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RESEARCH ON FUEL CONSERVATION FOR CARS

by

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## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>1</td>
</tr>
<tr>
<td>1. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>2. Research into fuel conservation</td>
<td>2</td>
</tr>
<tr>
<td>3. Driver performance</td>
<td>4</td>
</tr>
<tr>
<td>4. Vehicle design and operation</td>
<td>6</td>
</tr>
<tr>
<td>5. Road layout and traffic</td>
<td>9</td>
</tr>
<tr>
<td>6. Concluding remarks</td>
<td>11</td>
</tr>
<tr>
<td>7. Acknowledgements</td>
<td>12</td>
</tr>
<tr>
<td>8. References</td>
<td>13</td>
</tr>
<tr>
<td>Annexe 1: Energy used by transport in the United Kingdom (1977)</td>
<td>27</td>
</tr>
<tr>
<td>Annexe 2: Instrumented car using microprocessors for energy studies</td>
<td>29</td>
</tr>
<tr>
<td>Annexe 3: Fuel consumption of diesel and petrol cars</td>
<td>32</td>
</tr>
<tr>
<td>Annexe 4: A guide to mechanical devices for the improvement of fuel economy</td>
<td>34</td>
</tr>
</tbody>
</table>

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RESEARCH ON FUEL CONSERVATION FOR CARS

ABSTRACT

Fuel conservation for cars is considered for the short-to-medium term period when natural oil is available, but becoming scarce and expensive.

Conservation measures are considered under three headings:

- driver performance
- vehicle design and operations
- road layout and traffic

Examples of potential fuel savings are given from TRRL and other research work. Driver education could perhaps save 10 to 15 per cent of car fuel, and a target fuel economy for a new car design is suggested as 50 miles per gallon, instead of the present 30 miles per gallon. Traffic management schemes to reduce congestion can make some contribution.

The value of research in fuel conservation is emphasised.

1. INTRODUCTION

Transport is not the largest sector of the economy in its use of primary energy, but transport, and road transport in particular, depends almost entirely on liquid fuels derived from natural oil. Because of the difficulties of substituting alternative fuels in the short-to-medium term, the share of oil used by road transport is likely to increase in the future as other sectors (domestic, industry) find substitutes. As Figure 1 shows, the fraction of oil used by road transport is, indeed, increasing, and is at present about one-quarter of the total. To put the figure in perspective, transport as a whole accounted for about 14 per cent of primary energy use in the United Kingdom in 1977, and road transport was the major user at 11 per cent of primary energy*. Thus road transport, though not a large user of energy, has at present a particular dependence on natural oil, which is expected to become increasingly scarce, and for which substitution is difficult.

This report is concerned with fuel conservation in internal combustion-engined cars in the short-to-medium term, when natural oil will still be available, but increased in price as it becomes scarcer. Department of Energy projections suggest that this period might extend to the end of this century when energy prices 'could well be more than double current levels in real terms'. For the car user, motor spirit price 'net of tax might be expected to increase by about 50 per cent in real terms by the year 2000'. While this order of price rise (in 1973) had only a small effect on use, the rise was quickly masked by general inflation, and it is, at the very least, possible that real price rises of 50 per cent or more, if sustained, will make conservation measures much more important.

* Figures for energy use are notoriously easy to misquote. These are based on TRRL leaflet LF 661 (Issue 2) which is reproduced as Annexe 1.
The private car must be a major consideration in conservation, as at present it consumes over 60 per cent of road transport fuel. While future demand for private car travel is uncertain, no forward projections show a decline in car ownership and use, and most indicate substantial increases by the end of the century\(^3\) (though the levels are lower than those projected a few years ago). The value of conservation in the use of fuel in cars is thus likely to increase in the future.

