MINISTRY OF TRANSPORT

ROAD PRICING:

The Economic and Technical Possibilities

Report of a Panel set up by the Ministry of Transport

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FOREWORD

Economists have claimed that considerable net benefits could accrue to the nation if vehicle owners had to pay higher charges or taxes when they used congested roads than when they used uncongested ones, without there necessarily being any change in the total motor taxation paid by them. These charges would be in the nature of prices for using the roads, the prices varying from one place and time to another according to the costs-notably the congestion costs- involved in driving in a particular area at a particular time. The Ministry of Transport set up a panel, under my chairmanship, to make a preliminary examination of the technical feasibility of collecting such taxes, and to consider some of the economic implications. The members of the panel have served in an individual capacity and their report does not necessarily express the views of their respective organisations.

I wish to emphasize that the panel have considered only *how* various forms of taxes could be levied so as to differentiate between more and less congested roads; it was not considered whether such a charge should be accompanied by a change in the total revenue paid by vehicle owners. However, in order to calculate some of the effects of such a system it was necessary to make some assumptions about the distribution of the revenue and, for this purpose, the panel assumed that the introduction of road prices would be accompanied by a corresponding reduction in existing taxes so that the motoring population as a whole would pay no more than it would otherwise have done.

After preliminary study of various proposals for implementing such a change the panel have concluded that practical pricing methods could probably be devised. Some of the information necessary for an accurate estimate of the likely effects is not available, but it is tentatively estimated that the measurable net gain to the community from the higher speeds consequent on the reduction and reallocation of traffic would be about £100-£150 million per year under present conditions. This figure takes no account of the non-measurable benefits such as reduction of noise, fumes and frustration.

The full implications of such a revolutionary change are wider than the panel's field of enquiry. Inevitably some persons and firms would pay more than they do now, while others would pay less. The panel have recommended that such matters be investigated simultaneously with the development of any pricing equipment that may be decided on.

In considering road pricing as a means of regulating traffic congestion the panel have made the point that pricing by itself cannot produce a 'cure' for congestion. The proposal to charge for use of congested roads should not be regarded as an alternative to new and better roads; it is rather a means of obtaining better value from the roads that already exist and from those that are yet to be built.

R. J. Smeed
Chairman

MEMBERS OF THE PANEL

Dr. R. J. Smeed, B.Sc., Ph.D., F.S.S. (Chairman)	Road Research Laboratory
W. F. Adams, M.I.C.E., M.I.H.E., A.M.Inst.T.	Ministry of Transport
Dr. M. E. Beesley, Ph.D., B.Com.	London School of Economics
R. H. Bird, B.A.	Ministry of Transport
C. D. Foster, M.A.	Jesus College, Oxford
W. O. Jennings, B.Sc.	National Physical Laboratory
G. J. Roth, M.A., B.Sc.(Eng.)	Department of Applied Economics, University of Cambridge
Professor A. A. Walters, B.Sc.(Econ.), F.S.S.	University of Birmingham
J. G. Wardrop, B.A., F.S.S.	Road Research Laboratory
C. B. Winsten, M.A., F.S.S.	Ministry of Transport and Imperial College, London
J. M. Thomson, B.Sc.(Econ.), F.S.S. (Secretary)	Road Research Laboratory

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REPORT OF THE PANEL

1 INTRODUCTION

1.1 We were set up by the Ministry of Transport to study and report on the technical feasibility of various methods for improving the pricing system relating to the use of the roads, and on relevant economic considerations. We were not required to consider the social and political aspects of any changes which we might study; and, although it is difficult to extricate the technical and economic issues altogether from these other matters, we have sought to avoid the major social and political issues inherent in our subject. We are, however, fully aware of their importance, and we would not wish our approach to the subject to be misinterpreted on account of our limited terms of reference.

1.2 We began work in August 1962, since when we have held nine full meetings and about 60 other meetings. We have considered over 30 papers on different aspects of the subject, mostly prepared by our own members. We have consulted 16 companies and research organisations for expert advice on technical matters, and several firms have offered detailed proposals for new types of pricing equipment which we have submitted in confidence to the Ministry of Transport. We recognise that much further development may be possible, some of it by firms which we did not approach in the course of our studies. But we have at this stage given brief descriptions, in Section 6 of our report, of those schemes which we have considered and think have technical merit.

1.3 At the end of our report are five Appendices prepared for the Panel by the Road Research Laboratory. We considered that they should be published to provide a basis for further discussion.

2 THE PURPOSE OF ROAD PRICING

2.1 In 1962 motor revenues totalling £713 million were collected by means of fuel tax, annual licences and purchase tax. These taxes are regarded by vehicle owners as a charge for using the roads, although to what extent they serve as a price system is debatable. Our task is to consider other methods of charging whereby the price system may be usefully employed. One of our main objects will be to see if the use of appropriate pricing methods can help to lessen the problem of congestion. The existing taxes apply generally to the whole road network, and in the final analysis it may well be necessary to consider a pricing structure for the network as a whole, but we shall here devote our attention mostly to the problem of congested areas and we shall examine some pricing methods for specific use in such areas. We do not, however, wish to give the impression that pricing can by itself produce a cure for congestion. The need for investment in urban highways will still remain.

Congested areas

2.2.1 Congestion may be said to occur when one road user impedes the movement of another. On highly congested roads one person may cause inconvenience and delay to many others. For example, cars slow each other down, pedestrians slow down cars, and fast-moving vehicles delay pedestrians who wish to cross the road, or make them walk a long way to do so. These obvious facts have led to many regulations and systems of control designed to facilitate the movement of all kinds of traffic; for example, one-way streets, parking restrictions, zebra crossings and cycle tracks.

2.2.2 Regulations of this kind often raise the question as to which of the various conflicting demands on the use of the roads should be satisfied and which should be restrained. For example, when a decision has to be taken whether or not a road should be designated a clearway, how does one weigh the interests of residents, who wish to park their cars and receive deliveries of goods and so on, against the interests of vehicles passing through? Before such regulations are imposed, assessments are necessary of the various losses and benefits likely to result. Changes in the pricing methods by which people are charged for using the roads also cause a mixture of losses and benefits, the net result of which has to be assessed before one can say how valuable the changes are. When dealing with prices, however, the problem of assessment is eased by the fact that some road users can themselves give some information about the value they attach to their respective uses by their willingness to pay the price. Different people attach very different values to their various uses of the road; and the value they attach to a particular use may vary greatly from one time to another.

2.2.3 Prices charged for using the road generally have the effect of restraining the amount of use that people make of the roads. Two questions that immediately arise are: how far should use be restrained, and should some traffic be restrained more than other traffic? A useful guiding principle is that journeys should not be made if they are valued at less than the costs or losses they cause to other people; similarly, journeys should not be restrained if they are valued at more than the costs they cause. If this underlying principle is neglected, a waste of resources is likely to result.

2.2.4 How, then, can one compare the value of a journey with its cost? The money value attached by a road user to his journey is the price which he would be willing to pay for it; and the money value of the costs caused to other people is what they would pay to avoid these costs. The extent to which we are prepared to accept that these two money values can be compared depends largely upon (a) how far we consider that the distribution of wealth and income between the parties involved is acceptable,* and (b) how nearly the prices of alternative means of transport are similarly based on cost. Having regard to these things, when a pricing system is used on the roads, a useful general rule upon which to base prices is that the road user should pay a sum equal to the costs he imposes upon others. Subject to the above qualifications and given the manner in which the revenue from the pricing system is to be disbursed (see Section 8), the most beneficial way of obtaining it is likely to follow upon the application of this rule.†

2.2.5 The introduction of particular pricing systems must therefore depend on a careful calculation of the costs and benefits arising from them, both in the short and in the long run. These would need to be compared with the costs and benefits of alternative schemes, such as regulatory schemes which might forbid the use of some kinds of vehicles in certain city centres.

2.2.6 The costs that a vehicle user imposes on other people when he makes a journey may be divided into three classes:

(a) *Road costs:* the wear and tear on the road, and the cost of lighting, traffic control, etc. According to available estimates, for the great majority of vehicles these costs are unlikely to exceed a ½d. for each mile travelled in towns.([1])

(b) *Congestion costs:* the costs of delay to the rest of the traffic. For convenience we divide these into:

(i) the costs to cyclists, pedestrians wishing to cross the road, and other road users apart from motor vehicle users. We have as yet no estimates of these costs;

** The parties include firms and other organisations as well as individuals.*

† See Appendix 1 for a fuller discussion of pricing principles. See also paras. 2.2.7 to 2.2.12 below.

(ii) the costs to other motor vehicle traffic. The cost of delay includes higher labour costs, loss of people's time, higher fuel and running costs and lower utilisation of vehicles and their loads. Research on some of the important components of these costs has been carried out at the Road Research Laboratory. Estimates for central London, for example, show that the congestion costs imposed by a typical car on other vehicles rise from 4d. a mile at traffic speeds of 20 mile/h to 2/- a mile at 12 mile/h and 6/- a mile at 8 mile/h.‡ The costs imposed by heavy vehicles are often two or three times higher.

(c) *Other social losses:* the losses imposed on the general community – pedestrians, motorists, residents and all others affected by the accident risk, noise, fumes, dirt and other undesirable effects. We have no quantitative information about the magnitude of these costs.

2.2.7 Clearly, the costs caused by road travel in towns can be high. The possibilities of restraining people from adding to these costs without sufficient reason may be illustrated by a simple analogy. Suppose a man works a small ferry boat continuously across a river and that it costs 4d. a minute to run the boat, including the man's wages. Suppose that the boat can seat 10 passengers comfortably but can actually hold as many as 20 passengers. Suppose that each succeeding passenger increases the load so as to add half a minute to the time of the crossing. If there were six passengers in the boat and a seventh joined them he would increase the ferryman's costs by 2d. and he would also cost each of the other six passengers half a minute's delay which might be worth, say, ½d. each or 3d. in all. If there were 17 passengers each person would in effect be adding 2d. to the ferryman's costs and would also, by delaying 16 other people, be adding 8d. to their personal costs and appreciable discomfort on their journey. The ferryman might cover his costs if he let each passenger on for only 4d. but at this price the time and comfort of the majority of passengers might be sacrificed for some journeys which were not worth so high a sacrifice. There are several possibilities of improving this situation:

(1) Various regulations might be introduced. For instance, it might be decided that not more than 15 passengers should be allowed on the boat, on the grounds that more than this number created too much delay and discomfort. The problem of which passengers should be allowed on could be dealt with on the principle of 'first come, first served', or alternatively some system of priority might be devised, giving preference perhaps to those living nearest the ferry and depending on it most.

(2) The passengers could perhaps bargain amongst themselves. They might all be prepared to pay something to persuade one or more of the others to leave the boat. Some of them, less eager than the others to make that particular trip, might agree to accept a payment and take a later boat, say, or walk round by the nearest bridge. Thus all the passengers-but not the ferryman-would be better off.

(3) The ferryman could raise his price. A higher price could remove those passengers not prepared to pay the cost of time, money and comfort that their journeys would cause to the ferryman and the other passengers. As the numbers were thus reduced the associated costs would also be reduced, and if the price to the remaining passengers was set so that it just covered these costs this would ensure that journeys were not made if they were valued at less than the costs they caused. In this way, there would be an aggregate gain. But how this gain was distributed between the passengers, the ferryman and ultimately the rest of the community would depend upon many factors and could be affected –especially in the long term – by all sorts of consequential changes.

‡ These figures are tentative and more research is needed, especially on the valuation of leisure time. See Appendix 2.

2.2.8 In each of these three methods there is likely to be a different result in the distribution of income and advantage between the passengers, the ferryman and the wider community. The use of the roads involves similar problems to those of the ferry. A wide variety of regulations are possible. Alternatively, the bargaining analogy of 2.2.7 (2) would be if potential users of roads in a particular town paid each other to change their modes of transport. For example, if at some time of day buses were found to be a less congestion-forming method of transport than cars, taxes on cars might be used to improve the service for bus passengers, i.e. the car-owners who were almost indifferent between cars and buses would be paid by other car-owners to transfer to buses.

2.2.9 But there is no obvious system of direct bargaining by which people can persuade each other – pay each other – to stay off the road. A price system has to be imposed by some authority. The price mechanism enables people to assess their needs and to base their choice on the price that confronts them. For example, if one compares the pricing of cars with the banning of their use in city centres, a price system would enable people who strongly wanted to use the roads to do so if they were prepared to pay the price, whereas a ban might keep out some people who could obtain great benefit from their journeys and would readily pay a good deal for them.

2.2.10 In order to fix the prices the authority should predict the effects of different prices by measuring the costs and benefits to road users and others affected by congestion. Very important amongst these losses from congestion are losses of time, and therefore the pricing authority must measure time spent, time saved, etc. for the different components of traffic, and also establish what valuations are put upon time and the other costs by the different users.

2.2.11 Some calculations of the economic benefit of introducing a particular system of charges for the use of roads in towns have been made at the Road Research Laboratory. The method used and the assumptions made are described in Appendix 3. Costs have been estimated, and a few different assumptions have been made about the restraining effect of different prices. Appropriate price levels have then been estimated, from which the overall benefits have been assessed at between £100 and £150 million a year; they refer only to users of motor vehicles and exclude all benefits to pedestrians, cyclists and residents, and also all benefits resulting from the reduction of fumes, noise, dirt, vibration and so on, and any benefits which might arise outside towns. The figures are necessarily tentative and exclude social considerations, but they are believed to indicate the orders of magnitude.

2.2.12 Any such changes in the system of road charging would have different effects in different parts of the country and on different sections of the community, i.e. they would redistribute income. The effect on different sections of the community would depend crucially upon the way in which the proceeds of high road charges in towns were used. There are many possibilities. For instance, the proceeds could be divided in various ways between the local and central financial authorities; or they could be used for improving the road system, or for subsidising public transport in certain towns; or simply as general revenue. Whatever policy was adopted, the economic implications and the measurement of redistributive effects would provide a most important subject for future research. This, however, 'is a question which lies largely outside our present terms of reference. It would be wrong for us to express any view as to whether the current level of motor taxation is too high or too low and we do not wish to imply any such view. But we do wish to show that, for any given level of motor taxation, the economic consequences of one method of collection may be preferable to those of another. In order to demonstrate this, we have made calculations based on the current level of motor taxation, thus assuming that the additional proceeds from the new method of road charging would be returned in full to the motoring community by a reduction of existing taxes. But this assumption describes only one possible situation, not necessarily the best, and should not be regarded as an argument against either lower taxes or higher taxes.

2.2.13 The final choice amongst all schemes, in whatever proportion they depend on price or regulation, must be based on their expected consequences. The final assessment must take account of both economic and other factors.

Uncongested areas

2.3.1 Our remarks on the principles underlying road pricing in congested areas apply also in uncongested areas, with the important difference that there is, by definition, no cost of congestion to be charged for. This means that the cost of travelling on uncongested roads is not only much lower but also much less variable. That is to say, the total cost-to the vehicle-owner and all other parties-caused by travelling on uncongested roads normally varies little from one mile to another, except where important social costs arise such as damage or disturbance to beauty spots or village communities; whereas on congested roads the cost of travel varies greatly according to the degree of congestion experienced and the type of environment encountered, e.g. shopping centres, residential quarters, factory areas and so on.

2.3.2 Because of the relative lack of variability in the cost of using uncongested roads we think that the advantages to be gained there by changing the existing method of taxation are much less than in congested areas. The level of the fuel tax may well affect the amount of use made of roads in uncongested areas; we have not studied this question. Nor have we studied the costs to the community resulting from the use of uncongested roads. We feel that estimates of these costs should be obtained, so that consideration could be given to possible changes in the taxation paid in these areas.

2.3.3 Our concern, however, is not with the level of taxation but with the method of charging, and since there is no obvious and urgent need for a change of method in uncongested areas we shall not consider specifically the pricing of these areas. Most of the pricing methods we discuss will, in fact, be inapplicable to rural areas.

2.4 In the following pages we have first set out what we regarded as the operational requirements of a road pricing system. In the light of these requirements we have then attempted to assess the technical and economic merits of various pricing methods, commencing with the fuel tax and annual vehicle licence, and continuing with the differential fuel tax, differential licences, parking taxes, poll tax on employees, vehicle recording systems, driver-operated meters and automatic meters. When reading through these sections it will be found helpful to refer to the diagram on page 34.

3 OPERATIONAL REQUIREMENTS OF A ROAD PRICING SYSTEM

3.1 Having considered the relevant principles underlying the pricing of the roads we have compiled a list of operational requirements that are necessary if these principles are to be closely followed. This list forms the basic specification for a road pricing system and provides the starting point for our technical investigations. It consists of nine requirements which we regard as important if the method is to be workable and is to come tolerably close to its objectives; and a further eight requirements which are also considered desirable.

3.2 The most important requirements of the system are as follows:

(1) Charges should be closely related to the amount of use made of the roads.*

(2) It should be possible to vary prices to some extent for different roads (or areas), at different times of day, week or year, and for different classes of vehicle.

(3) Prices should be stable and readily ascertainable by road users before they embark upon a journey.

* *The most obvious ways of measuring road use are in terms of time or distance, each of which has its advantages and disadvantages. A study of this question is recommended in para. 9.1.*

(4) Payment in advance should be possible, although credit facilities may also be permissible under certain conditions.

(5) The incidence of the system upon individual road users should be accepted as fair.

(6) The method should be simple for road users to understand.

(7) Any equipment used should possess a high degree of reliability.

(8) It should be reasonably free from the possibility of fraud and evasion, both deliberate and unintentional.

(9) It should be capable of being applied, if necessary, to the whole country and to a vehicle population expected to rise to over 30 million.

