALL UPDATE(1, N32, N34, N36, N38, S, STT, PSSTLN, A1, HM1, LL1, NB, IC, 1)
1 STPPos)
GO TO 860

866 CALL UPDATE(1, N32, N34, N36, N38, S, STT, PSSTLN, A1, HM1, LL1, NB, C, IC, 1)
1 STPPos)

867 IF(1, EQ. 1, AND. IC, GT. NNL1 . OR. 1, EQ. 2, AND. IC, LE. NNL1)
3 CALL UPDATE(N31 + 1, N32, N34, N36, N38, S, STT, PSSTLN, A1, HM1, LL1, NB, C, 4 IC, 1, STPPos)
IF(N31.EQ.0) GO TO 840
IF(I.EQ.1,AND,Ic.LE.NNL1.OR,I.EQ.2,AND,Ic.GT.NNL1)
2 CALL UPDATE(1,N31,N34,N36,N38,S,ST,PSSTLNL,A1,MM1,LL1,KB,IC,1)
1 STPPOS

WRITE IN BLOCKS

840  N40=NVS(1C)

CHECK IF THE VEH. IS STILL ON THE SEGMENT

920  IF(V(IC,1,IJ1).GT.SPLDILS(1C))NVS(1C)=NVS(1C)-1
     N50=NVS(1C)
     N45=N46-N50
     JB(I,IC)=JB(I,IC)-1
     IF(Ic.LE.KC)JB(1OPS,IC)=JB(1OPS,IC)-1
     IF(N50.EQ.0) GO TO 860
     DO 870 J=1,N50
     DO 870 J1M=1,16
     870  V(IC,J1M)=V(IC,J+1,IJ1)
     860  DO 890 J1M=1,16
     890  V(IC,N50+1,J1M)=0.0
     815  CONTINUE
     N50=NVS(1C)
     J1=(N50-1)/4+1
     I1=3
     DO 910 II=1,J1
     II=II+4
     I2=II+3
     IF(I2.GE.N50) I2=N50
     910  WRITE(I,580)(V(IC,J1J1),V(1C,J1J2),V(1C,J1J3),I
     580  FORMAT(1X,4(4F7.2,2X))
     520  CONTINUE

SAMPLING & CALLING NOISE

810  CONTINUE

850  IF(T.LLT.STMH) GO TO 810
     IF(T=STMH.LT.0.01,AND,NCSNH,NE.1.OR.T=NTIME.LT.0.01.AND.NCEND,8
     & NE.1)CALL CORRECT(16,N17,NCSNH,NCEND,KA)
     855  IF(T=IST*IST=1T) B10,0,810
     KKK=KKK+1
     YXT(KKK)=KKK
     CALL NOISE(NVS,KKK)
     GO TO 810
     DO 875 IP=1,KA
     N52=NVS(IP)
     WRITE(IP,475)
     475  FORMAT(1X,NOISE FROM INDIVIDUAL VEHS. ADJUSTED TO DIS*/65(1")
     875  WRITE(IP,470)(CNL(IP,IQ),ADNL(IP,IQ),ANL(IP,IQ),IQ=1,N52)
     470  FORMAT(1X,12F9.2)
     810  CONTINUE
     800  CONTINUE
DO 930 IV=1,NBSP
WRITE(4,430)
DO 480 JV=1,NBSP
WRITE(4,540)(XT(IV,IK),IK=1,KK)
FORMAT(1X,10F10.2)
C -------- DRAWING THE HISTOGRAM
C
DO 940 IX=1,KK
XTT(IX)=XT(IV,IX)
CALL DEVICE(4,0)
CALL GRAFT(XTT,XTT,KK,0)
CALL PICCLE
CALL JTS4(KK,XTT(1))
WRITE(4,4)J1(XTT(IL),IL=1,KK)
DO 490 IX=1,10(2X,F10.2)
CALL HISTCOF(IX,15,7X,'LV',7X,'LE0',7X,'LNP'/50(1/-1)/
& 5F10.2)
WRITE(4,440)DOPTH(IV),DOPTC(IV)
445 FORMAT(1X,DISTANCE OF OBS. POINT FROM NEAR LANS =1 ;F10.2/
1 DISTANCE OF OBSERVATION POINT FROM CROSS LANS =1 ;F10.2)
C
CONTINUE
DO 730 IL=1,KA
NLBS(IL)=NCL(IL)+NHL(IL)+NHI(IL)+(N16(IL)-N17(IL))
NNAE(IL)=NCN(A(IL)+NHNACL(IL)+NHNACL(IL)
PCHV(IL)=NCHV(IL)+NHL(IL)+NNAE(IL)+100/(N16(IL)-N17(IL))
PCCHV(IL)=NCHV(IL)+NHL(IL)+NNAE(IL)+100/(N16(IL)-N17(IL))
MIL(IL)=(N16(IL)-N17(IL)+NNAE(IL)+1000,0)/(T-STNM)
WRITE(4,520)NT,TPCH,TPCH,ATQ
C
1 DO 740 IL=1,KA
NLBS(IL)=NCL(IL)+NHL(IL)+NNAE(IL)
NCN(A(IL)+NHNACL(IL)+NHNACL(IL)
PCHV(IL)=NCHV(IL)+NHL(IL)+NNAE(IL)+100/(N16(IL)-N17(IL))
PCCHV(IL)=NCHV(IL)+NHL(IL)+NNAE(IL)+100/(N16(IL)-N17(IL))
MIL(IL)=(N16(IL)-N17(IL)+NNAE(IL)+1000,0)/(T-STNM)
WRITE(4,510)IL,NCN(A(IL),NCHV(IL),PCCHV(IL),NCHV(IL),MIL(IL)
C
510 FORMAT(1X,1) LANE NUMBER =1 ,16
& //X,'ACHIEVED FLOW=1 ,F6.2,'VPH',5X,'NO. OF COMM. VEH.=1 ;F8.2/
1 5X,'ACHIEVED PERCENT OF HCV=1 ,F6.2,5X,'NO. OF MEDIUM VEH. =1 ;F
2 15,5X,'ACHIEVED PERCENT OF MED. COMM. VEH. =1 ,F8.2/)
C
C NT IS THE TOTAL NUMBER OF VEHS. IN ALL LANES
C NLBS NUMBER LEFT BEFORE STARTING NOISE MEASUREMENT
C
C
DO 740 IL=1,KA
NLBS(IL)=NCL(IL)+NHL(IL)+NNAE(IL)
NCHV(IL)+NHL(IL)+NNAE(IL)
MIL(IL)=(N16(IL)-N17(IL)+NNAE(IL)+1000,0)/(T-STNM)
WRITE(4,520)NT,TPCH,TPCH,ATQ
C
520 FORMAT(1X,'TOTAL NO. OF VEHS. =1 ,16,5X,'PER CENT MED. =1 ,F8.2/
1 PERCENTAGE OF HCV=1 ,F6.2,5X,'ACTUAL TOTAL FLOW=1 ,F8.2,'VPH')
CALL DEVE
STOP
SUBROUTINE UPDATE(N3111, N32, N34, N36, N38, S, STT, PSSTLN, A1, M1, LL1
N3, c, IC, I, STPPOS)