Conservation is taken here to mean performing the same (or very similar) transport task with the use of less fuel. This does not go into the arguments of alternative ways of performing the task, perhaps by public transport instead of private, but it does avoid the pitfall of 'conservation at any price'. This cannot be a reasonable objective. At one extreme it could lead to a 1600 miles per gallon car (Plate 1), which, though suitable for mileage marathons\(^4,11\) and extremely ingenious, bears little resemblance to the provider of transport for the family. At another extreme, it could lead to severe restrictions on private motoring, by petrol rationing, or banning private cars on alternative days: these measures are only acceptable in terms of crisis.

The aim is therefore to show how research can help to assess the potential for conserving fuel without reducing the quantity or quality of private car travel, and at a cost commensurate with the fuel saving. It must be noted that central Government may have different criteria for judging the value of conservation measures from those of individuals or commercial organisations. Central Government must judge a measure on the resource costs and benefits which flow from it (i.e. excluding the tax element). This approach must certainly include the effects of a possible future upward path of energy prices. If required, it can include weighting the prices to give extra emphasis to factors like resource depletion or security of supply. It is with cost-effective conservation measures that the rest of this report will deal.

2. RESEARCH INTO FUEL CONSERVATION

Four main factors interact to influence the fuel used on any particular car journey:

- Driver
- Vehicle
- Road system
- Traffic

These interactions, combined with the variation in performance of a particular driver or vehicle on different occasions, make it difficult to isolate the effect of any fuel-saving measure, and can make it difficult to assess in overall national terms the value of any measure. For example, the effect on fuel consumption of a driver aid which modifies the linkage between accelerator pedal and throttle is difficult to determine because of the interaction between vehicle, road system and traffic. The effect is also difficult to assess in national terms because it might be large with 'heavy-footed' drivers, but negligible with the 'light-footed'. The range of driver performance characteristics in the whole country therefore needs to be known before any total effect of the device can be estimated.

There is considerable information on the combined effect of two or three of the main factors operating together, but much less carefully measured data on the individual factors. For example, comparison between measurements of fuel consumption on cars in the Total Economy Run and as given in the motoring press might at first be taken to indicate the range of driver performance on fuel consumption (Figure 2). The results from the motoring press are roughly 50 per cent higher (in miles per gallon) than from the economy driving. But clearly the road system (test route) and the traffic conditions vary between the two tests, and there may also be differences in the standard of preparation of the cars, and the weather. The two sets of results are therefore difficult to compare in any precise way.
In the remainder of this report, the attempt is made to illustrate with more precision the effects of the individual factors on fuel consumption. The results are obtained from many sources, but many of them come from work at TRRL with instrumented vehicles, and with a computer model of car, driver and route.

The instrumented car which has been used for the past three years (Plate 2) is a Ford Escort 1300. It has transducers for measuring propeller shaft torque and speed, and throttle position as well as fuel flow rate. On-board data recording equipment preserves the information for further computer analysis, and also gives a visual display which allows the operator to observe, during the test run:—

- vehicle speed
- vehicle acceleration
- propeller shaft torque
- engine power output
- throttle opening
- engine efficiency
- fuel consumption.

A feature of the car is that it is able to be driven normally in ordinary traffic on public roads, and the instrumentation has no inhibiting effect on the way the car is driven.

Improved instrumentation, incorporating a microprocessor for on-board calculation of results, has been developed and installed in an Austin Allegro for future experimental work. (A brief description of the installation is given in Annexe 2).

Some results have also been obtained in trials in central London using light vans (based on the Bedford CF series) which have less complex instrumentation, but which are capable of giving comparative information on fuel consumption between petrol, diesel and battery electric versions of the same basic van design. These trials have been completed, and will be reported later.

The other new source of data is a computer model (or simulation) which represents the driver, the vehicle, and a simplified representation of the route, in a way which enables the fuel consumption to be calculated. A block diagram of the computer model is shown in Figure 3. It is essentially an analytical description of the characteristics of the driver/vehicle/route system, which is advanced in equal time steps to represent a journey.

In its present form, it has seven parameters which represent driver characteristics relevant to fuel consumption. The car’s acceleration is governed primarily by two parameters which characterise the driver’s determination to reach the permissible speed. The actual acceleration may well differ from that desired because of limitations imposed by the car, or more precisely by the way the driver is prepared to use the car. The car’s braking rate is controlled primarily by the driver’s anticipation parameter.