3.3 The requirements which we consider also desirable, but not so important, are as follows:

(10) Payment should be possible in small amounts and at fairly frequent intervals, say amounts not exceeding £5 and intervals not exceeding one month. This does not exclude payment in larger amounts where preferred.

(11) Drivers in high-cost areas should be made aware of the rate they are incurring.

(12) At the same time the attention of drivers should not be unduly diverted from their other responsibilities.

(13) The method should be applicable without difficulty to road users entering from abroad.

(14) Enforcement measures should impose as little extra work on the police forces as possible and should therefore lie within the capacity of traffic wardens.

(15) It would be preferable if the method could also be used to charge for street parking.

(16) The method should, if possible, indicate the strength of demand for roadspace in different places so as to give guidance to the planning of new road improvements.

(17) The method should be amenable to gradual introduction commencing with an experimental phase.

3.4 We have had to consider what is an acceptable cost for such a system. We suggested above that the net benefits to the community from efficient road pricing would be worth £100-£150 million a year if introduced as at present (see Appendix 3); and these potential benefits could increase at a rate much faster than the vehicle population itself. By usual investment standards a very high cost, if necessary, would be justified by a return of this magnitude; but, for practical reasons, we have set an arbitrary target of about £1 per vehicle per year, including servicing of capital, and we have aimed at a capital cost of under £5 per vehicle. Thus we have regarded as expensive those schemes which, for a present population of 10 million vehicles, require an initial capital expenditure of over £50 million or an annual administration cost of more than £5-£l0 million.

4 THE CURRENT METHOD OF CHARGING

4.1 Motor vehicles used on the roads are at present taxed by means of fuel tax, annual licences and purchase tax. The money paid in these various ways provides a contribution towards the general revenue of the state. It is not for us to comment upon the desirability of drawing general revenue from this particular source, nor upon the volume of such revenue, but it is of relevance to our problem to note that these taxes, from the point of view of the vehicle owner, stand as a crude scheme of prices for using the roads. We have, therefore, gone briefly into the origins of the present tax system and have considered how far it provides a satisfactory substitute for a price system.

4.2 After the decline of the turnpikes the cost of building and maintaining roads was borne by local and central government. The taxpayer paid for the roads, and the amount he paid was determined by the amount of road capacity which the community decided to provide. The use of the roads was 'free' in that there was no connection between the amount of road capacity he paid for and the amount he personally used.

4.3 With the advent of the motor vehicle large and costly road works were required, and in the Budget of 1909 motorists were made to shoulder these costs by a two-part system consisting of a fixed tax and a variable tax. The variable tax was the petrol tax which served as a rough and ready way of relating the charge to the amount of use made of the roads. But once a road was built and in use, the cost of letting additional motorists use it was very low, so that a petrol tax which covered only this cost would not have covered the capital costs and other overheads. On the other hand, if the tax had been raised to cover these fixed costs, motorists would have been needlessly deterred from using roads which once built could accommodate additional traffic at very little extra cost. The annual licence fee provided a second source of revenue which, being unrelated to mileage, did not deter motorists from using the roads except inasmuch as it may have deterred some people from becoming motorists at all.

4.4 In its essentials the 1909 system of road taxation has remained unaltered to the present day. The amounts have risen, of course, and parking charges have been added in some places. Purchase tax on vehicles has also been added. During the first world war and after 1926 contributions to general taxation were also made and the current practice is to credit the whole revenue from motor taxation to the Exchequer.

4.5 The annual administrative cost has been estimated as £3.6 million for the collection of motor licence tax (including the issue of driving licences) and under £1 million for the collection of fuel tax. The total cost of parking controls is not known, but it is estimated that in parts of London (Croydon, Finsbury, Holborn, St. Marylebone, St. Pancras and Westminster) the average cost per meter (including wages, maintenance, administration and loan charges) is about £41 per year.

4.6 We have called the existing system a two-part system. It is also an indirect system in that both parts are related only indirectly to the use of the roads. The fixed part stands at £15 per annum for a private car, with a steeply rising scale for commercial vehicles. The variable part stands at 2s. 9d. per gallon of fuel which represents a road charge of about 1d. per mile for a typical car, 1½d. per mile for a medium diesel-driven lorry and nearly 3d. per mile for a medium petrol-driven lorry.([2]) These rates work out higher in congested conditions. If the use of the roads is measured by the length of time spent on the road, the rate paid by a typical car varies from about 1s. 4d. per hour in a congested area, assuming an average speed of 10 mile/h, to about 3s. 6d. per hour on a good uncongested rural road. Parked vehicles pay nothing, or some 6d. per hour if at a parking meter, but they are increasingly prevented from occupying road space that is of much value to moving vehicles.

4.7 The 1909 road taxes resulted from important technical innovations which created a new factor on the roads-the motor vehicle. Since then continuing technical change combined with rapid social change have created another new factor-widespread severe congestion. The method of charging fails to meet the needs of the situation in several important respects. It fails completely to discriminate between those situations in which congestion costs of road use are high and those in which they are low, and we have already mentioned how very large this difference can be. A charge of 1d. per mile is higher than the cost of using uncongested roads and far lower than the cost of using congested roads and thus discourages the use of lightly-trafficked roads and encourages the use of crowded roads, though it is not known by how much.

4.8 Secondly, the use of the fuel tax is a rather haphazard method of relating the charge to the amount of use made of the roads. For example, a car with a high fuel consumption rate pays more than a car of similar size with a low fuel consumption rate, and a petrol-driven lorry more than a diesel-driven lorry.

4.9 Thirdly, the universal use of a fixed annual charge appears 'a priori' to have even less effect than the fuel tax in restraining congestion, although of course it may serve other useful purposes.* Its continued use in some outlying areas might, however, still be advisable as a means of raising revenue or contributing towards the overhead costs of the road system.

4.10 We conclude that, given the immense growth in the number of vehicles, the present taxation methods do not effectively restrain the use of the roads in the right places at the right times and new methods may have much to contribute in limiting the losses due to traffic congestion.

5 OTHER INDIRECT METHODS OF CHARGING

Differential fuel taxes

5.1.1 The current method of charging suffers from the inflexibility of charging a fixed standard rate for fuel tax. We shall therefore consider whether any benefit could be obtained by introducing differential fuel taxes.

5.1.2 It would be possible to levy fuel tax at different rates in different areas, relating it to the amount of congestion in each area. The technical feasibility of such a tax is not in doubt but its economic advantage would, we think, be small. The effectiveness of the differential would depend on the opportunities and incentives for avoidance, and on its ability to discriminate in detail against journeys on congested roads.

5.1.3 Avoidance could occur in two ways:

(a) taking on fuel while travelling on ordinary journeys through low-tax areas;

(b) making special fuel-fetching journeys to low-tax areas.

Avoidance of type (a) could not be stopped and must be accepted as an inherent weakness of the method. Avoidance of type (b) could be minimised by the careful planning of area boundaries and differentials.

** Additional revenue may be required either to cover the cost of the road system (see Appendix 1, para. 6) or for general tax purposes.*

5.1.4 Let us assume that motorists would merely fill their tanks and would not take reserve cans or drums to fill in low-tax areas. They would have to compare the gain from buying a tankful at a cheaper rate with the cost of driving to the cheaper area and back again. This cost would consist of vehicle running costs and the driver's time. The arithmetic of the tax is examined in Appendix 5, with the conclusion that fuel-fetching will be unprofitable for most motorists if the differential is under 1d. per gallon per mile, and will be profitable for most motorists if the differential exceeds 2d. per mile. If a small amount of fuel-fetching is to be tolerated, the differential could be as high as 14d. per gallon per mile. Thus, the maximum workable differential between places 20 miles apart is roughly between 1s. 8d. and 2s. 6d. per gallon, and for places 30 miles apart it is between 2s. 6d. and 3s. 9d. per gallon, assuming that the petrol used on the fuel-fetching journey is tax-free.

5.1.5 Quite large differentials are therefore possible, but only at intervals which are bound to include much low-cost road in high-tax areas and much high-cost road in low-tax areas.

5.1.6 There are two ways of setting areas: a 'contour' method whereby the areas consist of narrowly spaced contours around congested centres; and a zone method where the zones are large areas including whole conurbations. Zoning necessarily has the disadvantage of the boundary line with a big tax differential between one side of the line and the other. A certain amount of fuel-fetching is therefore certain to occur in the fringe area if the differential is to be at all effective; and the higher the differential the larger will the fringe area be: witness the fuel-fetching by French motorists from across the Swiss border where petrol is approximately 3 shillings per gallon cheaper. With the contour method there should be no fuel-fetching of any significance, if the differentials are kept within the workable limits suggested above. But, as soon as they exceed these limits, fuel-fetching begins to be profitable over large distances. With both methods, if the workable limits are exceeded, fuel-fetching is likely to become widespread.

5.1.7 Differential fuel taxes are therefore subject to a fundamental limitation on the size of differentials that are practicable between nearby areas. In a large, less built-up country this limitation would be of far less consequence. But in England it detracts seriously from the usefulness of the method.

5.1.8 Nevertheless a large measure of differentiation in the fuel tax is possible. What economic benefits could be expected? The scheme commends itself most obviously to conurbations, where a high tax could be levied throughout most of the built-up area and could be reduced gradually, as one moved away from the area, starting in the outer suburbs. If the total yield from the fuel tax was kept at its present level, many smaller towns and other congested areas would inevitably be included in cheap areas. Thus, while congestion might be eased in the conurbations, it might be worsened elsewhere.

5.1.9 In the conurbations, provided that avoidance of type (a) was not very great – though it probably would be – and that illegal evasion, say by black marketeering, was not too great, a fuel tax of 5s. per gallon would undoubtedly help to reduce congestion. But this does not necessarily mean that the tax would be beneficial. It would also discourage traffic in uncongested areas and at uncongested times, and the losses arising from this source might offset the gains in congested areas.

5.1.10 There are other difficulties, such as the effect on the fortunes of individual garages and the waste of resources caused by fuel-fetching. We cannot pretend that the assumption which we made for our calculations, that motorists would not fill cans or reserve tanks, is very realistic. Also commuters as a class would find avoidance easy unless the high tax areas were so large that they severely penalised a great deal of traffic in uncongested areas. We conclude that differential fuel taxes by themselves are no solution for the pricing problem. At most, they might assist other measures.

Parking charges

5.2.1 Parking restrictions and regulations can also be used to reduce traffic congestion on the roads, since they can be used to increase the difficulty, or put up the price, of making a journey and thus reduce the volume of moving traffic. We do not here give a complete appraisal of these methods, but only discuss the use of parking charges. The aim of such charges would be to reduce the number of parking places already available, or to reduce the number actually in use at any one time.

5.2.2 Public authorities often control a large proportion of the parking places at present available in congested areas, since these are usually on the street. Using parking charges to control congestion implies that these parking places would all be charged (as many of them are now) through meters and that the charges would be raised to a level which would lessen the number of journeys made in the congested area. If there are many parking places, the price may well be so high that a high proportion will be vacant much of the time.

5.2.3 If parking charges were high in public parking places, then there would be an incentive for the provision of commercial parking places, and also for an increase in garages and parking places attached to offices, factories and private homes. We have no estimate of how great this tendency is likely to be, but if it is large enough to counter substantially the reduction in public parking, then it in turn would have to be restrained. One possible way of doing this would be to impose a tax on parking places, both commercial and private. Such a tax, however, seems irrational and difficult to justify to those users who could easily provide themselves with private parking space, and this would make it difficult to enforce.

5.2.4 Those users who, despite the tax, did provide themselves with parking spaces at their offices, homes, etc. would treat the charge as a fixed one, independent of the number of journeys. For such users it would not influence the number of journeys.

5.2.5 At metered parking places a charge is made whenever a vehicle parks. Thus, in effect, a charge would be made each time a journey finished at such a place within a congested area. With commercially provided parking spaces, if these were taxed, the tax may well be passed on in a charge to the customer, so that in either case there would be an extra charge imposed for each journey.* Such charges would be independent of the length of the journey, although they would, of course, often vary with the length of time the vehicle is parked.

5.2.6 All the calculations to which we refer below assume a uniform charge per journey, which for convenience we will call a 'parking tax'.

5.2.7 *Economic advantage.* There is no doubt that in some places a parking tax, rigorously enforced and set high enough, could deter large numbers of vehicles from using the roads. It must be remembered, however, that the economic objective of the policy is not simply to reduce the volume of traffic, but to obtain the maximum benefit from the available road system. This is not achieved simply by forcing a certain amount of traffic from the road; the aim must be to reduce the traffic which is not worthwhile in the sense that it is not prepared to pay the real cost of its being there.

5.2.8 A parking tax is a crude way of charging vehicles for the use of the roads, because it bears no relation to the distance travelled nor to the type of roads used. Nevertheless, by placing a financial penalty on all vehicles parking in the area, it must deter some of the least worthwhile traffic. The questions then are: how far can a parking tax lead to the right volume and composition of traffic? How much net benefit can it achieve?

** One could ensure that it was passed on by levying it as a sales tax on the revenue of commercial providers of parking space.*

5.2.9 Calculations have been made of the benefits which might be produced by a parking tax in different sets of circumstances. These are described in Appendix 4. Broadly they attempt to take account of the three main deficiencies of such a policy. The first is that traffic which does not park in the area, or which manages to avoid taxed parking places, is not merely unaffected but is actually encouraged by whatever reduction the scheme extracts from other traffic. Thus traffic wishing to use the area is kept out to make way for traffic passing through the area. This difficulty may be alleviated by specific road improvements and traffic engineering techniques. Secondly, a vehicle coming in from outside the town, causing congestion all the way, pays the same as a vehicle coming only a short distance and, because the tax forms a smaller proportion of its total journey cost, is less likely to be deterred by the tax. Thus the traffic that causes least congestion is kept out to make way for the traffic that causes most congestion. Thirdly, a tax that is efficient in the peak hours is likely to be too severe in the off-peak hours. If the same tax has to be charged throughout the day a compromise must be sought between an over-congested peak period and an under-utilised off-peak period. A fourth factor, omitted from the calculations, is the effect of the tax on vehicles parked in the area but not used during congested hours.

5.2.10 The net economic benefits would be the gross benefits to remaining traffic due to reduced congestion, less the losses to the traffic forced off by the tax. It has been estimated that in Central London the best tax-equal to about 6s. a day-would reduce traffic by about 11 per cent in the off-peak period and by 7 per cent in the peak. As a result, off-peak speeds are calculated to rise from 10.7 mile/h to 12.6 mile/h, and peak speeds from 9.8 mile/h to 11.1 mile/h. The real cost of travel (i.e. the cost excluding tax) would go down by 12 per cent but the real savings (after taking losses into account) would be about 74 per cent or 1.5 pence per original vehicle-mile (see Appendix 4).

5.2.11 This saving is comparatively modest; both the effect on speed and the net benefits obtainable from the tax are about 40 per cent of what is obtainable from direct pricing systems.

5.2.12 These estimates are based on present traffic demands and on a 30 per cent proportion of non-parking traffic. However, the demand for uncongested road space, and hence the amount of non-parking traffic (which is not deterred by the tax), may be expected to increase from year to year, and the benefits from the parking tax would decrease. Thus with non-parking traffic at 25 per cent, a tax of 6s. a day would yield a net benefit of 1.6d. per vehicle-mile; with non-parking traffic at 50 per cent the best tax would be 7s. a day and would yield a net benefit of 1.3d. per vehicle-mile.

5.2.13 We conclude that a parking tax may, under certain conditions, give some beneficial relief to traffic congestion, although it can never of itself be regarded as an efficient solution. If the proportion of non-parking traffic is large or susceptible to a big increase as soon as the state of congestion permits, the tax will give little net benefit. This may have special relevance for small areas of congestion where the proportion of through-traffic is often large. In larger areas, on the other hand, if the traffic tends to consist mainly of long and short-distance traffic, with little middle-distance traffic, again the parking tax will give little net benefit.* If there is a very pronounced peak traffic, this too will detract from the value of the tax, except insofar as the proportion of parking traffic (e.g. commuters) may be higher during the peak than during the off-peak.

** This point is brought out in Appendix 4.*

Differential licences

5.3.1 We discuss two forms of differential licence: first, the differential annual licence suggested in 1952 by James M. Buchanan and (independently) in 1954 by Walters([3]); and second, the differential daily licence. Under both schemes it is proposed that the licences should be varied in two ways:

(1) by area, differently priced licences being required for different areas; and

(2) by time, different licences being required for different times of the day.

5.3.2 Area variations would require congested areas to be divided into zones of different classes, for example, ‘red’ zones, ‘blue’ zones and ‘yellow’ zones. Areas of heavy congestion could be designated red, areas of moderate congestion blue, and less congested areas yellow. Special licences would be required in these areas. A yellow licence would give access to yellow zones, a more expensive blue licence to blue and yellow zones, and a still more expensive red licence to all three classes of zone.

5.3.3 Time variation would distinguish between day and night usage and possibly between peak and off-peak usage. A zone might be declared ‘red’ at the peak, ‘blue’ during day-time off-peak hours and ‘yellow’ at night; or more simply, ‘blue’ at peak hours and ‘yellow’ at all other times.

5.3.4 Feasibility of the annual licence. To be effective, licences for heavily congested areas would have to be (a) expensive – £100 a year might be the level required; and (b) transferable, so that people could obtain a licence for a short period and people holding a licence would have an incentive to give it up when they did not have any strong reason for keeping it.