DIMENSION NA(2, 8), PSSTLN(2, 8), STT(2, 8), C(8, 100), STPPOS(2, 8)
COMMON/BLCK 5/NGS, ML1, NNLZ, NCL1, NCL2, NCL3, NCL4, NN, WC, DMIC
COMMON/BLCK 20/4Q(2, 8)
COMMON/BLCK 3/ML1, M2, M3
COMMON/BLCK 12/RDTV, RDBTV
COMMON/BLCK 14/IJ1, IJ2, IJ3
COMMON/BLCK 16/VC(R, 100, 16)

DO 830 J = 3111, N341

IF(NB(I, IC),EQ,1, AND, VQ(I, IC),GT, 0, AND, J, EQ, N34) GO TO 831
VQ(I, J, IJ1) = VQ(I, J, H1) + VQ(I, J, H2) + 05 * VQ(I, J, H3) * S**2
VQ(I, J, IJ2) = VQ(I, J, H2) + VQ(I, J, H3) * S
IF(VQ(I, J, IJ2), LT, 0, U) GO TO 832
IF(NB(I, IC), EQ, 2, AND, J, EQ, N34, AND, N34, EQ, N3111) GO TO 833
IF(J, EQ, 1) GO TO 834
CALL RELTDIS(I, IC)

IF(NB(I, IC), EQ, 2) GO TO 839
IF(RDBTV, LT, 5, AND, VQ(I, IC, J, 1, IJ2), LT, 0, 10)

1 AND, VQ(I, IC, J, IJ2), LT, 0, 10) GO TO 835
IF(RDTBV, LT, 2, AND, VQ(I, IC, J, 1, IJ2), LT, 0, 10)
1 AND, VQ(I, IC, J, IJ2), LT, 0, 10) GO TO 832
IF(NS3, LT, 5, AND, VQ(I, J, GT, N34 + N35 - 1) AND
1 J, LT, (N34 + N35) GO TO 835
GO TO 838

839 IF(J, GE, N34) CALL QUEUE(N34, N32, IC, PSSTLN(1, 1)
QD = VQ(I, IC, J, IJ1)

IF(J, GE, N34, AND, VQ(I, IC, J, IJ1), GT, 0) GO TO 832
IF(J, EQ, N34, AND, RDBTV, GT, 0) ABS(VQ(I, IC, N34, IJ11) - (PSSTLN(1, IC)) GO TO 833
1 TO 837

838 IF(VQ(I, IC, J, IJ2), LT, 0, 1) VQ(I, IC, J, IJ2) = 1.0
IF(RDTBV, LT, 5, 0) GO TO 834

837 VQ(I, IC, J, IJ3) = 0.1 +(VQ(I, IC, J, IJ2))**H1 + (VQ(I, J, 1, H2) - VQ(I, J, H2))**H2
1 ABS(RDTBV, 2, 0) ** LL1
IF(VQ(I, IC, J, IJ3), LT, 0, 0) VQ(I, IC, J, IJ3) = 0.0
IF(VQ(I, IC, J, GT, 0, 0) VQ(I, IC, J, IJ3) = VQ(I, J, 4)

GO TO 830

833 QD(I, IC, 34) = PSSTLN(1, IC)
IF(VQ(I, IC, 34, IJ1), GT, QD(I, IC, N34) - 1) GO TO 832
VQ(I, IC, N34, IJ3) = * (VQ(I, IC, N34, IJ2))**H1 VQ(I, N34, 2) - (PSSTLN(1, IC))** LL1
1 VQ(I, IC, N34, IJ3) = ABS(SV(I, N34, IJ3))
IF(VQ(I, IC, N34, IJ3), LT, 0, 0) VQ(I, IC, N34, IJ3) = -0.0
GO TO 830

832 CALL STOP(J, IC)
GO TO 830

834 VQ(I, J, IJ3) = VQ(I, J, 4) - (1.0 - VQ(I, J, IJ2) VQ(I, J, 3))
GO TO 830

835 VQ(I, J, IJ2) = 0.0
VQ(I, J, IJ3) = 0.0
GO TO 830

831 CALL FIRST(STPPOS, N34, C, STT, IC, I)
830 CONTINUE
RETURN

END