The driver’s use of the engine is represented by a personal operating region, reduced in size from the car engine’s allowable operating region according to three parameters:

- the proportion of the available maximum power that the driver is prepared to use,
- the minimum and maximum engine speeds the driver will use in the low speed (‘labouring’) region.

This personal engine operating region is illustrated in Figure 4.
The choice of gear and manipulation of the clutch in a manual transmission car are governed through an algorithm by the need to keep within the personal engine operating region, and also by the last parameter, the time taken to execute a gear change.

These seven driver behaviour parameters are all that is required in the model to describe a particular driver. From tests with a rather non-random selection of drivers (from the Laboratory staff) it appears that driver behaviour — as far as fuel consumption goes — can be represented quite well by this section of the model.

The vehicle part of the computer model takes the physical parameters of the car — rolling and aerodynamic resistance, vehicle mass, gear ratios and engine fuel map — and combines them in the usual equations of Newtonian mechanics. The need to represent manual gear changing is a complication here and in the driver section, but one that has been successfully incorporated. At present, the computer model has been set up to represent the Ford Escort 1300, so that comparison between the instrumented Escort and the model can be used for calibration purposes. However the great advantage of the computer model is that it can be modified fairly easily to represent other vehicles, or modifications to the Escort. This facility has been used in some of the results which are presented later.

Finally, the computer model has to represent a route over which the driver and car are taken, and preferably some representation of traffic conditions. This is the most difficult part to model realistically, and at present is only represented at an elementary level. If the route can be represented by a speed/time profile like the ECE 15 urban driving cycle (Figure 5), the model can ‘drive’ the car over this cycle accurately — but of course the characteristics of the driver have been entirely suppressed. The effect of traffic and junctions has also been frozen into the start-stop cycles. One change which has been developed in the computer model to improve the realism of the driver/vehicle interaction is to replace the closely defined profile, with its specified gear change points, with the concept of a ‘permissible speed’ profile. This now represents the route characteristics and traffic delays by a series of ‘square wave’ functions (Figure 5) which represent maximum permissible speeds at different parts of the route. Different drivers will then use the power of the car to different degrees to approach the permissible speed profile. In this way, driver characteristics again become important, the effect of different gear-change habits can be represented, and some of the less realistic features of fixed speed/time profiles* can be overcome.

The following sections bring together results from the instrumented vehicles, from the computer model, and from other sources to show quantitatively how different factors affect fuel conservation in cars.

3. DRIVER PERFORMANCE

The driver can affect fuel consumption on a journey by the way he drives over a particular route, reacts to other traffic, and by his style of driving. These aspects are illustrated by examples to show the numerical effect of driver performance variations, and so gain some insight into the savings that might be made, for example, by driver education.

The first diagram (Figure 6) shows the fuel consumption measured in the instrumented Escort on a test route 2.6 km long (with 11 junctions and 6 stops) laid out on the Small Road System in TRRL.

* For example, the apparently better fuel economy of some automatic transmissions compared with manual gear boxes.
During the tests all drivers were asked to drive around the test route in their normal way, and were given time to become accustomed to the car’s behaviour: each of the nine drivers drove ten times over the test route. No other traffic was present, and the results indicate the variation between different drivers, and the variation of performance of a particular driver on a number of occasions. It is interesting to see both the large difference (50 per cent) between the least and most economical driver, and also the differing consistency of different drivers (ranging from ± 1.4 per cent of the average to ± 14 per cent).

It must be stressed that the traffic-free conditions were artificial, and that the drivers were again a non-random selection of Laboratory staff, but it is tempting to perform the arithmetic to see what fuel savings might be possible if, say, the worst drivers were encouraged to improve their standard. By taking the average performance of the five best drivers instead of the whole sample, an improvement of 8 per cent in fuel consumption is possible. This is, of course, an illustration only: the danger of extrapolating from limited tests to national totals is too obvious to need emphasis.