5.3.5 The price of an annual licence would be fixed at a level calculated to limit the volume of traffic at peak times to a predetermined amount. The success of the scheme depends upon the creation of a free market in licences. The dealers in this market would probably include most garages, who would buy licences from the authorities and hire them at market prices to the public. Motorists would thus – according to the theory – find it cheaper to hire a licence occasionally from, say, their local garage than to buy one from the authorities.

5.3.6 We have considered the practical details of such a scheme in order to determine the form of licence that might lend itself to the organisation of such a market. The principal difficulties are the high value of the licence, which causes problems of theft, fraud and finance; and the cost of administration allowing for an adequate return on the high risk borne by dealers. We have not found a satisfactory solution to these difficulties.

5.3.7 Feasibility of the daily licence. The daily licence is not so ambitious as the differential annual licence. It need not be transferable, although there is no reason why it should be non-transferable. The prices (of red, blue and yellow licences) are fixed by the authorities. The licences are numbered in large figures or letters to denote the day and are sold in two kinds of book: (a) daily books consisting of a number of licences for a given day intended for retailers (e.g. garages); (b) monthly or yearly books consisting of one licence for each day of the month or year intended for the use of individual vehicle owners. A rebate is given for licences not detached from the book.

5.3.8 Unlike transferable licences, there are no purely technical difficulties in a system of daily licences. It is simple and should not be difficult to implement. In effect, the daily licence has much in common with the parking tax. It has the considerable advantage, however, of applying to all traffic entering the congested area, whereas the parking tax misses through-traffic and other non-parking traffic. On the other hand, while the parking tax can be gradually reduced towards the outer regions of the area, the daily licence involves an abrupt change in tax at the zone boundaries. Tentative attempts to delineate zones in particular towns have shown that in some towns it is not easy to find a ‘natural’ boundary. These sharply discriminating boundaries inevitably result in inequity. The division of areas into three grades of zones is an attempt to ease the discrimination but clearly it can only be a partial solution to this difficulty, while introducing undesirable complications into the system.

5.3.9 In addition, the daily licence shares much of the arbitrariness of the parking tax. The short journey pays the same as the long journey. Long-distance traffic with a red licence would be encouraged to pass through all zones where congestion had been successfully reduced, thus diminishing the apparent fairness and reasonableness of the system.

5.3.10 Economic advantage. The economic effects of a daily licence system would be similar to those of a parking tax. The main difference would be that non-parking traffic would have to pay. This is a considerable advantage for the daily licence over the parking tax. But, as already noted, the effect on through-traffic might still not be very satisfactory, because all long-distance traffic arriving at one side of a red area, but having already obtained a licence for use in another red area, would not be deterred from crossing through the area, but rather would be encouraged to do so by the easier conditions prevailing as a result of the scheme. The problem of through-traffic is therefore only partially solved.

5.3.11 Another advantage of the daily licence over the parking tax is that it may be used specifically for restraining peak hour congestion. In some other respects, however, it is inferior to the parking tax. We have pointed out that a parking tax may be tapered off towards the edge of the congested area, but with a daily licence there is no similar way of avoiding the abrupt boundary, and economic inefficiencies must result from the sudden, arbitrary change in price from one side of the boundary to the other.

5.3.12 The fixing of prices presents another difficulty. Unlike the parking tax, which can vary from town to town, it would not be practicable for a large number of towns to issue their own licences. If the system were to be widespread, the same licences, with the same prices, would need to be valid throughout the country. This would mean that the best available price in some places would not be satisfactory.

5.3.13 Clearly the relative weight of these various considerations varies from one area to another. On balance, the advantage of including non-parking traffic in its coverage seems to more than offset the economic disadvantages of the daily licence vis-a-vis the parking tax. If a nation-wide system of daily licences were adopted there would be nothing in the system to prevent parking taxes also being used in some places.

Other indirect congestion taxes

5.4.1 Taxes on vehicle-ownership, petrol and parking are not the only ways of indirectly taxing road users, but we do not think that there are any other such taxes which by themselves, and within the limits of what is practicable and relatively harmless to other activities, can produce much benefit on the roads, although they may prove useful in combination with other methods.

5.4.2 One such measure is the poll tax on employees in congested areas. The main arguments in favour of a poll tax do not concern the use of the roads, and the more important aspects of such a tax lie outside the scope of this report. We are concerned only with its likely effect upon road traffic. The volume of road traffic would only be affected inasmuch as the tax caused changes in the use of property, assuming that new construction was under strict planning control. The demand for road space would then be affected mainly as follows:

(a) Organisations with large numbers of relatively low-earning employees would tend to move out and their places taken by organisations with fewer, but higher-earning, employees. The number of car owners among the latter, and their desire to travel by car, might be as high as among the former, thus giving no relief on the roads, except possibly on the buses. It is conjectural what the overall net effect of such changes in property use would be.

(b) Large employers of labour would tend to be replaced by organisations which generated less commuter traffic but more commercial, business or tourist traffic. Without much more information on land use and its effect on traffic requirements, we cannot assess the net result of these changes.

(c) A poll tax would encourage further mechanisation of labour, such as lift operating, book-keeping, dictation and retail service. The level of car ownership among the classes of labour affected is low.

(d) In the long run a poll tax would lower the demand for building new offices. Whether this would affect the actual amount of new building would depend largely upon the effectiveness of planning controls as an alternative restraint. To some extent a poll tax and planning controls are substitutes. Also in the long run the growth of car-ownership among the lower income-groups will weaken some of the above arguments against the poll tax.

5.4.3 Supposing that the effect of a poll tax was to remove an appreciable volume of the existing commuter traffic from the roads, we believe that this traffic would soon be replaced by other commuters. The level of commuter traffic is limited now by heavy congestion and parking restriction. There is ample evidence from statistical studies of car ownership and traffic speed in towns that without some additional constraint which is not provided by a poll tax, any reduction in congestion would be taken advantage of by the reserve of car-owning commuters.

5.4.4 On balance, therefore, without undertaking the long and complex study which a full examination of a poll tax implies, we have little doubt that its effect upon the volume of road traffic would be of minor value.

5.4.5 Other taxes directed at city centres, such as a property tax, would doubtless reduce the demand for new building. It is questionable whether the volume of new building would be affected unless the tax were very high. If it were not, it could do little to reduce the amount of traffic on the roads. We know of no other similar tax which would have even as much effect on traffic as a poll tax.

6 THE FEASIBILITY OF DIRECT CHARGING

6.1.1 Having considered methods of charging indirectly for road use, that is, charging for some other product or service more or less closely correlated with road use, we now turn to the possibilities of charging directly for road use itself. Toll-gates have, of course, long been used in many places and are still used on bridges and tunnels and on foreign motorways with few points of access. But for ordinary roads in urban areas they are costly and inefficient and impede the flow of traffic, and even with modern refinements we do not regard them as practicable.

6.1.2 In our search for ideas we have spread the net widely in order not to exclude any radical new methods which, though seemingly fanciful at first sight, might eventually become an appropriate feature of a motorised community. With modern techniques many methods of charging are technically possible, and in comparing them we have had to take account of their cost, as well as their closeness in meeting the requirements specified in Section 3. The various methods which have been proposed fall into two basic categories:

(a) Off-vehicle recording systems, whereby the charges payable by vehicles are recorded elsewhere than on the vehicles. These systems are analogous to telephone charging methods.

(b) Vehicle metering systems, whereby the charges are registered on the vehicles themselves. These systems are analogous to taxi-meter methods of charging. They may be driver-operated or automatic.

Off-vehicle recording systems

6.2.1 In off-vehicle recording systems every vehicle is fitted with a piece of equipment which can be automatically identified, and a record made, by detectors placed in, over or beside the road at suitable pricing points. The recording that a vehicle has passed a certain pricing point could then, in theory, be used in one of two ways. The first, which we call point pricing, involves setting up pricing points within congested areas, vehicles being debited with the appropriate charge when passing any pricing point. The alternative is a type of continuous pricing which involves setting up pricing points on the borders of congested areas, and charging the vehicle according to the time spent in the zone, as deduced from recordings at the points of entry and exit.

6.2.2 Any continuous pricing system of this type would have to enable the charging to cease when vehicles enter private premises, and to be reduced in some parking places. This raises the considerable technical difficulty of monitoring private entrances and parking places within pricing zones. This cannot be done at an acceptable cost. Continuous pricing systems of this kind would also require equipment of a higher standard of accuracy than that required for point pricing. This is because under a point pricing system occasional errors could be tolerated; no one would mind very much if a vehicle passed 50 points and was charged for only 49 of them. But under continuous pricing little errors could have serious results. If a vehicle was recorded as entering a zone and its corresponding record of exit was missed or mislaid, it would find itself being charged for an indefinite period. This sort of error could not be tolerated, and methods of avoiding it would add considerably to the cost of the equipment. For these technical reasons we have concluded that any feasible off-vehicle system would work only on a point pricing basis.

6.2.3 Off-vehicle systems comprise the following stages:

(a) Identification of vehicles at the pricing points.

(b) Transmission of information from the pricing points to a central computing station.

(c) Processing of data at the computing station.

(d) Collection of payment.

6.2.4 *Vehicle identification.* Vehicles must carry identification units which enable their presence to be recorded by roadside apparatus. The recording must be in a suitable form to comprise the input data of the computing equipment. The system must be capable of distinguishing between, say, 30 million different vehicle identities. Although on general grounds this problem appears soluble, none of the methods proposed to us have come near the cost levels we set in paragraph 3.4. We have enquired about optical, electro-magnetic, radar and sonic methods, and the only serious proposal put to us was the electro-magnetic Link Tracer suggested by Professor William Vickrey for vehicle identification in Washington, D.C.([4]) The capital cost quoted for the vehicle, roadside and computing equipment in Washington was £12 10s 0d. per vehicle, but we have been advised that for a population of 30 million vehicles this cost could easily double. However, even £12 10s 0d. is a good deal higher than the £5 per vehicle that we allowed.

6.2.5 *Transmission of information.* The simplest method would be to accumulate the records at each pricing point in the form of paper or magnetic tape and to transport the tapes to the computing station at regular intervals by van. The alternative would be to transmit the information automatically by telephone or by radio signals. Separate transmission channels could be provided for each pricing point but this could be wasteful. A more economic arrangement might be for a number of pricing points to share a transmission channel, and for temporary storage capacity to be provided at the pricing points to prevent the loss of records generated simultaneously at several places sharing the same channel. Temporary storage capacity at the computing station input would also be needed to prevent loss when a large number of channels transmit simultaneously. The transmission of data from the pricing points to central computing stations does not appear to present any special difficulty.

6.2.6 *Processing of data.* This also does not appear to be difficult with conventional equipment. All charges would have to be sorted by vehicle identification number, added and printed out at intervals. Local accounts could be retained for mailing, and other accounts (the region being indicated by the number) sent to their respective regions either direct or through a central clearing house. As a final stage charges would have to be multiplied by the appropriate charging factor (which might be 1 for a private car, 2 for a lorry, ½ for a motorcycle, etc.). Bills could be sent at monthly or quarterly intervals as required.

6.2.7 *Collection of payment.* The difficulties and costs of bill collection from motorists would need careful study. If there were 10 million accounts and if each year one account in a thousand failed to pay after the usual reminders, there would be some 10,000 cases a year to follow up, some of them through the courts. The authorities could obtain some protection by making renewal of vehicle licences conditional on all road charges being paid up to date. Nevertheless, many difficult cases would remain, and it would clearly be undesirable to allow large numbers of people to become debtors for the considerable amounts involved in road pricing. One solution might be to require payment in advance. The equipment in the computing station could be programmed to print out the vehicle numbers of those falling into debt, and the owners of the vehicles involved could be dealt with immediately .

6.2.8 *Conclusions.* The advantages of a fully automatic system, with ample price flexibility, in which the vehicle-owner has no more to do than periodically send a cheque, are obvious. But the above brief sketch of off-vehicle systems indicates a number of disadvantages in comparison with automatic metering systems:

(a) They require equipment for the storage, transmission and processing of data. Having regard to the large number of places where vehicle movements would need to be recorded, and to the present cost of standard equipment, the provision of this equipment-while not difficult-would undoubtedly be expensive.

(b) They require centralised book-keeping, invoicing and progressing of bills. Payment in advance would not always be easy to obtain.

(c) They threaten the privacy of vehicle users, insofar as they enable vehicle movements to be traced by public authorities. (This disadvantage would be mitigated by the greater ease with which the police would be able to trace stolen cars, and by the usefulness to some vehicle owners – and to road planners – of vehicle movement records).

6.2.9 In view of these disadvantages-which are not sufficiently offset by advantages-it appears to us that off-vehicle systems should be considered only if they offer considerable financial savings over meter systems. In fact, all the systems suggested to us cost much more than the meter systems which we are about to describe, and we therefore conclude that, on the basis of present information, off-vehicle systems should be rejected in favour of vehicle metering systems.

Driver-operated meters

6.3.1 These systems work on a continuous charging basis. Zones are defined in congested areas and are allocated colours which indicate the prices to be charged within the zones. Thus a conurbation might be divided into three zones, an expensive purple zone in the centre, encircled by a cheaper green zone in the inner ring, encircled again by a still cheaper pink zone in the suburbs. Outside the pink zone the roads are free, subject of course to any fuel tax in force. In other cities two zones might be sufficient, and in smaller towns there might be only one. The colours of the zones are displayed electrically at all points of entry and exit and can be switched so that during off-peak hours during the day the purple zone can be derated to green and the green zone to pink, and the pink zone can either be derated to a fourth colour, say brown, or dezoned altogether. During the evening and at night, and on Sundays and Bank Holidays, all zone signs might be switched off and the zones made free.

6.3.2 Every vehicle entering a charging zone must carry a road meter. When the meter is switched on and working it shows a coloured light, indicating the rate at which it is running. Thus the driver switches to pink when he enters a pink zone and if he later drives out of that zone into a free zone or a purple zone he switches his meter accordingly. The meter is fixed at the bottom centre on the inside of the windscreen within comfortable reach of the driver's left hand, so that the switching operation would be comparable with that of switching a trafficator. Thus a driver might need to make three such operations on a journey from the outskirts of a conurbation to the centre, which is probably a small fraction of the number of driving operations he would be saved by driving in the less congested streets.

6.3.3 If pink represents a charging rate of ½d. per minute, the meter is designed to register or consume at that rate when switched to pink, and similarly for the other colours. One or two lower rates for parking may be added, thus providing what is in effect a personal parking meter and removing the need for pavement meters.

6.3.4 Different classes of vehicle are issued with different classes of meter, so that if a private car, say, carries a Class A meter, a 10-ton lorry might carry, say, a Class D meter with a higher charging rate.

6.3.5 We have examined two possible systems of driver-operated meters and have submitted details of them to the Ministry of Transport. Here we shall confine ourselves to a simple description of each of them in turn.

6.3.6 *A clockwork meter:*

6.3.6.1 *Timing mechanism.* This consists of a spring-driven motor working through a clocklike mechanism. The five colours are selected by means of a gearbox. The spring is electrically wound and is connected with the vehicle's electrical circuit.

6.3.6.2 Through its gears, the mechanism moves a counter which is visible to the driver. The meter is initially supplied with a number of shillingsworth (e.g. 100) set on the counter, representing the value of time being purchased. As the meter is used, the counter runs down at the predetermined rates, and when it reaches, say, ten shillings below zero an expiry flag appears together with an indicator light. The purpose of allowing the meter to go below zero is to give a period of grace in which to exchange the meter for a fresh one.

6.3.6.3 *Method of payment.* The motorist purchases a meter at a post office or authorised depot. The value of time set on the meter may vary widely according to customers' requirements. When the meter is expired, it can be exchanged for one that has been already reset. At the same time any excess units used, i.e. units below zero, must be paid for. In view of the workshop facilities that garages possess and the unfair temptation that would be put in their way, the authorities might not wish to use them or any other agencies, apart from post offices and official meter depots, as distributive outlets. The resetting of meters would be carried out at depots by insertion of a special key, this action involving the destruction of a lead seal or similar security device, which would afterwards be replaced by the depot.

6.3.6.4 *Other features:*

(a) *Visibility.* The zone indication is provided by coloured illuminated translucent sectors shown through a window in the face of the meter. On the side facing the driver there is another window with a coloured disc showing.

(b) *Appearance.* The meter is box-shaped, about 4 in. × 3 in. × 3 in. On the front is the lighted window. On the top is a place for replacing bulbs. On the side facing the driver is the selector knob, the counter window and the window showing him the zone colour. On the bottom is the connection with the vehicle battery circuit and the fixing bracket. The meter cannot be fitted permanently, since it must be exchanged periodically; at the same time it must not present too easy a prey for thieves.

6.3.6.5 *Security against fraud*. The final casing may be an aluminium die casting with provision for sealing over a sunken screw. The resetting of the meter would then require a special key. These arrangements do not appear sufficient by themselves to prevent fraud, and further investigation is required on this point.

6.3.6.6 *Cost*. A preliminary estimate, assuming large quantities, indicates a cost of £8-£10 per meter. It is hoped that closer attention to production engineering requirements will bring the cost down. The administrative costs of the scheme would arise mainly from the running of the meter depots.

6.3.7 *An electrolytic meter:*

6.3.7.1 *Timing mechanism.* A ‘ throw-away’ electrolytic timer is used. Cylindrical in shape, it is inserted into the meter by the driver and, when pushed home, forms part of a circuit connecting the meter lamp with the vehicle battery. Also included is a network of resistors so that the timer runs down at the correct predetermined rates when switched to different colours. An essential feature of the timer is that its life is accurately gauged. When it reaches its designed end-point the circuit is broken and the meter lamp cuts out. Before this happens, when the timer is down to, say, its last ten shillingsworth, a warning light appears, to remind the driver that his timer will soon need replacing. When it is finally exhausted it can be removed from the meter and replaced.

6.3.7.2 The timer can pass an accurately predetermined electrical charge before exhibiting an electrical change sufficient to control a switching circuit. No basic difficulty is anticipated in producing a timer which will perform this function satisfactorily. Several different designs have been discussed, and similar devices are actually in use for various industrial purposes in the United States. The question that remains is whether a satisfactory design can be produced cheaply enough for this purpose; and the answer to this question requires investigation.

6.3.7.3 *Method of payment.* The main reason for preferring electrolytic timing to a more conventional mechanical method is that it overcomes difficulties of payment. Timers are bought ‘over the counter’ from garages or post offices in units of, say, £l, £2 or £5. Thus the meter need never be read or removed for resetting. This is convenient for both the motorist and the authorities. The revenue due to the Government could be collected as an excise duty from the timer manufacturers.

6.3.7.4 *Other features: (a) Visibility.* The zone colours are displayed by a bulb about as bright as a sidelight beamed through a sector of coloured filters. The colours must be distinct at a sufficient distance to facilitate supervision but need not be as brightly illuminated as a trafficator. Hence, although the pricing period would include some hours of darkness in the winter, no dazzle is expected from the meter lamp. The coloured light can also be seen from the rear:

(b) *Initial flasher.* When the meter is switched on or turned from one colour to another, the bulb flashes for 20 seconds before stabilising.

(c) *Parking.* If the meter is required for parking, a clock dial may be fitted to the face of the meter and used as a parking disc. A time switch can also be fitted for the benefit of drivers who park during charging hours and want their meter automatically to stop charging when parking becomes free.

(d) *Appearance.* The design envisaged is circular, about 34 inches in diameter and 14 inches deep. The face of the meter contains a window for the lamp. On top is a place for replacing bulbs and fuses and an aperture for the insertion and extraction of the timer: and underneath is the lead (preferably encased in a bracket) to the vehicle's battery circuit. On the rear of the meter, the side facing the driver, is a selector knob with six positions suitably marked, and a rear window aperture. When required, a lock can also be incorporated to guard against theft of the timer; this is especially desirable on open cars and motorcycles. Every meter also bears an identification number.

6.3.7.5 *Security against fraud.* Those parts of the meter which could profitably be tampered with are potted in plastic and wholly encased. The timer chamber and the circuit are so designed that only an accurate forgery of the timer, both of its shape and its electrical properties, could work. Spot inspection of both meter and timer can be made by the police in the same way that licences are checked.

6.3.7.6 Since there is no need ever to remove the meter from the vehicle, there is no difficulty in maintaining control over meters issued. When a meter is issued it may be registered in the log book of the vehicle for which it is intended. An arrangement is desirable whereby the meter is returned when the vehicle is scrapped. Having taken these steps to ensure as far as possible that only one meter exists for each vehicle, a meter test can be included in all regulation vehicle tests.

6.3.7.7 Meter 'dodging' – switching off when there is no enforcement officer in sight – is discouraged by the tell-tale 20-second flasher.

6.3.7.8 *Cost*. It is thought that the meter could be produced (excluding the parking time switch) for a price of about 30s. The principal objective of further development is to produce a timer for less than a shilling. The production cost will probably be much the same for a £1 unit as for a £5 unit; the proportion of revenue lost being rather high on the former and very low on the latter, so that some incentive may be desirable to promote the sale of the larger unit.

Automatic meters

6.4.1 The principal drawback of the driver-operated meter is that it adds to the responsibilities of both driver and traffic authority, although of course this is expected to be more than offset by the easier traffic conditions that result. The automatic meter tries to eliminate much of this responsibility by placing control apparatus in the road which switches meters on passing vehicles to the correct position. We have examined four possible systems of automatic meter, details of which have been submitted to the Ministry of Transport. Two of them are similar to the driver-operated system with electrolytic timing mechanism except that the switching operations are carried out automatically. These are referred to as continuous systems A and B. The other two systems work on a point pricing basis and are referred to as point systems A and B.

6.4.2 *Continuous system A:*

6.4.2.1 Under this system the method of charging and the arrangements for payment are the same as for the driver-operated meter described in 6.3.7 above. The main difference between the two systems is that, whereas in the latter the motorist sets his meter to the appropriate running rate, under the automatic system this function is performed for him by an additional switching circuit which operates in response to signals received from road-sited transmitters installed at the zone entry and exit points and at intermediate points within the zones. Manual control of the automatic meter is still retained for the selection of parking rates. A manual over-ride is also provided to enable a motorist to stop his meter charging when he enters private premises situated within a charging zone. The over-ride is itself over-ridden, however, if subsequent to its use the meter receives a signal from a transmitter to levy a charge.

6.4.2.2 Another important difference is that only one colour indication is needed.

6.4.2.3 *Timing mechanism*. This is exactly the same as in the driver-operated electrolytic system.

6.4.2.4 *Switching mechanism:*

(a) *Road Equipment.* This consists of a short-range low frequency transmitter which can be set to transmit a signal at one of several possible frequencies, according to what charge is required at the time. The signal is radiated from a cable laid across the whole width of the road and is picked up by a vehicle passing in either direction. The meter on the vehicle is automatically switched to the charging position corresponding to the signal frequency. The outermost cables around a charging area will carry the OFF signal, so that vehicles entering from the free area outside will be unaffected by the first cable they cross. But a little further on they will cross another cable which will set their meters to the required charging position. When travelling inside the area they may cross a number of cables, some of them internal controls which will not affect meters which are already set to the correct rate, and some denoting entry to another zone with a different rate. Quite small areas, or even single streets, could be made separate zones. When charging ceases each day, all cables are automatically reset to transmit the OFF signal. The transmitters are very compact and the little power they require should normally be obtainable from the street lighting system. In fact, the most convenient place to install the transmitters, which could then be housed in sealed cast-iron containers, might be to attach them to the base of existing light standards. Inside each container there would also be an electrically operated perpetual time switch which would control the daily and weekly sequence of frequencies to be transmitted. It would be possible for the police or traffic wardens to change the normal frequency sequence on special occasions such as bank holidays.

(b) *Vehicle equipment.* The vehicle equipment is so designed that the switching arrangements inside it will operate in response to the frequencies picked up from the cables in the road. On receipt of a signal to charge at a certain rate the meter will charge at that rate until it receives a further signal either to charge at a different rate or to switch off or until the manual over-ride is used to switch off the meter. The signal is picked up by a coil attached to the underside of the vehicle chassis.

6.4.2.5 *Method of payment*. This also is the same as for the driver-operated meter.

6.4.2.6 *Other features:*

(a) *Visibility*. As in the case of the driver-operated meter, indication that the meter is working is provided by a light which is visible to an outside observer. With the automatic system, though, the same light can be used for all the running rates. There is no need to indicate that the meter is switched to the correct rate.

(b) *Parking*. The arrangements are the same as for the manual meter.

(c) *Appearance*. The location of the automatic meter is the same as for the manual meter, i.e. at the inside centre of the windscreen, and the only external difference in the appearance of the two meters is that in the case of the automatic one no switch positions are needed for the running rates.

6.4.2.7 *Security against fraud:*

(a) *Meters*. Whenever a meter undergoes a change of rate, the meter light will blink OFF and ON for a fraction of a second. A meter which has been tampered with in such a way that it no longer responds to the normal automatic switching signals, e.g. one whose coil has been screened, will fail to show this indication and can thus be detected quite easily. As in the case of the manual meter the circuit will be 'potted' and therefore completely inaccessible.

(b) *Timers*. Production of a counterfeit timer would be comparable in difficulty to forging a bank note. If necessary the police could be given authority to make spot checks of timers on a small sample basis.

6.4.2.8 *Cost.* At the moment it is envisaged that the cost per unit of the vehicle equipment would be about £3, excluding fitting costs which would be small. The road equipment would probably cost about £50 per point, excluding the cost of connection to the mains and the cost of laying the road cables. This latter operation, however, could be carried out without actually digging up the road; all that is needed is a slot about an inch wide and few inches deep, and special drilling apparatus could probably be made to cut the slots quickly and cheaply.

6.4.3 *Continuous system B:*

6.4.3.1 This scheme is based on coloured charging zones with an option of three charging rates denoted by three colours, used in exactly the same way as in the driver-operated systems already described.

6.4.3.2 *The timing mechanism.* Electrolytic timers are used as in the A system, the main difference being that in the B system the timer is not a 'throw-away' item but is used repeatedly in the same meter. A constant current is made to flow through a sealed electrolytic cell depositing copper from one electrode to another and, when this process nears completion, say after one hour at the highest rate, the current is automatically reversed and the process is repeated in the opposite direction, and so on. Every time the cycle is completed an electro-magnetic counter is moved down by one unit. The counter, which on issue might register, say, 20 units, would eventually reach zero and would automatically switch out the circuit.

6.4.3.3 *The switching mechanism*. This is much the same as in the A system.

6.4.3.4 *Method of payment.* When the counter needs resetting, a small cassette containing the electrolytic timers and the counter is removed from the meter and taken to an appropriate centre. The cassette must be handed in while there is still a refundable amount showing on the counter, and either reset on the spot or exchanged for one already reset; or alternatively a spare cassette can be kept ready and inserted as soon as the old cassette expires.

6.4.3.5 *Other features:*

(a) *Visibility*. Four lamps are employed, one colour for each charging rate and a fourth no-charge lamp to indicate that the equipment is switched on. This last lamp will be visible both from inside, at low intensity, and outside the vehicle.

(b) *Parking*. Two alternative systems may readily be accommodated. A flat rate for parking could be used, set somewhat lower than the lowest running rate. Alternatively, the ignition circuit could be carried through the equipment and would cause a lower rate of charge to be levied when the ignition was switched off than when the vehicle was moving within that zone.

(c) *Appearance*. The meter is box-like in shape, 3¼ in. × 2½ in. × 1¾ in. In the front are four small light apertures. The no-charge light is also visible from the rear. There is also a window showing the number of units on the counter.

6.4.3.6 *Security against fraud.* Police or traffic wardens would be required to observe the light indications which must be shown in the appropriate zones. These indications should be readily apparent from the kerb-side, even from quickly moving vehicles. However, it might be possible to adjust either the indicator or the count in the meter if the seal were broken, and it is therefore suggested that portable transmitters producing changes in the lamp indicators could easily be provided for officers to detect any cheating.

6.4.3.7 *Cost.* It is thought that the equipment to be mounted on the vehicle, i.e. the pick-up coil and meter, could be quantity produced for about £4-£5. The zone-switching signal transmitters could be produced for about 25s. each. The operating costs would arise mainly from the cost of running meter depots for handling cassettes.

6.4.4 In the point pricing systems the meter does not run continuously while in a charging zone but registers one or more units every time it passes a charging point. It is in effect a sophisticated toll-gate. The advantage of point pricing is that the price may be varied from point to point and the points themselves may be deployed more or less densely, so that highly flexible pricing is possible. The disadvantages are that, unless the points are spread in very large numbers, they can be to some extent avoided, and the fewer there are the less accurately do they relate to costs and the more arbitrary and anomalous are their effects upon traffic. But large numbers of points add to the cost.

6.4.5 *Point system A:*

6.4.5.1 *The counting mechanism.* The meter is designed to be carried on the outside of the vehicle, either near the bumper or on one wing. It is issued containing a definite number of units. Whenever the vehicle passes a charging point, a number of units, between one and ten, is deducted. In its basic form the counter produces no visible sign, so that it is not possible to read the counter in any way. Provision is made for part of the unit to change its colour as soon as a predetermined number of impulses is recorded, and provision can also be made for a second change of colour to appear at any intermediate stage. Thus the counter could be issued in, say, green form when unused, turning to yellow when almost exhausted and red when completely exhausted. A visual indicator (needing some training to read) can be attached at an extra charge, and a decimal converter can be added at a further charge.

6.4.5.2 Power requirements for the meter are very small and may come from one of three sources: (a) an independent internal power supply generated by the movement of the vehicle; (b) a self-contained long life battery; (c) the vehicle battery.

6.4.5.3 *The switching mechanism*. Electric cables carrying a very low current are laid transversely across the road, either in or on the surface, and are energised continuously so that any vehicle moving across a cable receives an impulse. Vehicles stopping on top of a cable do not pick up more than one impulse. It is proposed that the cables be laid in groups of up to ten at each charging point, so that the number of impulses to activate meters at each point can be varied accordingly. Changes of charging rate could be made manually at each charging point or automatically from central control stations.

6.4.5.4 *Method of payment.* Two methods are suggested. A prepayment meter may be sold with a given capacity and exchanged when exhausted. Since this meter must be removed from the vehicle periodically it cannot be fixed permanently and must therefore be securely locked to the vehicle. Alternatively, a credit meter can be issued which can be fixed permanently to the vehicle and taken at intervals to authorised stations to be read and paid for. This type of meter would be registered in the name of the owner. Precautions against theft need further investigation.

6.4.5.5 *Other features:*

(a) *Visibility*. No illumination is provided. As long as the meter is in working order evasion is not possible except by carrying an expired prepayment meter, in which case the chances of avoiding detection need be no higher than with an expired vehicle licence at present. Illumination may therefore be unnecessary.

(b) *Parking.* Cables are laid along parking places and impulses emitted at fairly long intervals corresponding with the required parking rate.

(c) *Appearance.* The meter is envisaged as an encapsulated box about 6 in. x 3 in. x 1 in. The only feature on the surface is the window showing the colour and the counter.

6.4.5.6 *Security against fraud*. Tampering with the meter itself is considered very unlikely because of the degree of encapsulation possible and the complexity of the mechanism. Screening, however, may be possible and investigation is required on this point.

6.4.5.7 Another danger of fraud seems to lie in the possibility of putting a prepayment meter out of action, although the manufacturers claim that the meter will be almost indestructible. The best way of defeating the prolonged use of out-of-action meters may be to change the style and colour of the casing at frequent intervals.

6.4.5.8 *Cost*. The tentative cost estimates are as follows:

For the static meter:	£3 to £5
For the binary indicator:	£3 to £5
For the decimal converter:	£3 to £5

We have suggested that the static meter alone would be sufficient for a prepayment unit, but a credit meter might require the two attachments.

6.4.5.9 The cost of ground equipment will depend upon the number of charging points adopted. For a national system covering all congested areas we estimate that the minimum number of points needed to give tolerably efficient results would be about 20,000. The maximum cost per point is estimated at £250, but may well prove to be lower than this. Thus we may set a maximum cost for ground equipment at £5 million.

6.4.5.10 The operating costs of the system consist mainly of the costs of the meter depots. The overall cost of maintaining and administering a credit meter should be comparable with that of a gas meter. No estimate is available of the costs of running an exchange scheme for prepayment meters.

6.4.6 *Point system B:*

6.4.6.1 *The counting mechanism*. Every vehicle would carry a unit containing a pick-up device, a receiver and an electro-magnetic unit counter. The unit would be on the outside of the vehicle and wired permanently to the vehicle battery. Every time the vehicle passed a charging point (consisting of a loop in the roadway) the receiver would pass one or more pulses through a transistorised circuit which would advance the counter by the same number of units.

6.4.6.2 *The switching mechanism.* Three arrangements could be used together. Long loops could be placed in the road to transmit pulses at a rate corresponding to the charging scale in use. The frequency proposed is below 10 kilocycles so as to avoid interference from other comunicational and navigational signals. The loops would be laid below the surface extending for the full width of the road and from 30 feet up to a city block in length, although this would cause difficulties for road repairs. The current used would be of the order of 1 amp. To provide for differential charges the pulse rate could be changed by time switch. Alternatively, short loops could be placed at intervals on the road transmitting either pulses or a continuous wave. To provide for differential charges some of the loops could be switched off separately by time-switch. In all three arrangements small transmitters would be used, mains-operated and conveniently mounted on lamp posts, walls, or beneath the pavement.

6.4.6.3 *Method of payment*. It would be necessary for the meter to be read periodically and it is suggested that this could be done at garages. The vehicle owner would be under an obligation to have his meter read at least once every three months, say. Any approved garage could do this and accept payment, in return for a payment voucher which would bear the date and which could be fixed to the windscreen. The payment would then be remitted to the local authority who would keep an account for each meter issued. If a meter fell overdue for payment there would thus be two checks, the payment voucher and the account. The authority could refuse to renew the licence of any vehicle with an overdue account.

6.4.6.4 It is proposed that the issue of payment vouchers should be made by a locked and sealed machine installed at each approved garage and operated by a garage attendant. The machine 'reads' the necessary information on the previous voucher (inserted for the purpose) and issues a new voucher in accordance with this and the setting of two sets of dials by the attendant. It can refuse to accept a setting that leaves the motorist in debt. The purpose of the payment machine is both to make payment fast and simple, and to prevent fraud by either motorist or garage.

6.4.6.5 *Other features:*

(a) *Visibility*. A small lamp would be situated inside the vehicle where it could be seen by the driver and observed by a warden as the vehicle passed. When the vehicle meter picked up a pulse or signal, the lamp would flash, thus informing the driver that he was being charged and at the same time providing an outward indication that the meter was functioning.

(b) *Parking*. The system is readily adaptable to use on parking sites.

(c) *Appearance*. The best location for the meter has not yet been decided but it would be placed on the outside of the vehicle. It would consist simply of a hermetically sealed unit, with a single glass or perspex window provided for the counter, and with leads to the battery and indicator lamp. The vehicle registration number might be reproduced on the inside of the counter window. The colour of the case could denote the price class of the vehicle.