The benefits from economical driving are obvious: the penalties may be a longer time taken for the journey, and possibly more stress on the vehicle if the driving style involves a lot of low speed, top gear driving. However, the driver may suffer from less stress, and may then not rate the longer journey time as a penalty.

Driving habits can influence fuel consumption in many ways. Ten years ago Everall measured the effect on fuel consumption and average speed by asking drivers to drive in different ways over a route in ordinary traffic. The route was partly urban, partly rural and the ‘normal’ average speed was about 50 km/h. The drivers were asked to drive normally, and then ‘as economically as possible’ and finally ‘as if you were in a hurry’. The results, for a small car, showed that average speed and fuel consumption were both about 12 per cent greater than normal when driving fast, and about 12 per cent less when driving economically.

Another way of looking at driving habits is to examine the fuel used during acceleration from rest. Using the computer model of the Escort, the fuel used to accelerate at various rates from rest up to 60 km/h (and travel a fixed total distance) have been calculated (Figure 7). It is clear that on this car there are penalties for hard acceleration, and an optimum value (at about 0.07g) which, perhaps by coincidence, is close to the measured average value used by the drivers from the Laboratory in tests quoted earlier.

Taking this a stage further, the fuel used for a start to stop cycle of 0.2 km has been calculated for ‘gentle’ acceleration and braking, and for ‘hard’ acceleration and braking. The fuel used in the ‘hard’ case is 2.1 times that in the ‘gentle’ — but the trade off with time taken is almost as striking, as the ‘hard’ case takes only 57 per cent of the time taken by the ‘gentle’ driver. As so often in fuel conservation, there are balances to be struck, but bearing in mind the extra wear and tear on the car in the ‘hard’ driving, it seems likely that the balance would favour gentle driving and fuel saving.

A last example of driving habits is the effect of varying the instantaneous speed above the average on a rural road or motorway. The computer model for the Escort shows (Figure 8) the effect of a ± 5 km/h variation with a period of about 20 seconds. The engine characteristics make this quite wasteful at around 40 km/h with a 30 per cent increase in fuel used compared with steady running, and aerodynamic drag contributes to the increase of 20 per cent at 120 km/h. Speed ‘hunting’ of this kind is believed to be quite common, both in urban and rural driving, and it could point to benefits to be obtained from cruise speed.
control devices which are commercially available. Whether the benefits outweigh the costs must be determined by the individual driver on the basis of the mileage that he drives on roads where the device could be used.

A cruise speed control is one example of a driver aid to economical driving. There are a large number of others, and those on the American market have been listed and tested extensively. TRRL has not attempted to test all the devices which are commercially available, but some preliminary tests have been made on examples of two types of aid, more with the aim of examining the problems in test technique than in the expectation that they would be very beneficial. In tests on one device (a vacuum indicator lamp) the variability between drivers and between traffic conditions on different tests made it difficult to determine whether the indicator had any effect at all. The other device modified the linkage between accelerator pedal and throttle in a way which was influenced by manifold vacuum. The test results showed that use of this modification lead to a small saving in fuel used (about 5 per cent) though at the expense of lower acceleration performance and increased journey time. The value of some types of driver aid is, perhaps, questionable as they could easily lead to driving habits which are unsafe. For example, an aid in the form of an instantaneous fuel flow meter might encourage drivers to drive more slowly on motorways, but they would also indicate that it saved fuel at the higher speed to drive a car close behind a heavy lorry, and benefit from aerodynamic drag reduction. On the whole, the kind of driver aid which modifies the car performance directly, rather than gives an indication to the driver, seems preferable, even though there is likely to be a trade-off between economising on fuel and some other aspect of car performance.

Finally, there is one case where knowledge of the high fuel consumption could deter the driver from using his car at all. Measurements on the instrumented Escort of short journeys with a cold engine (Figure 9) illustrate very dramatically the low fuel economy which results. For a 1 mile journey only half the fully warmed-up miles per gallon is obtained: for a 2-mile journey less than 60 per cent. Other work reported for American cars showed that some 12 miles of running (even at an ambient temperature of 21°C) was required to reach 90 per cent of the fully warmed-up fuel economy. This is perhaps the case where for energy and health reasons it is better to leave the car at home and walk the short distance.

4. VEHICLE DESIGN AND OPERATION

This section attempts to indicate the order of magnitude of fuel conservation that is possible in the car as used at the moment. The starting point is the flow of energy through the vehicle as it is driven on urban and other roads, and calculations with the computer model will give the sensitivity to various design changes like reduction of weight, of rolling resistance and of aerodynamic resistance for both urban and rural driving. The effect of other changes will be discussed, but in a more general way. It is not the intention here to go into details of engineering design but rather to set out a framework within which potential improvements in fuel economy can be assessed.

The first of a series of graphs (Figure 10) shows the sensitivity of fuel consumption to vehicle mass. The basic case is again the Ford Escort, taken as a typical European medium sized car, and the computer model has been used to estimate the change in fuel consumption with change in vehicle gross mass for two types of driving. The first is the urban (congested) condition represented by the urban cycle of ECE 15 (Figure 5). The second is rural (uncongested) driving represented by the 90 km/h steady speed specification, again from ECE 15. At present in this country, driving on urban roads represents 50 per cent of total car kilometres, the rest being on rural roads or motorways. The relative importance of the urban and rural results shown in Figure 10 can therefore be easily judged.
As expected, vehicle mass is rather more important in the start/stop urban traffic, where a 20 per cent saving would yield a saving of 6 per cent in fuel consumption: the steady speed rural driving would yield about a 4 per cent saving.

The result for urban driving is very dependent on the particular driving cycle used. ECE 15 is characterised by gentle acceleration (0–50 km/h in 26 seconds) and braking, by long periods spent stationary (60 seconds out of 195 seconds), and by a low average speed — less than 19 km/h — and these factors tend to reduce the importance of vehicle mass. Other driving cycles could indicate a greater sensitivity to mass in urban conditions.

Similar graphs, calculated in the same way (Figures 11 and 12) show the effect of reductions in rolling resistance and in aerodynamic drag. For rolling resistance, the difference between urban and rural driving is quite small, and a 20 per cent reduction would give about a 3 per cent saving of fuel. For aerodynamic drag, the effect on fuel consumption in the urban driving cycle is slight, as expected with the maximum speed limited to 50 km/h. The rural (90 km/h) case indicates that a 20 per cent reduction in drag would save about 6 per cent of fuel. These relatively small savings for the car contrast with the larger potential for fuel economy by drag reduction with the heavy goods vehicle.

The examples given so far relate to the car design excluding engine and transmission, and the potential for fuel saving is quite modest. Even if all the exemplary 20 per cent savings were achieved, the net saving of fuel used overall in the mix of urban and rural driving would only be about 10 per cent. The next paragraphs therefore deal with the more complex area of engine and transmission, where larger gains may be possible.

The first example (Figure 13) examines how the choice of final drive ratio can affect fuel consumption. This seems a very straightforward matter, but in fact has a number of subtleties when considering urban driving. The steady-speed rural driving example is clear: reducing the final drive ratio (giving a higher road speed for a given engine speed) reduces fuel consumption. This is the well known overdrive effect, and gains of 10 per cent on fuel consumption are easily possible, though with some reduction in top gear flexibility.

In urban driving, the closely defined ECE 15 urban cycle suggests the same result — though the fuel gain for a given ratio change is less. However, if the driver is given freedom to select appropriate gear change points (by defining the driving cycle in terms of 'permissible speed') the effect of final gear ratio is much less. A higher overall gear ratio may even cause more fuel to be used, because the driver stays longer in a lower gear. These results are, of course, specific to the Escort 1300, and should not be taken to apply to all cars, but they illustrate the fact that the selection of an optimum gearing for a car is quite complex.