6.4.6.6 *Security against fraud*. As already stated, the meter would consist of a hermetically sealed unit and the vehicle registration number could be inscribed inside the counter window on issue. The range of the counter would exceed the maximum requirement of any vehicle so that the meter need not normally be removed during the life of the vehicle. Meters should be obtainable only through the authorities and should be returned when the vehicle is scrapped. The counter would be readily observable when the vehicle was stationary and the current payment voucher would need to be displayed, probably on the windscreen, so that wardens could verify that payment was up to date. Since the meter would be on the outside of the vehicle, any attempt to screen the pick-up device would be readily detectable. The wiring between the unit and the vehicle battery is the most difficult problem: a simple arrangement is favoured, which could be easily inspected, consisting of a flying lead hard-soldered and sealed to the battery cable immediately adjacent to the battery terminal.

6.4.6.7 The indicator lamp would be an effective way of ensuring that meters were properly functioning. Vehicles could be observed passing any charging point. Officers could be provided with test torches which, when directed at a vehicle, would cause the lamp to flash and the counter to register one unit. (The cost of one unit under this system would only be about one-tenth of a penny so this need not cause any difficulty).

6.4.6.8 *Cost*. In full production the cost of the vehicle equipment is tentatively quoted as £5-£10. Of this cost 65 per cent is attributable to the electro-mechanical counter, so the final cost would depend largely on whether this could be reduced. The road equipment is estimated at £100-£150 per unit (excluding installation costs); the number of units needed for a nation-wide scheme being possibly 20-30,000, excluding parking sites. The cost of the payment machines, of which 10-20,000 might be needed, is not known.

Zone marking

6.5.1 If an automatic system is adopted, zone marking presents no problem, since it exists only to inform, not to instruct. With a driver-operated meter it must be unmistakable. It must tell the driver which rate is required and it should permit changes of rate to be made at certain predetermined times. If rate changes are to be made regularly and quickly, electrical signs will be required.

6.5.2 It is suggested that zone marking consists of primary marking at all points of entry and exit, and secondary marking within the zone. The primary marking might be achieved by beacons, not necessarily of the same shape as crossing beacons. The lighted part of the beacon could consist either of a large white glazed shade containing bulbs of the necessary colours, or of separate lamps after the fashion of traffic lights. As it is important that the system should be simple, it is unlikely that more than two colours would often be required for the same beacon. The beacons would be switched on at the correct time, either by hand or by time switch, and could be switched from the off-peak colour to the peak colour, and so on, without difficulty. The cost of a beacon has been estimated at about £42.

6.5.3 Secondary marking might consist of small sign-boards placed at prominent places within the zone such as traffic lights, parking sites, and in other places where motorists might need to see them. These boards could be fixed to lamp posts and other suitable posts already in existence including the peripheral beacons. Their purpose would be to inform the public of the general pricing regulations applying in that area.

6.5.4 Parking sites embraced by the scheme would need suitable notices explaining the charging colour required and any time limits in force.

Supervision and enforcement

6.6.1 The operation of the price system (or any system of distribution) requires supervision and enforcement. Most retail trades rely upon sales assistants for supervision. Transport services, and many other service trades, rely also upon inspectors. Many thousands of people are employed wholly or partly on this function of supervision. Underpinning their authority lies the power of the law, upon which the enforcement of the price system ultimately depends. Both supervision and enforcement are necessary costs which must be taken into account when discussing new systems of road pricing.

6.6.2 One of the advantages of the present system of fuel tax and vehicle licences is that it requires very little supervision and enforcement. This must be borne in mind when considering the advantages of other systems.

6.6.3 Where parking meters are used, their supervision is undertaken by traffic wardens. In London it is estimated that the cost of wardens will reach £600,000 a year when all parking zones are in operation. The organisation needed to trace drivers who fail to pay excess dues and fines adds a substantial further cost. Thus street parking systems are expensive to enforce and supervise, but this is partly because of the time limits.

6.6.4 With or without time limits, parking meters require traffic wardens, and their duties may seem naturally extendable to the supervision of road meters, which charge for both moving and parking. It seems unnecessary that the routine inspection of road meters and the supervision of their operation should be a function of the police.

6.6.5 With a driver-operated meter there are broadly two ways of avoiding payment: either by failing to operate the meter correctly or by tampering with its mechanism. With an automatic meter only the latter possibility exists but there may be greater scope for exploiting it. With adequate zone marking the amount of accidental avoidance should be small, and we shall therefore confine our attention to deliberate avoidance by 'dodging' or tampering.

6.6.6 The dishonest driver's willingness to commit fraud depends upon the gain from the fraud, the probability of detection and the penalty. To some extent the last two factors are substitutable, but the severity of the penalty is in practice limited by public opinion. The gain from meter tampering could be large; it could give the beneficiary 'free' motoring for an indefinite period. So the chance of escaping detection indefinitely must be kept small. Heavy penalties would doubtless be permissible for this more serious type of fraud. Experience of meter tampering in the gas and electricity industries seems to suggest that, unless there is a coin box, this sort of fraud is very rare; and we think that this is due to the conditions surrounding the use of the meter rather than the inviolability of its design. Provided that the fraud cannot be easily and permanently concealed, the mere possibility of an occasional check will deter all but the criminal-minded. If the meter can be retarded in some way and then rectified later on, the checks must be random. Ignorance of the mechanism is another deterrent. The registration of meters, making drivers accountable for them, is another powerful deterrent. If drivers are permitted to obtain only one meter per vehicle and are held responsible for it, they will hesitate to interfere with it for fear of spoiling it. In short, given a reasonably secure design with a confidential mechanism, combined with registration and a system of regular and random checks, we would not anticipate much trouble with meter tampering. These conditions give an advantage to the meters which can be permanently encased and fixed to the vehicle.

6.6.7 Meter 'dodging' presents a different sort of problem because it might not be regarded by many members of the public as a criminal activity and heavy penalties might therefore be impracticable. On the other hand, the gain to be enjoyed from each act of 'dodging' would be trifling, and only by frequent repetition could a substantial gain result. Given a meter with good visibility characteristics, the chances of evading detection for long would, we believe, be very small. The initial 20-second flasher suggested for the driver-operated meter would be a useful feature.

6.6.8 A firm initial effort to obtain strict compliance might be advisable because drivers with dishonest inclinations might hesitate to become the 'odd man out' by committing petty offences in full view of other drivers who were observing the law. A high degree of compliance, once achieved, might thus be self-perpetuating. This principle is used in Russia to obtain payment on conductor-less buses.

6.6.9 It is impossible to predict how big an enforcement effort would be necessary. But before weighing this effort against the advantages of better road pricing one must take account of the savings that would accrue to the police through reduced congestion. In Central London alone it is estimated that the anticipated reduction in congestion would save about £800,000 a year in police costs.

Conclusions on the feasibility of direct charging

6.7.1 We have now described the various ways known to us of charging for the use of the roads. When charging for a commodity or service it is logical to look first for a direct method of doing so and there are in fact very few commodities or services which, if charged for at all, are not charged for directly. The decision that the use of the roads by vehicles should be charged for was made by Parliament in 1909. At that time some form of meter would have been possible but not at a reasonable cost. Today, half a century later, we can say the same thing about off-vehicle recording systems; they are technically feasible but it is controversial whether they are superior, or whether they would be acceptable to the public, and their cost, for the moment, is high. On the other hand, it seems that a simple, effective meter can now be produced quite cheaply with manual control, and may be provided with automatic control for an extra cost which need not be regarded as excessive.

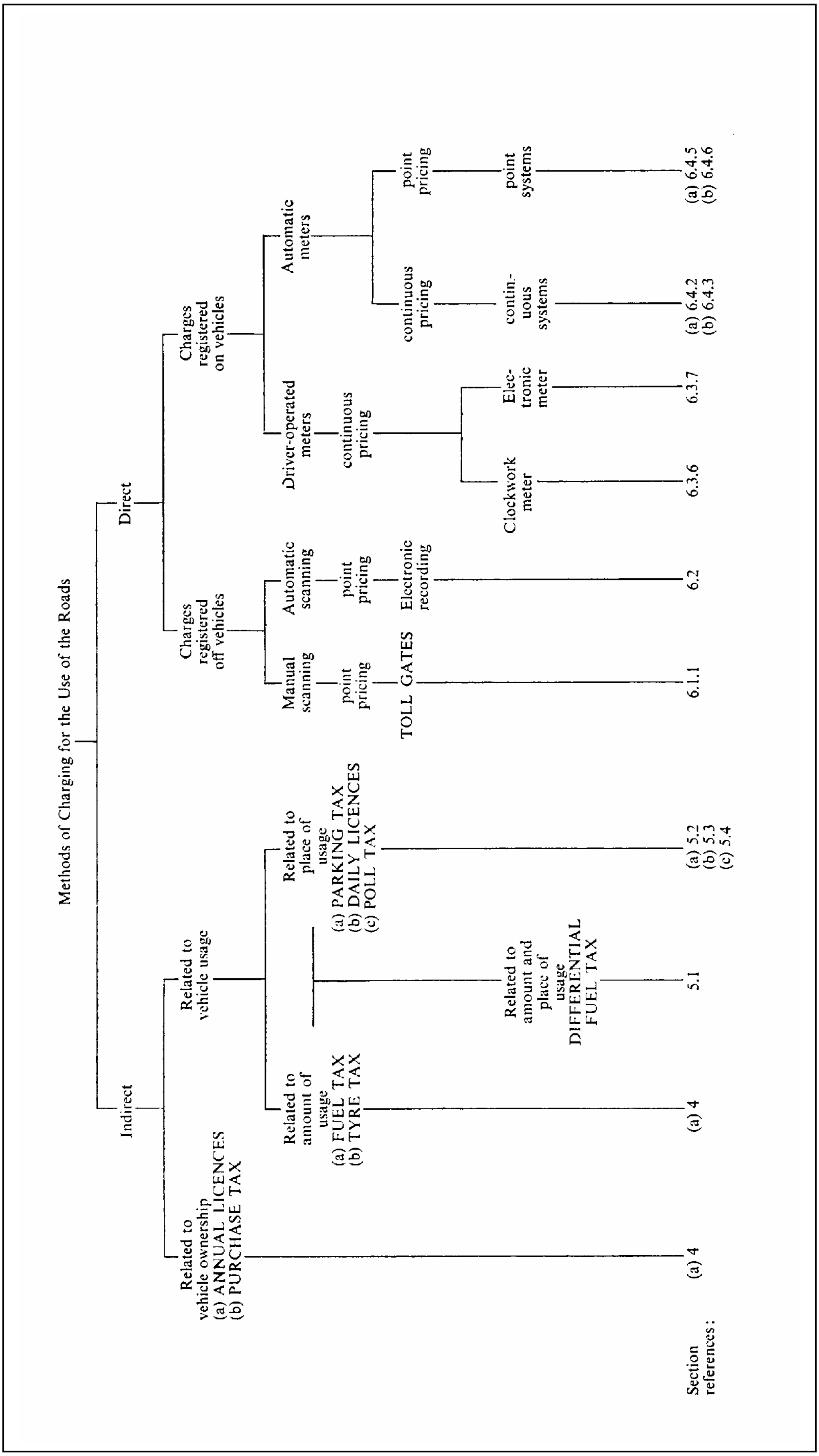
6.7.2 None of the meter systems put forward has been developed to the point where it could be adopted without qualification. Further development work is needed which, although quite straightforward and not costly, will require some encouragement from the Government. Given the signal to proceed, manufacturers expect to produce fully developed prototypes and detailed costing within a year.

6.7.3 After this period of development it should be possible to select the most promising method or methods. In the meantime arrangements could be made for operational and introductory trials. New methods must first be tried out on a small scale and should, if possible, be introduced gradually. Thus one would suggest a technical trial in a place where the issue of meters to incoming vehicles is easily arranged, followed by an experimental scheme, possibly in Central London. Any adjustment of prices, including fuel tax and vehicle tax, could only be completed once a national scheme was in force. During the introductory stage there would be anomalies. Relatively low prices could be charged at first, accompanied possibly by local reductions in vehicle tax.

7 THE PRICES

7.1 We stated above that, in general, road prices should equal the costs arising from the passage of each vehicle. We also stated that these costs, which are mainly congestion costs, vary from about 4d. a mile when the average traffic speed is 20 mile/h to about 6s. a mile when it is only 8 mile/h. This does not mean, of course, that these are the right prices to charge, because, as soon as a price is introduced and causes the volume of traffic to fall, congestion costs will also fall, and in much greater proportion. The prices for using congested roads should be based on the congestion costs expected after the prices have been introduced. The problem is to judge what effect different prices will produce on the volume of traffic and hence on the cost of road use.

7.2 Thus it is necessary to estimate the cost of road use for different traffic speeds on each road or area of roads and to judge the reaction of traffic to different prices. The estimates of cost used here (see Appendix 2) are made from data of (a) the speeds normally achieved for different volumes of traffic on the particular road or area under consideration; (b) the costs borne by each type of vehicle at different speeds including the value of their occupants' time; and (c) the composition of traffic, i.e. the proportion of different types of vehicle. Traffic studies are needed to extend some of this information and also to determine the existing traffic speeds and flows. Given this information, there is no difficulty in obtaining realistic cost estimates. Accurate ways of estimating the reaction of traffic to different prices have, however, not yet been developed; they may be developed by a process of carefully controlled trials.


Methods of Charging for the Use of the Roads
Indirect
Direct
Related to vehicle ownership
(a) ANNUAL LICENCES
(b) PURCHASE TAX
Related to vehicle usage
Related to amount of usage
(a) FUEL TAX
(b) TYRE TAX
Related to amount and place of usage
DIFFERENTIAL FUEL TAX
Related to place of usage
(a) PARKING TAX
(b) DAILY LICENCES
(c) POLL TAX
Charges registered off vehicles
Manual scanning
point pricing
TOLL GATES
Automatic scanning
point pricing
Electronic recording
Charges registered on vehicles
Driver-operated meters
continuous pricing
Clockwork meter
Elec-tronic meter
Automatic meters
continuous pricing
contin-uous systems
point pricing
point systems
Section references:
(a) 4
(a) 4
5.1
(a) 5.2
(b) 5.3
(c) 5.4
6.1.1
6.2
6.3.6
6.3.7
(a) 6.4.2
(b) 6.4.3
(a) 6.4.5
(b) 6.4.6

7.3 With this information, price assessments can be made for every road or group of roads in a congested area. The normal pattern will be for the highest prices to occur in the centre of a town, declining as one moves away from the centre. If a continuous pricing system is adopted, price assessment should be made for areas large enough to be considered as zones. If only one zone is contemplated in a town, the larger the zone the lower will the price normally be. If two zones are contemplated, an inner and an outer zone, the prices in both zones will fall as the inner zone is made larger. If a point pricing system is adopted, the best prices will be judged according to the conditions in the surrounding area.

7.4 The ability to adjust the effect of prices by moving the zone boundaries is important because under the meter schemes put forward only a few prices would be available to meet the needs of every town and city in the country. As a result of price calculations made for London and Cambridge the following scale of prices is suggested* together with possible colour indications:

PURPLE	2d.	per minute
GREEN	1d.	" "
PINK	0.5d.	" "
BROWN	0.2d.	" "
BLUE	0.ld.	" "

The blue rate is intended mainly as a parking rate (6d. per hour). The brown rate could serve both as a low running rate and as a high parking rate. The availability of two parking rates would be a considerable advantage in helping to divert some of the parking demand from the more popular to the less popular parking sites and thus maintain a better balance between demand and supply both in an area as a whole and in different parts of the area.

7.5 From time to time price changes, up or down, might be required. In all the meter systems described above such changes need cause no difficulty provided that the ratios of the five prices to each other remain the same.

7.6 We are aware that a great deal of theoretical argument may be advanced on the questions of what prices to charge and how to calculate them. But as in other sections of the economy a good deal about prices can be learned by trial and error. Prices can be adjusted until they give the best results. We would warn, however, against the use of prices to reduce traffic to an arbitrary level. The ‘best’ level of traffic varies greatly from one urban area to another. From an economic point of view the only satisfactory way to know what the best level of traffic is in any particular area is to work out the costs in the way described above and try to set a price just high enough to bring the volume of traffic down to the level at which the costs imposed by vehicles are equal to the price charged. Our calculations suggest that considerable variations from the ‘optimum’ price may be made with little loss of benefit.

** The calculations indicate that ‘optimum’ prices might sometimes be higher than 2d. per minute. There is much to be said, however, for pitching prices on the low side.*

8 ECONOMIC CONSEQUENCES OF DIRECT CHARGING

The overall benefits

8.1.1 The basic effect of applying any of the direct charging systems that we have described would be to reduce traffic in congested areas and hence to increase the average speeds and lower the costs (before tax) of the remaining vehicles. If the prices were fixed according to the method described above (and demonstrated in Appendix 3) average speeds might rise to 14 mile/h in areas where they are now only 10 mile/h, and to 17 mile/h where they are now only 14-15 mile/h.([6]) According to data collected in central London, the reductions in traffic flow necessary to produce these higher speeds are 20-25 per cent where the present speed is 10 mile/h and 15-20 per cent where it is 14-15 mile/h. There would be little purpose in extending direct pricing to roads where traffic speeds are already over 20 mile/h.

8.1.2 The net benefits to the community resulting from higher traffic speeds can be classed as follows:

(a) Savings in the paid working time of persons who travel in working hours, including the crews of commercial vehicles and buses.

(b) Other time savings, including time travelling to and from work, shopping, etc.

(c) Savings in fuel and other vehicle running costs.

(d) Greater productivity from buses and commercial vehicles insofar as the same number of journeys can be made by fewer vehicles, requiring less capital investment.