If optimum overall gearing is complex, the designers choice of engine size, power and torque characteristics and intermediate gear ratios is obviously an order more difficult. The new question is whether design for better fuel consumption would lead to different solutions from the ones based in the past more on optimising road performance. If the possibility of developing efficient and durable infinitely variable gears for the medium sized car is included, the area is one where research studies are needed to indicate the size of the possible gains — and, of course, the penalties which may be paid in terms of road performance and increased cost.
The largest single change in car design for fuel economy is likely to come from the replacement of the present petrol engine with a higher efficiency engine like the light-weight diesel. Diesel engines for cars and taxis have, of course, been available for many years and their virtues of fuel saving under part load conditions are well known. But these diesels have been available in the larger engine sizes, and have tended to be heavier and slower running than the petrol engine of the same power. A significant development has now been made by Volkswagen in the design of a light-weight 1500 cc diesel engine for the small Golf car. The road performance of this car is almost identical with that of the 1100 cc petrol-engined version and in terms of 'driveability' it is difficult to fault. The diesel is still slightly heavier than the equivalent petrol engine, and the overall gearing has been changed to match the different characteristics, but fuel economy (on a volumetric basis) 40 to 70 per cent better than the petrol engine version has been shown in tests at TRRL. This suggests that there could be an improvement of about 50 per cent in miles per gallon in mixed urban and rural driving. Preliminary results are given in Annexe 3, and a full evaluation of the results from the particular cars is being carried out. For other cars, the gains may be smaller, but 25 to 30 per cent should be possible by changing to a higher efficiency engine.

Finally, from a large potential gain to a smaller one, the penalties in fuel consumption from poorly maintained vehicles are not negligible. A number of studies have been carried out which point to the importance of idling mixture strength and ignition timing in overall fuel economy. The latter should be improved by the more widespread adoption of electronic ignition which remains 'in tune' for longer than the mechanical kind. The importance of idling mixture strength can be illustrated by measurements on the instrumented Escort in heavy Glasgow traffic. The engine was idling for 40 per cent of the time of the test run, and 18 per cent of the total fuel was used at engine idling conditions. These results are in broad agreement with others, and give some indication of how maladjustment at idling can affect overall fuel consumption in urban conditions. Carburettors now have sealed idling settings for emission control purposes, and this should go some way to eliminating fuel wastage from bad adjustment.

With the present mix of cars, badly maintained examples can have their consumption improved by 20 per cent, but a more realistic fleet average might be a 5 per cent improvement, achievable by development already in hand.

This section has examined the potential for fuel economy in the present car, and it is tempting to bring the different figures together to give an economy target. This economy car would be lighter, but not smaller, than today's medium size car and would have a road performance comparable with the present average. With this admittedly rather imprecise goal, the preceding figures could indicate savings in miles per gallon of:

| Reduced weight, drag and rolling resistance | 10 per cent |
| Matching of engine and transmission for fuel saving | 10 per cent |
| Change to higher efficiency engine | 25 per cent |
| Reduction of out-of-tune conditions | 5 per cent |

* The empty weight of the diesel car is about 50 kg greater than the petrol car as tested.
† This is rather different from the concept of a low performance 'eco-car' proposed by Wilson and Tee and others.
Overall, these fairly modest individual improvements could combine to give a car with a fuel consumption in mixed urban and rural driving reduced to less than 60 per cent of today’s average — say from 10 to 61/100 km (or improving fuel economy from roughly 30 to 50 miles per gallon). Other authorities have suggested even greater possible gains, so that the 60 per cent value can perhaps be regarded as an achievable target.

No credit has been taken for the use of fuel-saving inventions in achieving the target: this is because, in spite of their proliferation, experience has tended to show that many of the savings are produced at the expense of other aspects of performance. It is, of course, essential to compare like-with-like in evaluating fuel savings as with anything else. An authoritative view on such devices is quoted in Annexe 4 (from reference 11, p 243).