(e) Losses to people who as a result of the price changes refrain from making journeys which they would otherwise have made.

(f) Gains and losses to other road users such as pedestrians and cyclists.

(g) Changes in the costs caused by accidents. It is not known how a reduction in congestion would affect either the number of accidents or their severity.

(h) Changes in the costs imposed by road users on the rest of the community by way of fumes, noise, dirt and other undesirable features of motor traffic.

8.1.3 The five classes (a) to (e) are to some extent measurable and, according to the estimates (Appendix 3), would yield net benefits of between £100 million and £150 million a year if a meter system of the sort described were adopted under present traffic conditions. The total, of which about 7 per cent would accrue in Central London*, is comprised approximately as follows:

(a)	Savings in paid working time:	+40	per cent
(b)	Other time savings:	+63	" "
(c)	Vehicle running costs:	+ 7	" "
(d)	Capital savings:	+10	" "
(e)	Losses:	-20	" "

The remaining three classes, if they were measured, would probably add significantly to the total benefit. With each year that passes, if congestion continues to grow wider and deeper, the potential benefits from improved pricing will rise at a steeper rate than the rise in vehicle-mileage.

** Central London is taken to mean the area covered by the R.R.L. London Traffic Surveys.*

8.1.4 The magnitude of the benefits would depend to some extent on the type of meter system adopted and how it was used. Up to a point, the more refined systems may yield greater benefit than the simpler systems, but of course they are bound to cost more. We would not expect the cost of running the system to be more than 5-10 per cent of the measurable benefits. The estimates assume a fairly simple system; with a more refined system the benefits might possibly be higher than the upper estimate.

8.1.5 There are places, such as certain 'bottleneck' areas, where the presence of congestion would not in itself justify the introduction of a pricing zone, or where prices should be deliberately kept low in the interests of, say, local traffic. There are places where suitable pricing zones might be difficult to define because of the diffuseness of congestion. There is also no doubt that under any system the prices charged would often be inappropriate for the prevailing traffic conditions and that road users would not always respond predictably to them. Such inefficiencies are inevitable and we hope that the estimate of benefits allows sufficiently for them.

8.1.6 The benefits of a new pricing system would be fully realised only after a period of adaptation. Those who stood to gain would need time to adjust their habits to the new conditions. But more important, those who stood to lose would need time before they found-or were offered-the best alternatives and adjusted their habits so as to minimise their losses. Some people would travel at cheaper (i.e. less congested) times, some would travel by cheaper (i.e. less congested) routes. Some commercial operators, such as owners of delivery vans, might make fewer journeys but with larger payloads. Shoppers might make fewer but bigger shopping expeditions. Commuters would be induced to share their cars more than at present. Some people would transfer to buses and railways. Some might walk or take a bus for the last part of their journey. Some, but probably a small minority, would decide that their journey was not worthwhile.

The effect on incomes

8.2.1 Changes in the method of pricing the roads would inevitably cause changes in the distribution of real income, that is to say, some people would benefit more than others and some people would lose. The way in which different groups of people were affected would depend largely upon the manner in which the revenue from the pricing system was used. For instance, unless steps were taken to avoid it, there might be a change of relative income between town and country. There might be a transfer of income from road-users to non-road-users. Special concessions might be necessary for some road-users, and additional restraints for others, e.g. expense account motorists might need special attention.

8.2.2 There are, of course, innumerable ways in which the revenue could be used. It could be used simply as general revenue, in which case there would be a transfer of income from affected vehicle users to the rest of the community. It could be distributed between local authorities in a manner calculated to compensate residents in areas where road prices were highest. It could be used to subsidise public transport, thus compensating those forced from private to public transport. It could be used to reduce the existing motoring taxes, in particular those such as the annual licence fee which do little to restrain the use of congested areas. It is clearly outside our terms of reference to suggest how the revenue should be used. We can only point out, therefore, that the consequences of road pricing, like those of any other charge or tax, cannot be fully assessed until the answer to this question is known.

Private motorists

8.3.1 At present motorists are discouraged from entering congested areas by three forms of restraint: (1) price, as represented by fuel tax and parking charges, (2) congestion, and (3) the difficulty of finding a suitable parking place for a sufficiently long period. Under a road pricing system the first of these three restraints would be substantially increased and the other two considerably reduced. Motorists in these areas would thus find driving conditions better but more expensive, and some motorists – while continuing to use these areas – would on balance consider themselves worse off than before. It should be observed, however, that, if the volume of traffic could be controlled thus by price, there would be no reason why adequate off-street parking should not eventually be provided in congested areas. The savings in time and convenience which adequate parking facilities can bring to the motorist have not been included in our estimate of benefits.

8.3.2 The main way, however, in which motorists as a class could gain would be if it were decided that the revenue from road prices paid by them to the Exchequer should be used to reduce the existing taxes on motorists. For instance, if the money were returned in the form of reduced annual licence fees or purchase tax, they would benefit from direct lump sum compensation. Or, if fuel tax were reduced, they would benefit every time they motored outside charging zones, say on rural journeys, and outside charging hours, such as during the evening or at weekends.

Public transport

8.4.1 One effect of raising road prices in towns would be to increase the numbers travelling by rail commuter services. Greater crowding of these services would impose losses on existing rail passengers. We cannot analyse here the full consequences for railways, but clearly there might be a need to review fares, schedules and investment programmes in the light of possible changes in road prices.

8.4.2 The effect of road pricing upon bus services would be, by reducing congestion, to improve both their speed and their regularity. As with the railways, some increase in the number of passengers could be expected. It is not clear how much buses should be required to pay in the way of road charges. With the assistance of the London Transport Board we have examined the effect of road pricing upon bus finances, and hence upon fares, under a variety of different assumptions.([17]) Reduced congestion can bring considerable savings in the operating costs of bus companies, largely because the same service can be provided by fewer buses and crews. If buses were to pay road prices, the correct charging factor would need careful study, as also would the redistributive effects of the system upon bus finances and upon peak and off-peak travellers. There is no necessary reason why road pricing should cause increases in fares. Under some policies it could lead to lower fares.

Revenue

8.5.1 It is difficult to predict how traffic would react to the price system which is being discussed, and hence it is difficult to predict with any accuracy what general level of prices would finally materialise. We would judge, but we may be far from correct, that the revenue from the price system in urban areas would amount to £300-£400 million per year under present traffic conditions. But, whatever this figure happened to be, the revenue could easily be adjusted within large margins by changes in existing motor taxes or in the urban road prices themselves, without seriously detracting from the benefits of the system.

8.5.2 Looking ahead, as vehicle-ownership increases, the pressure of demand should tend to force road prices up, but the progress of road improvements and traffic management should increase the supply of road space and hence tend to bring prices down. In the earlier years, when the growth of vehicle-ownership is likely to be fastest, we would expect prices and revenue to rise. Later on prices and even revenue may fall. It has to be realised that investment in new and better roads, while producing an increase in community benefit, must often produce a fall in revenue.

Effect on city development

8.6.1 It is sometimes suggested that the imposition of higher charges for the use of congested streets would result in cities losing their attractiveness as centres of population, industry and commerce. The question is: would the restraint of traffic by high charges have a more adverse effect on cities than would restraint by congestion or by other means? We can only indicate some of the effects which an increased charge for road use might have on city traffic. These effects will vary considerably according to the kind of charging system used.

8.6.2 The occupancy of cars would tend to rise and there would also be a shift from private cars to buses. Occupations associated with large road requirements would tend to leave city centres and to make way for occupations requiring less road usage. Road-users who place a high value on their time would tend to replace those who put a low value on theirs. For example, the proportion of mileage run for business and professional purposes would probably rise. Under an improved pricing system traffic would become less ‘peakish’, i.e. more uniformly distributed both over time and over the city area. For example, deliveries of goods in central areas would occur to a greater extent outside the hours of peak congestion.

8.6.3 Some of these effects would help to offset the loss of vehicle-mileage caused by higher road prices, and the number of people entering the city might not decline despite a fall in the number of vehicles. The increased efficiency in the use of city streets should increase, rather than decrease, its attractiveness. We cannot follow through the implications of these effects, but we can see no a priori reasons for believing that they would, in general, be harmful to city development.

Investment criteria

8.7 The present system of road taxes gives little information about the demand for road space at different levels and compositions of flow. It is very difficult to estimate what people would be ready to pay for road improvement, if they are not, in fact, asked to pay. One of the advantages of road pricing is that it would give some guidance as to the places where the need for road improvement is greatest.

9 RECOMMENDATIONS FOR FURTHER WORK

9.1 If it is decided to continue the technical development of meter schemes there is much research in allied fields of traffic, economics and sociology which could usefully be carried out at the same time. There are six subjects which should, if possible, be explored further before any detailed pricing proposals are made. They are:

(1) The congestion costs caused by different kinds of vehicles in different traffic conditions; including comparisons between different sizes of cars.

(2) The theory of prices and price zones, with case studies.

(3) The comparative advantages of charging by time, distance or points.

(4) The possible income redistributive effects of urban road pricing.

(5) Plans for operational and introductory trials.

(6) The effect of road pricing on the cost of commercial transport.

9.2 Other subjects which merit further study and investigation are:

(7) The evaluation of costs, especially those relating to pedestrians and cyclists and the valuation of unpaid time.

(8) The proportion of through-traffic in towns of different kinds.

(9) The proportion of through journeys spent in congested areas.

(10) Estimates of demand for road space by different user-classes at different price levels, based on present data and including an enquiry into the conditions under which travellers change from one form of transport to another.

(11) Estimates of benefits obtainable from different systems of direct pricing.

(12) The effect of road pricing on the operations of buses, taxis and hire cars.

(13) The effect of road pricing on railway congestion.

(14) The effect of road pricing on retail trade and the development of shopping centres.

10 SUMMARY AND CONCLUSIONS

		Section reference
10.1	We have tried to answer the question: can a method of charging for the use of the roads be found to serve effectively the role of the price system? We have pointed out the deficiencies in this respect of the present methods of taxation, notably their inability to restrain people from making journeys which impose high costs on other people, and we have suggested that road charges could usefully take more account than they do of the large differences that exist in congestion costs between one journey and another.	4 2
10.2	We have examined a number of possible charging methods, including new methods of charging directly for movement on the roads. We have found little advantage in two measures sometimes proposed: the differential fuel tax, which could not be related at all closely to congestion costs, and the poll tax on employees in congested areas, which – whatever its merit in other fields – would have little effect on road congestion.	5.1 5.4
10.3	We believe that the parking tax could bring significant benefits, in spite of its inequitable results and its undesirable effects in encouraging non-parking traffic and penalising local traffic. Preferable to a parking tax might be a system of daily licences, which would embrace all traffic in the areas concerned but would in turn give rise to difficult boundary problems.	5.2 5.3

10.4 Whatever the merits of the parking tax and the daily licence, considerably superior results are potentially obtainable from direct pricing systems. By charging more when costs are high and less when costs are low, it is estimated that a practicable system in urban areas could yield economic benefits from reduced congestion of £l00 million to £150 million a year under present traffic conditions; and this estimate excludes some important items which cannot be measured. Appendix 4

10.5 We have examined a number of proposals for direct charging methods, and we have described six meter system-two manual and four automatic-which, with development, could probably be made effective. When we started our work, we set out a list of 17 requirements which we considered desirable for a road pricing system. Some at least of the six meter systems show promise of satisfying all these requirements. The main conclusion that emerges from our work, therefore, is that there is every possibility that at least one of these proposals could be developed into an efficient charging system and could yield substantial benefits on congested roads. 6

10.6 We have made no attempt to decide which of the six systems is likely to be the best. A choice between them cannot be made until further development has been carried out by the manufacturers. The necessary development would probably take about a year or eighteen months from the time that the Government gives the necessary encouragement. If the technical development is to be continued there are a number of other allied subjects which we have recommended for investigation at the same time. 9

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APPENDIX 1*

Note on Marginal Cost Theory and Road Pricing

1. *Marginal cost*

1.1 Consider a particular road which permits vehicles to undertake a specific journey from a point X to another point Y. The service which the road supplies (including such lighting, traffic control, cleaning, maintenance, etc. as are provided) is the facility for vehicles, together with their passengers and other contents, to make the journey from X to Y.

1.2 We make the following simplifying assumptions:

(a) all vehicles make the same journey;

(b) all vehicles using the road are identical and are driven in an identical manner so that in any given set of conditions the costs associated with their use are identical;

(c) the influence upon traffic speed of all factors other than the number of vehicles, such as pedestrians or weather conditions, or the spacing of vehicles, is constant and may be regarded as one of the permanent characteristics of the road determining its speed/flow relationship.

1.3 If there is no tax of any sort, and if n vehicles per hour make the journey in t minutes each, the costs incurred are:

$$n\,f(t) + r(n) + s(n)$$

where f (t) represents the operating costs of each vehicle, as a function of time t, and r (n) represents the road maintenance costs and s (n) represents the other social costs (such as the effects of noise, dirt and fumes). It may be noted that these costs do not include the original cost of building the road or any other costs which are not affected by the volume of traffic which now uses the road.

1.4 If the flow of vehicles increases to n + l per hour and the journey time for each vehicle consequently rises from t to t^1 the total costs increase to $(n + 1)\,f(t^1) + r(n + l) + s(n + l)$. Thus the increase in total cost is:

$$(n + l)\,f(t^1) - n\,f(t) + r(n + l) - r(n) + s(n + l) - s(n)$$

This is the marginal cost at (n + 1) vehicles per hour.

2. *Private and public cost*

Now for the sake of simplicity, let us assume that the differences $r(n + l) - r(n)$ and $s(n + l) - s(n)$ are both negligible when n is large, although this assumption may not always be valid. Then marginal cost equals $(n + l)\,f(t^1) - n\,f(t)$. This is the cost that could be avoided if any one vehicle refrained from making the journey. But the cost actually borne by each vehicle, if there is no tax, is only $f(t^1)$ which is less than the costs it causes by an amount $n\,[f(t^1) - f(t)]$. This is sometimes called the difference between private and public cost. According to the theory, unless some added restraint is exercised journeys will be made which are valued at more than private cost but less than public cost. A tax may provide the added restraint.

** Prepared for the Panel by the Road Research Laboratory. See also References 19-31.*

3. *Diagrammatic demonstration*

3.1 The theory may be demonstrated by means of a diagram, Fig. 1, as in Beesley and Roth (21).

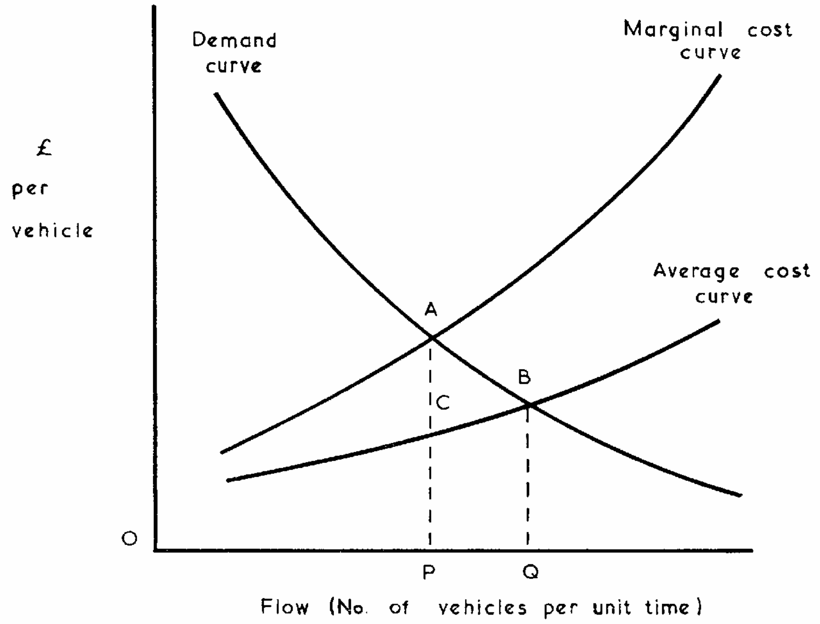

Fig. 1.

Three variables are represented. First, the average cost curve shows the sum of avoidable vehicle operating and road costs, for a journey, at different volumes of traffic, i.e. vehicle flows. As the flow increases, after a certain point speed declines and costs rise. (At some extreme point there is a maximum possible flow and it is believed that, if the number of vehicles trying to use the road exceeds this maximum, it can lead to an actual flow less than the maximum. Hence the cost curve turns back at this point. But this is irrelevant to the argument.)

3.2 Road users pay their own operating costs, which for the sake of simplicity we have assumed to be equal for all vehicles, and we shall now also assume that they pay their part of road costs, say by means of a fuel tax. Then, if no additional charge is made, the price of a journey which each vehicle has to pay is the sum of its own operating costs and its contribution to road costs, i.e. the amount represented by the average cost curve. As the price rises, the number of vehicles that will make the journey declines, and this is represented by the demand curve. The position of equilibrium is indicated by the point of intersection B, between the demand curve and the average cost curve, where flow is Q.

3.3 The third curve, the marginal cost curve, shows the marginal cost at different levels of flow, i.e. the increase in total costs caused by the addition of each extra vehicle. It is evident that, as the flow increases, each extra vehicle adds more to the total cost than it pays and, when the flow exceeds P, there are some vehicles which are not willing to pay the costs they cause. If a charge CA reduces the flow of traffic from Q to P, where the demand curve intersects the marginal cost curve, journeys will not be made unless they are valued at more than the cost they cause.

4. Variations between vehicles

4.1 In the above argument we assumed that all vehicles were identical and that their costs in any given set of conditions were also identical. If we now withdraw this assumption it is clear that the cost per mile caused by one vehicle can vary considerably from that of other vehicles. If the same price per mile is charged to all vehicles, some will pay more than the costs they cause and others less. (It is sometimes useful to measure costs and prices in units of time rather than of distance since a price per minute will usually give a closer approximation to cost than will a price per mile.)

4.2 The inefficiency of charging all vehicles the same price clearly varies with the extent to which individual vehicle costs vary. One way of reducing this inefficiency is to classify the vehicle population (into, say, cars, motorcycles, taxis, lorries of various sizes, etc.) and to charge each vehicle according to its class. There may be other reasons too for wanting to charge one class of vehicle more than another.

5 Variability of other factors

Our assumptions excluded the effect on journey costs of fluctuations in external factors, such as pedestrians and weather, and also of fluctuations in the timing of journeys themselves. The occurrence of these factors can at any time cause journey costs to be higher or lower than normal. Many fluctuations are unpredictable and unavoidable. But many others are predictable and can, in theory, be allowed for in the setting of prices. For instance, hourly, daily and seasonal fluctuations are largely predictable both as regards the volume and composition of traffic demand and the degree of interruption to be expected from pedestrians and cyclists. Nevertheless, insofar as such fluctuations occur and are not allowed for, further inefficiencies may occur.

6 Recovery of total costs

For reasons which do not concern us it may be necessary to recover total costs, including original building costs, or to contribute towards general taxation. If prices are made equal to marginal cost, the total revenue obtained may fall short of the required amount. It may be necessary to avoid either a surplus or a deficit and this probably cannot be done without causing a divergence between price and marginal cost and hence some shift in the use of resources. There are, however, several different methods of increasing revenue, and some methods cause a smaller shift than others in the use of resources. A deficit may sometimes be recovered simply by raising prices, or by price discrimination, or by various kinds of indirect prices or taxes, the choice of method depending upon the circumstances and, in particular, upon the complex of demand elasticities. Since in practice there is no difficulty in recovering the total costs of the road system, we shall not discuss this aspect further.

7 Conclusion

7.1 We have been careful to distinguish between road costs and vehicle operating costs, although both groups of costs are equally essential to the production of journeys. The reason for the distinction is simply that the first group, road costs, are usually paid by the agencies which manage the roads while the second group, the vehicle operating costs, are usually paid direct by the consumer. This unusual division of responsibility for the costs causes much confusion about road pricing. It is helpful to think of a situation similar to that on the railways in which the ‘management’ of the road also owns all the vehicles and pays all the drivers. They, the management, will then need to take account of the marginal cost of journeys, i.e. the effect of each additional journey on the costs of the whole enterprise, and will try to prevent journeys taking place which do not yield a return at least equal to their marginal cost, unless there are special reasons for permitting them.

7.2 The most efficient price system might appear to be one in which price varied with cost on every road at every moment of the day. But this presupposes that road users are able and willing to take account of such a highly complicated system. In practice, of course, they are not. If the price system is complicated road users will probably find simple ‘ rule of thumb ’ methods to tell them approximately what the average prices are and roughly what the prices of particular journeys are likely to be, and they will act accordingly. If this is so the complicated system may be no more efficient than a simpler system.

7.3 In conclusion, therefore, the argument for making road users pay the costs which their journeys inflict on others, including other road users, is subject to certain reservations of which we mention three. One is the requirement regarding total revenue. Another is the limit to the amount of complexity which in practice can have any useful effect on the decisions of road users. A third reservation, which is the main topic of the Panel’s report, is the technical possibility of charging the prices and collecting the payment.

APPENDIX 2*

Calculation of marginal cost

1. Consider a road network on which v represents the average speed of traffic at a given time, expressed in miles per hour, and q represents the average flow (i.e. the number of vehicles per hour passing a point) at that time.

$$\text{Let } v = f(q)$$

The operating cost per mile for an average vehicle is given by c. Variable road cost is given by r. All costs are in pence per mile.

$$c = g(v)$$
$$r = h(q)$$

Total variable cost is given by C, marginal cost by m.

$$C = cq + r$$

$$m = \frac{dC}{dq} = c + q\frac{dc}{dq} + \frac{dr}{dq}$$

We know that $\frac{dr}{dq}$ is relatively small and in the absence of data we assume it to be a constant R.

Let marginal public cost, i.e. the cost inflicted by one road user upon other road users, be denoted by m′.

$$m' = m - c - R$$
$$= q\frac{dc}{dq}$$

It has been demonstrated by Charlesworth and Paisley ([8]) that c may be expressed in the form

$$c = a + \frac{b}{v} \qquad \text{(a, b constants)}$$

It has been shown by Thomson([6]) (following Wardrop([11])) that for a network, as for a single road, v may be expressed in the form

$$v = d - f\,q \qquad \text{(d, f constants)}$$

It follows that $m' = q\frac{dc}{dq} = \frac{b(d - v)}{v^2}$

** Prepared for the Panel by the Road Research Laboratory.*

It remains to put values to b and d. Dawson's estimate for 1962, b = 230 pence, includes leisure time at three-quarters the value of working time; composition of traffic is taken as 68 per cent cars, 4 per cent buses, 14 per cent light commercial, 14 per cent other commercial. For the constant d, we take Thomson's 1961 estimate for Central London, d = 28.

Thus $$m' = \frac{230\ (28 - v)}{v^2}$$

In Table 1 values of m′ are given for speeds between 5 and 20 mile/h. There are dangers in extrapolating too far and for this reason the values of v <8 mile/h should be viewed with caution. To translate from marginal public cost to the appropriate price at any given speed, bearing in mind that the speed must be that obtaining after the imposition of the price, one must add something for R, which may be about one penny per mile.

Table 1

Marginal public cost

Traffic speed (mile/h)	*Marginal public cost* (pence per mile)
5	212
6	140
7	98
8	72
9	54
10	41
11	32
12	26
13	20
14	16.4
15	13.3
16	10.8
17	8.8
18	7.1
19	5.7
20	4.6

2. The estimates in Table 1 apply to an 'average' vehicle. The costs caused by a car would normally be a little less. These estimates are based on data which applies to London off-peak traffic. Obviously the parameters vary from one town to another and from one time to another. The most important difference between different places might be the average width of streets. Estimates show, however, that the width of street makes little difference to the marginal cost at any given speed.

APPENDIX 3*

Estimate of Economic Benefits from Direct Pricing

1 Several sets of calculations have been made, for a nation-wide system([5])([7])([12]),for Central London([6]), and for Cambridge([13]). Here we give an example of the basic method adopted. Minor variations of method exist and the calculations can be carried to different levels of refinement.

2 Consider a road network in which the flow is q and the price per mile is p, p being understood to denote all costs borne by the vehicle drivers and passengers, including the cost of their time. The flow is related to the price by a demand curve of the form q = f(p). Alternatively this may be expressed as the inverse relationship $p = f^{-1}(q)$, where $f^{-1} f(p) = p$.

Before the introduction of any price change, let the price be a and the flow be Q. It may be assumed that when the price is p, the 'gross' benefit to every user‡ of the network (including the price of making the journey) is at least equal to p. By integrating over all road users, it may be deduced that the gross benefit to all road users is:

$$\int_o^Q f^{-1}(q)\,dq$$

From this must be subtracted the total price αQ giving for the net benefit (or consumer's surplus) to all road users:

$$\int_o^Q f^{-1}(q)\,dq - \alpha Q \qquad \text{.................... (1)}$$

Now suppose that an additional charge per vehicle-mile of β is imposed. When the charge is added the flow declines, giving rise to higher traffic speeds and a consequent reduction in costs from α to α' (let α-α'=g). Let the new flow be Q′. The gross benefit to all road users becomes:

$\int_o^{Q'} f^{-1}(q)\,dq$ and the total price is $(\alpha'+\beta)$ Q'

Therefore the net benefit or consumer's surplus is:

$$\int_o^{Q'} f^{-1}(q)\,dq - (\alpha' + \beta)\, Q'$$

However, the amount βQ' is a transfer payment and represents no real cost to the community. Therefore the real net benefit is:

$$\int_o^{Q'} f^{-1}(q)\,dq - \alpha' Q' \qquad \text{.................... (2)}$$

Subtracting (1) from (2) gives the increase (or decrease if negative) in net benefits resulting from imposition of the charge β.

The increase G in net benefits is

$$G = \alpha Q - \alpha' Q' - \int_{Q'}^{Q} f^{-1}(q)dq \qquad \text{.................... (3)}$$

** Prepared for the Panel by the Road Research Laboratory.*

‡ Assuming that there are no road users apart from vehicle users.

If it is assumed that when the flow is of the order of Q or Q′ the demand function is $q = f(p) = \frac{k}{p}$, so that the elasticity of demand is unity, then $Q = \frac{k}{\alpha}$, $Q' = \frac{k}{\alpha' + \beta}$ and $p = f^{-1}(q) = \frac{k}{q}$. By substituting in equation (3) it can readily be deduced that the increase in net benefits is:

$$G = \beta Q' + \alpha Q \log \frac{Q'}{Q} \qquad \text{.................... (4)}$$

and therefore:

$$\frac{G}{Q} = \beta \frac{Q'}{Q} + \alpha \log \frac{Q'}{Q} \qquad \text{.................... (5)}$$

where $\frac{Q'}{Q}$ is the ratio of the new flow to the old flow.

3 In order to quantify the above relationship a process of inspection is necessary because $\frac{Q'}{Q}$ varies with β. First the relationship between g and $\frac{Q'}{Q}$ must be established.

This follows from the speed-cost relationship and the speed-flow relationship.

The speedcost relationship has been taken here as:

$$\alpha = \frac{1}{13.92}\left(4.1 + \frac{224}{v}\right) \qquad \text{.................... (6)}$$

where α is the average cost in shillings for one passenger car unit travelling at v mile/h. This is the formula from Charlesworth and Paisley(8) brought up to present-day values and converted to a p.c.u. basis. The speed-flow relationship has been taken as:

$$v = 28 - \frac{q}{125} \qquad \text{.................... (7)}$$

where q is the flow in p.c.u's per hour and v is the speed in mile/h. This is Thomson's formula(6) for Central London.

4 From these two formulae we obtain Table 2, which gives the value of g for various flow reductions $\frac{Q'}{Q}$ from five initial situations in which the base-speeds selected are 8, 10, 12, 14 and 16 mile/h.

Table 2

Table of g and Q′/Q

Journey speed mile/h	Average private cost per p.c.u. mile (shillings)	Base-speed 8 mile/h		Base-speed 10 mile/h		Base-speed 12 mile/h		Base-speed 14 mile/h		Base-speed 16 mile/h	
		g	100 Q′/ Q	g	100 Q′/ Q	g	100 Q′/ Q	g	100 Q′/ Q	g	100 Q′/ Q
8	2.328		100.0								
9	2.082	0.246	95.0								
10	1.904	0.424	90.0		100.0						
11	1.757	0.578	85.0	0.147	94.5						
12	1.636	0.692	80.0	0.268	88.9		100.0				
13	1.532	0.796	75.0	0.372	83.3	0.104	93.7				
14	1.444	0.884	70.0	0.460	77.8	0.192	87.5		100.0		
15	1.367	0.961	65.0	0.537	72.2	0.269	81.2	0.077	92.8		
16	1.300	1.029	60.0	0.604	66.7	0.336	75.0	0.144	85.7		100.0
17	1.242	1.086	55.0	0.662	61.1	0.394	68.7	0.202	78.6	0.058	91.7
18	1.188	1.140	50.0	0.716	55.6	0.448	62.5	0.256	71.4	0.112	83.3
19	1.142	1.186	45.0	0.762	50.0	0.494	56.2	0.302	64.3	0.158	75.0
20	1.099	1.229	40.0	0.805	44.4	0.537	50.0	0.345	57.1	0.201	66.7

5 Values of Q′/Q can now be found for different values of α and β. The net benefits per vehicle-mile, $\frac{G}{Q}$, resulting from a charge β shillings per vehicle-mile, then follow from formula (5). Some results are shown in Table 3.

Table 3

Net benefits from different charges at different speeds
(in pence per p.c.u.-mile

Initial traffic speed mile/h	3d.	6d.	9d.	1/-	1/3d.	1/6d.	1/9d.	2/-
				- Benefits -				
8	2.0	3.6	4.7	5.5	6.0	**6.0**	5.9	5.5
10	1.4	2.4	3.4	3.6	**3.7**	3.4	2.9	2.1
12	1.2	2.0	2.1	**2.2**	2.1	1.4	0.7	-0.4
14	1.0	1.5	**1.7**	1.3	1.0	0.5	-0.4	-1.8
16	0.8	**0.9**	0.8	0.3	-0.4	-1.1	-2.0	-2.8

The benefits in bold type indicate the optimum prices at each of the five speeds.

6 It has been estimated that the number of motor vehicle-miles run in urban administrative areas in 1959/60 was nearly 37,000 million.([14]) There is very little information of the speeds at which this mileage was travelled. It is assumed that one-half of this mileage occurs in areas which become charging areas. Various hypothetical speed distributions can then be considered. For instance, if the mileage all occurred at 16 mile/h and a rate of 6d. per mile were charged, the benefits would be about £70 million. This may be regarded as a minimum estimate.

7 Estimates by Tanner, Thomson and Foster, using a variety of assumptions, have yielded figures of between £109 million and £213 million. A fair estimate probably lies within the range £l00 to £150 million.

APPENDIX 4*

Benefits from Parking Taxes

Fixed Parking Tax without Non-parking Traffic or Peak Flows

1. (a) *Reduction of traffic*

Consider a road network in which a parking tax of β per p.c.u.. is imposed on every journey, non-parking traffic being ignored. Since the tax per p.c.u. journey is fixed, the tax per mile depends on the length of journey. If the journey length is t miles, the tax is β/t per p.c.u.-mile.

Now suppose that the demand function for journeys of length between t and t + dt is:

$$q_t \, dt = \frac{f(t)\,dt}{p_t^{\,e}}$$

where p_t is the price per p.c.u. mile (including the cost of time and the tax if any), e is the elasticity of demand and f(t) is a function of t. Let the cost per mile, excluding tax, be reduced from α to α′ as a result of the reduction in traffic when the tax is introduced. Then if Q_t dt and Q'_t dt are the p.c.u. mileages travelled on journeys of length between t and t + dt before and after the introduction of the parking tax, respectively,

$$Q_t \, dt = \frac{f(t)\,dt}{\alpha^e} \text{ and } Q'_t \, dt = \frac{f(t)\,dt}{\left(\alpha' + \frac{\beta}{t}\right)^e} \qquad \ldots\ldots\ldots (1)$$

Integrating over all journey lengths gives the total p.c.u. mileages Q and Q′ before and after introduction of the tax.

$$Q = \int_o^{oo} \frac{f(t)\,dt}{\alpha^e} \text{ and } Q' = \int_o^{oo} \frac{f(t)\,dt}{\left(\alpha' + \frac{\beta}{t}\right)^e}$$

The simplifying assumption is now made that f(t) is constant say, K, for journey lengths t_1 to t_2, and zero otherwise, that is to say, every journey length interval between t_1 and t_2 possesses the same demand function (in terms of vehicle-mileage) and journeys whose lengths are outside this range are ignored.

$$\text{Then } Q = \frac{(t_2 - t_1)\,K}{\alpha^e} \text{ and } Q' = K \int_{t_1}^{t_2} \frac{dt}{\left(\alpha' + \frac{\beta}{t}\right)^e} \qquad \ldots\ldots\ldots (2)$$

$$\therefore \frac{Q'}{Q} = \frac{\alpha^e}{t_2 - t_1} \int_{t_1}^{t_2} \frac{dt}{\left(\alpha' + \frac{\beta}{t}\right)^e} \qquad \ldots\ldots\ldots (3)$$

* *Prepared for the Panel by the Road Research Laboratory.*

2. (b) *Net benefits*

The consumer surplus before imposition of the tax is:

$$\int_{t_1}^{t_2} \left\{ \int_o^{Q_t} p_t \, dq - \alpha' Q_t \right\} dt$$

and when the parking tax is imposed this is altered to:

$$\int_{t_1}^{t_2} \left\{ \int_o^{Q't} p_t \, dq - \left(\alpha' + \frac{\beta}{t} \right) Q'_t \right\} dt$$

However, the term $\frac{\beta}{t} Q'_t$ is a transfer payment which does not affect the net change in total benefits. The net gain or net increase in benefits is therefore:

$$G = \int_{t_1}^{t_2} (\alpha Q_t - \alpha' Q'_t) \, dt - \int_{t1}^{t_2} \int_{Q'_t}^{Q_t} p_t \, dq \, dt$$

$$= \alpha Q - \alpha' Q' - \int_{t_1}^{t_2} \int_{Q'_t}^{Q_t} p_t \, dq \, dt$$

If $q = \frac{K}{p_t^{\,e}}$, if $t_1 < t < t_2$ and $q = 0$ otherwise then

$$\mathrm{G} = \alpha \mathrm{Q} - \alpha' Q' - \int_{t_1}^{t_2} \int_{Q'_t}^{Q_t} \left\{ \frac{K}{q} \right\}^{\frac{1}{e}} dq \, dt$$

$$= \alpha Q - \alpha' Q' - \alpha \left(\frac{Q}{t_2 - t_1} \right)^{\frac{1}{e}} \int_{t_1}^{t_2} \int q^{\frac{-1}{e}} \, dq \, dt \qquad \text{………. (4)}$$

3. (c) *Formulae for particular elasticities*

By substituting various values of the elasticity of demand e in equations (l), (2), (3) and (4), formulae can be derived for the relative vehicle-mileages and benefits. The following results have been found.

If $e = 1$

$$\frac{Q'}{Q} = \frac{\alpha}{\alpha'} \left\{ 1 - \frac{\beta}{\alpha'(t_2 - t_1)} log \frac{\alpha' t_2 + \beta}{\alpha' t_1 + \beta} \right\}$$

$$\frac{\mathrm{G}}{\mathrm{Q}} = \frac{\alpha}{t_2 - t_1} \left\{ t_1 \, log \frac{\alpha' t_1 + \beta}{\alpha t_1} - t_2 \, log \frac{\alpha' t_2 + \beta}{\alpha t_2} \right\}$$

If $e = ½$

$$\frac{Q'}{Q} = \frac{\sqrt{\alpha}}{\alpha'(t_2 - t_1)} \left\{ \sqrt{t_2 (\alpha' t_2 + \beta)} - \sqrt{t_1 (\alpha' t_1 + \beta} - \frac{\beta}{\sqrt{\alpha}} log \frac{\sqrt{\alpha' t_2 + \beta} + \sqrt{\alpha' t_2}}{\sqrt{\alpha' t_1 + \beta} + \sqrt{\alpha' t_1}} \right\}$$

$$\frac{G}{Q} = 2\alpha + \frac{2\sqrt{\alpha}}{t_2 - t_1} \left\{ \sqrt{t_1 (\alpha' t_1 + \beta)} - \sqrt{t_2 (\alpha' t_2 + \beta)} \right\}$$

If $e = 2$

$$\frac{Q'}{Q} = \frac{\alpha^2}{\alpha'^2}\left\{1 - \frac{2\beta}{\alpha'(t_2 - t_1)} log \frac{\alpha' t_2 + \beta}{\alpha' + \beta} + \frac{\beta^2}{(\alpha' t_1 + \beta)(\alpha' t_2 + \beta)}\right\}$$

$$\frac{G}{Q} = \frac{\alpha}{\alpha'}\left\{\alpha - \alpha' - \frac{\alpha\beta^2}{(\alpha' t_1 + \beta)(\alpha' t_2 + \beta)}\right\}$$

The Introduction of Non-parking Traffic into the Model

(a) Reduction of traffic

4. $$Let\, Q = Q_p + Q_n \qquad \ldots\ldots\ldots (1)$$

and $Q_n = \sigma Q$

where Q_p Q_n are the volumes of parking and non-parking traffic expressed in p.c.u.-miles. This describes the starting position with no parking tax and price equal to α. After the imposition of a parking tax β equation (1) becomes:

$$Q' = Q'_p + Q'_n$$

Let the demand function for non-parking traffic be:

$$q_n = \frac{K'}{p^e} (K' \text{ constant})$$

$$\therefore K' = \alpha^e Q_n$$

After imposition of tax, $Q'_n = \dfrac{\alpha^e Q_n}{\alpha'^e} = \dfrac{\alpha^e \sigma Q}{\alpha'^e}$

and $Q'_p = (1-\sigma)Q.\dfrac{Q'_p}{Q_p}$

$$\therefore \frac{Q'}{Q} = (1-\sigma)\frac{Q'_p}{Q_p} + \frac{\alpha^{e\ \sigma}}{\alpha'^e}$$

We know the value of Q'_p / Q_p in terms of α, α′, t_1, t_2 and β, for the different elasticities of demand, e = ½, e = 1, e = 2.

(b) Net benefits

5 . The total gain G is the sum of the gains G_p and G_n to parking and non-parking traffic respectively.

Thus $\dfrac{G}{Q} = \dfrac{G_p}{Q} + \dfrac{G_n}{Q} = (1-\sigma)\dfrac{G_p}{Q_p} + \sigma\dfrac{G_n}{Q_n}$

By similar reasoning to that given in 14.2,

$$\mathrm{G_n} = \alpha Q_n - \alpha^1 Q'_n + \int_{Q_n}^{Q'_n} p\,dq$$

If $$e = 1, \frac{G_n}{Q_n} = \alpha \log \frac{\alpha}{\alpha'}$$

Hence if $$e \neq 1, \frac{G}{Q} = (1-\sigma)\frac{G_p}{Q_p} + \alpha\sigma \log \frac{\alpha}{\alpha'}$$

If $$e = 1, \frac{G_n}{Q_n} = \frac{\alpha}{1-e}\left\{1-\left(\frac{\alpha'}{\alpha}\right)^{1-e}\right\}$$

Hence if $$e = ½, \frac{\mathrm{G}}{\mathrm{Q}} = (1-\sigma)\frac{G_p}{Q_p} + 2\alpha\sigma\left(1-\sqrt{\frac{\alpha'}{\alpha}}\right)$$

and if $$e = 2, \frac{G}{Q} = (1-\sigma)\frac{G_p}{Q_p} + \frac{\alpha\sigma(\alpha-\alpha')}{\alpha'}$$

$\frac{G_p}{Q_p}$ have already been calculated in terms of $\alpha, \alpha', t_1, t_2,$ and β

Numerical Evaluation

(a) *a fixed parking tax without non-parking traffic or peak flows*

6. The most simple, basic situation is that in which there is no non-parking traffic, and the volume of parking traffic is constant throughout the day, or throughout the period of control. In the formulae obtained for calculating the net benefit that would result from a fixed parking tax, the only variable about which nothing is known is the elasticity of demand. The elasticity of demand is the proportionate effect that a change in price will have upon the volume of demand. Thus when the elasticity is ½, a price increase of x per cent produces a fall in demand of ½ x per cent; when the elasticity is 2, the same price increase produces a fall in demand of 2 x per cent. Elasticities of ½, 1 and 2 are considered and thus a fairly wide range of possibilities is allowed for.

7. The first results are shown in Table 4 and refer to vehicle mileage evenly distributed on journey lengths of between 1 and 20 miles, with no non-parking traffic and no peak flow. Six possible situations are considered, in which the elasticity of demand is low, medium and high (½, 1 and 2) and in which the base-speed (i.e. the average journey speed before tax) is alternately 10.7 mile/h, which is the current speed in Central London, ([15]) and 8.0 mile/h, which is the speed to which traffic might descend if no permanent cure for congestion is found. The table shows the effect of parking taxes ranging from 3s. to 15s. upon the volume of traffic, and the net benefits in pence per vehicle-mile (i.e. per vehicle-mile travelled before tax).

Table 4

Effect of a fixed parking tax:
(without non-parking traffic or peak flows)

Base-speed	Parking tax (shillings)	Percentage reduction in traffic if elasticity of demand is:			Net benefits (pence per veh/mile)		
		(a)½	(b)1	(c)2	(a)	(b)	(c)
10.7 mile/h	3	6.5	9.3	11.6	1.5	1.9	2.2
	4	8.3	12.3	15.5	1.7	2.1	2.4
	5	10.1	15.0	19.3	1.8	2.2	2.5
	6	11.9	17.6	23.3	1.9	2.2	2.6
	7	13.5	20.2	27.0	1.9	2.2	2.4
	8	15.1	22.7	31.0	1.9	2.1	2.2
	9	16.6	25.1	34.2	1.8	1.9	2.0
	10	17.9	27.4	37.6	1.1	1.7	1.7
	15	24.3	37.7	47.0	0.8	0.2	0.2
8.0 mile/h	3	4.1	5.7	6.7	2.2	2.7	2.9
	4	5.6	7.5	8.8	2.7	3.2	3.4
	5	7.0	9.3	11.0	3.1	3.6	3.8
	6	8.3	11.1	13.3	3.4	3.9	4.2
	7	9.5	12.9	15.6	3.6	4.2	4.2
	8	10.6	14.7	17.9	3.7	4.3	4.6
	9	11.7	16.5	20.3	3.8	4.4	4.7
	10	12.8	18.3	22.7	3.8	4.4	4.7
	11	13.9	20.1	25.2	3.9	4.4	4.7
	12	15.0	21.8	27.7	3.9	4.3	4.6
	13	16.1	23.5	30.2	3.8	4.2	4.5
	14	17.1	25.2	32.6	3.7	4.0	4.2
	15	18.1	26.9	35.0	3.6	3.9	4.0

8, Some interesting points arise from the results in Table 4. The exact level of the tax makes little difference to the benefits. A difference of a few shillings either side of the optimum makes a big difference to the level of congestion but very little difference to the net benefits. In other words after a certain initial amount of traffic has been forced off the roads there is a wide range over which the losses roughly equal the gains. Eventually, of course, as the tax is raised higher and higher the losses exceed the gains.

9. Because of the way in which the benefits 'flatten out' at the top, the elasticity of demand becomes of little consequence. The same tax gives the optimum results for each of the three elasticities studied. When the base-speed is 10.7 mile/h the best tax is clearly 6s; when the base-speed is 8.0 mile/h the best tax is 11s. Moreover the elasticity of demand makes little difference to the benefits. The base-speed, however, has a big influence upon the benefits.

10. In the optimum positions for the six situations under consideration the net benefits vary from 1.9d. per veh/mile to 4.7d. per veh/mile.

(b) *A variable parking tax*

11. A variable parking tax means that motorists pay according to the number of hours that they are parked. It is assumed in our model that there is no correlation between the number of hours parked and the length of journey within the area. A variable tax is then the same as charging a fixed tax, T, to one-hour parkers and a fixed tax, 2T, to two-hour parkers, and so on. The maximum benefits will be obtained when the average tax is at or near the optimum for a fixed tax but they will obviously be lower than under a fixed tax since the tax will be far higher than the optimum for long parkers and far lower for short parkers.

12. This argument against the variable tax applies in all circumstances unless parking time is highly correlated with length of journey, which is unlikely to occur in practice.

(c) *The position after introducing non-parking traffic*

13. We now introduce non-parking traffic into the model. The appropriate formulae have been derived above and an example of the results is shown in Table 5. In this example two of the six situations used in Table 4 are used again to show the effect of non-parking traffic. The proportion of non-parking traffic is shown before and after the tax and each situation is considered with three different levels of non-parking traffic. For each situation the optimum tax has been calculated, i.e. the tax which produces maximum benefits, and the benefits are compared with what they were before the introduction of non-parking traffic.

Table 5

Effect of non-parking traffic

Base-speed mile/h	Elasticity of demand	Percentage Non-parking traffic		Optimum tax	Percentage reduction in traffic	Net benefits with and without non-parking traffic pence per vehicle / mile	
		Before tax	After tax	s.		With	Without
10.7	1	10	13.5	5	13.2	1.9	2.2
		25	33.0	6	12.1	1.6	2.2
		50	60.4	7	8.1	1.3	2.2
8.0	1	10	15.7	10	15.3	3.9	4.4
		25	36.3	11	12.4	3.1	4.4
		50	62.3	11	7.0	1.9	4.4

14. The conclusions to be drawn from Table 5 are that the presence of non-parking traffic (a) has little effect on the optimum parking tax; (b) leads to a higher degree of congestion at the optimum; and (c) causes a considerable reduction in the benefits to be obtained from the policy. In the two examples shown the elasticity of demand = 1. If it were lower than this the effect of non-parking traffic would be less marked, and vice versa. There is no reason to suppose, of course, that the elasticity of demand for non-parking traffic will be the same as for parking traffic. The worst situation will be where the former is high and the latter is low so that the tax leads to a small reduction in parking traffic which is almost entirely offset by the increase in through-traffic.

(d) *Estimate for London*

15. We shall now make our model resemble London as closely as possible. Vehicle- mileage has already been taken to be evenly distributed on journeys of length between 1 and 20 miles, and this is thought to be a reasonable approximation for London conditions. The relationship between flow and operating costs is known quite well. The proportion of non-parking traffic has been assumed to be 30 per cent. The peak flow in Central London is known to be only about 10 per cent above off-peak, although it is much more pronounced in suburban areas. The biggest gap in our knowledge is the elasticity of demand. This is assumed to be 1 in the off-peak and ½ in the peak.

16. The incidence of congestion is not uniform throughout London and therefore a policy of parking restriction would not be applied throughout the city, but only in the centre and in some suburban centres. It is difficult to say whether the unevenness of congestion tends to make our estimates too high or too low. The estimates are given in Table 6 and show the effect of a tax upon the volume of traffic during both peak and off-peak hours, and also the value of the net benefits. Different values of tax are considered between 3s. and 15s.

17. The figures in Table 6 indicate that the best parking tax would be 6s. This tax would reduce traffic by about 11 per cent in the off-peak period and by 7 per cent in the peak, and speeds would rise from 10.7 mile/h to 12.6 mile/h, and from 9.8 mile/h to 11.1 mile/h respectively. The real cost of travel in London would go down by 12 per cent but the real savings (after taking the losses into account) would be about 7½ per cent or 1.5 pence per original vehicle-mile.

Table 6

A parking tax in London

Tax s.	Off-peak hours			Peak hours			Net benefits (pence per vehicle / mile
	Speed		Reduction in traffic per cent	Speed		Reduction in traffic per cent	
	Before	After		Before	After		
3	10.7	11.8	6.5	9.8	10.5	3.9	1.2
4	10.7	12.1	8.1	9.8	10.7	5.1	1.3
5	10.7	12.4	9.6	9.8	10.9	6.2	1.4
6	10.7	12.6	11.1	9.8	11.1	7.2	1.5
7	10.7	12.9	12.5	9.8	11.3	8.1	1.5
8	10.7	13.1	13.7	9.8	11.4	9.0	1.4
9	10.7	13.3	14.9	9.8	11.6	9.8	1.3
10	10.7	13.5	16.0	9.8	11.7	10.5	1.2
	…	…	…	…	…	…	…
15	10.7	14.3	20.9	9.8	12.3	13.9	0.5

18. The effect of a parking tax in London would therefore appear to be of modest value. To put the matter in perspective one may compare it with an efficient road pricing solution. Both the effect on speed and the net benefits of the parking policy are about 40 per cent of what is claimed for a pricing solution.([6])

APPENDIX 5*

Differential Fuel Taxes: fuel-fetching Journeys

5.1 If it is assumed that drivers fill only their tanks, fuel-fetching journeys will not be worth making if the tax differential per gallon per mile is less than:

$$\frac{2 \times \text{Total vehicle operating cost per mile}}{\text{Tank capacity}}$$

$$= \frac{2 \times \text{fuel price per mile (excl. tax)}}{\text{Tank capacity}} \times \frac{\text{Total operating cost per mile}}{\text{Fuel price per mile (excl. tax)}}$$

$$= \frac{2 \times \text{fuel price per gallon (excl. tax)}}{\text{Tank capacity} \times \text{fuel consumption (m.p.g.)}} \times \frac{\text{Total operating cost per mile}}{\text{Fuel price per mile (excl. tax)}}$$

$$= \frac{2 \times \text{fuel price per gallon (excl. tax)}}{\text{Range of vehicle in miles}} \times \text{Ratio of total operating cost per mile to fuel price per mile (excl. tax)}$$

5.2 Thus, whether it would pay drivers to make fuel-fetching journeys would depend on the tax differential, on the range of their vehicles, and on their operating costs, including an evaluation of their own time and inconvenience.

5.3 Excluding petrol tax, the average operating cost of cars has been estimated at just over three times the basic cost of petrol. Drivers' evaluation of time and inconvenience varies both between individuals and for any given individual from one time to another. One might expect that drivers would tend to make fuel-fetching journeys in time on which they placed a low value, provided that this coincided with the times when their cars needed refuelling. It is, therefore, thought that most drivers would probably estimate their total operating costs (including the cost of time and inconvenience) at between, say, 5 times and 8 times their basic tax-free petrol costs (assuming journey speeds of less than 30 mile/h).

5.4 The average price of petrol, excluding tax, is about ls.9d. per gallon.

5.5 Most British cars have a range of between 180 and 300 miles, but since it is not usually possible to judge exactly when tanks will run dry, it would be reasonable to assume ranges of between 150 and 300 miles. If a car has a range of 300 miles and the driver estimates his total operating costs at 5 times the tax-free petrol cost, then fuel-fetching journeys to tax-free areas will be profitable if the tax differential exceeds

$$\frac{2 \times \text{1s. 9d.} \times 5}{300} \text{ per gallon per mile}$$

or 0.7 pence per gallon per mile.

* *Prepared for the Panel by the Road Research Laboratory.*

5.6 If a car has a range of 150 miles and the driver estimates his total operating costs at 8 times the tax-free petrol cost, then fuel-fetching journeys to tax-free areas will be worth while if the tax differential exceeds

$$\frac{2 \times 1\text{s. } 9\text{d. } \times 8}{150} \text{ per gallon per mile}$$

or 2.24 pence per gallon per mile.

5.7 If the fuel to be fetched is subject to some tax, the above figures should be increased slightly, e.g. if the tax is 1s. per gallon, the differential of 0.7d. should be raised to 0.8d; if the tax is 2s. per gallon, the differential should be raised to 0.9d.

5.8 If we assume that the tax would never fall below 1s. per gallon, we conclude that, if the differential did not exceed 1d. per gallon per mile, few drivers would make fuel-fetching journeys, whereas if the differential was more than 2d. per gallon per mile, fuel-fetching journeys would probably become profitable for most drivers.

5.9 However, even if the tax differential was below 1d. per gallon per mile, some drivers could be expected to make fuel-fetching detours from their normal routes, if these involved less additional mileage and inconvenience than journeys for the sole purpose of fuel-fetching.

5.10 A further factor to be considered is that the speed of a fuel-fetching journey has been assumed as less than 30 mile/h. With the advent of motorways fuel-fetching could be made much faster and hence more profitable for many motorists, indicating a lower limit to the differential than that suggested above.