So far, there has been no discussion of the costs of achieving the target fuel consumption, and some rough calculations may be useful. They will be made from a national resource viewpoint, excluding taxation as a transfer payment, and will consider the effect of increasing the fuel economy of a car from 30 to 50 miles per gallon. The average motorist, driving 9000 miles in a year would save about 120 gallons of fuel every year with the more economical car. The present (June 1979) price (excluding tax) of petrol or diesel at the pumps is around 50–60p per gallon. Taking the upper value as representing the price of petrol or derv, the average motorist would save £72 each year. For a 10-year vehicle life at a discount rate of 10 per cent this saving would be balanced by an increase in first cost of the car of about £440. So to be worthwhile in notional terms for the average mileage driver, the improvement to the vehicle must be obtained at less than this cost*. Of course, the individual motorist would do his (personal) calculation including taxation, and would see a greater saving in fuel price to offset any increase in vehicle first cost — though he might wish to see the return on the extra first cost in only a few years instead of over the car’s whole life. This effect of taxation on fuel could in some cases encourage the lower mileage driver to invest in, say, a diesel car, when the national interest calculation showed a disbenefit. Such a possibility points to the need for very careful assessment of the effects of taxation on motor fuel, especially if it were proposed to use a tax differential as a way of encouraging the use of diesel cars.

5. ROAD LAYOUT AND TRAFFIC

Previous sections have discussed, in fuel economy terms, the role of the driver as the controller of the journey, and of the vehicle as a piece of engineering. This section considers the road system and other traffic as the setting in which the driver and vehicle operate. This is a difficult area for the derivation of numerical results: it needs either major experiments with numbers of instrumented cars, or a modelling or simulation technique which can realistically represent the effect of (particularly) urban traffic. It has been noted earlier that the computer model as presently developed has only a rather rudimentary representation of other traffic, and so the approach here is to select examples of road layout and traffic effects and see whether general conclusions can be drawn.

It is a commonplace experience that, on a particular route, the heavier the traffic the slower the journey and the higher the fuel consumption. An example from tests with a petrol engined light van in central London gives numerical force to this experience. In light traffic, the average speed for a 2.2 km journey was nearly 30 km/h, while in heavy traffic on the same route the speed had dropped to about

* As an example, the difference in ex-tax price between the VW Golf LD (1.5 diesel) and Golf L (1.1 petrol) is around £580. It is not possible to quote the difference in resource cost.
20 km/h and the average fuel consumption had increased by nearly 25 per cent. These results are averages of five test runs in each condition all with one driver. The variability of fuel consumption (ratio of standard deviation to average) was almost the same for both traffic conditions.

The same trend of speed and fuel consumption has been measured many times and is shown graphically\(^7\) (Figure 14) over the range of average speeds from low values on congested roads to higher speeds where traffic has little effect. One conclusion to be drawn from these measurements is that methods of traffic management which increase the average speed of urban traffic (up to around 50 km/h) tend also to reduce the fuel used*. This happy combination of reduced journey time and fuel saved is unusual enough to be worth noting, and has led to a rule-of-thumb for urban traffic management that saving 10 per cent on journey time saves about 7 per cent on fuel used\(^7\).

The beneficial effect of general traffic management prompted the question of whether specific adjustments to an existing scheme could increase fuel savings still further. The area traffic control network in central Glasgow was used in a series of experiments (with the full cooperation of the traffic authorities) where the strategy for traffic light control was changed from settings to minimise delay to ones which minimised number of stops. The reasoning was that a minimum delay strategy could give a low journey time, but be associated with a number of short duration stops which wasted fuel: minimising stops could save fuel at the expense of journey time. The two strategies were monitored by a number of cars fitted with fuel measuring equipment and following 'typical' routes through the city. The results showed that the minimum stop strategy did indeed save fuel, but the amount and the effect on journey time varied on different test routes. With one car used on two routes, a 6 per cent saving in fuel consumption was recorded with an insignificant increase in journey time\(^5\). With different cars on other routes, the saving in fuel was about 3 per cent with a 3 per cent reduction in journey time\(^16\). This overall reduction in journey time was surprising even though changes were small and significant in only one of the four test periods. The conclusion from this piece of work is that ‘fine tuning’ of area traffic light strategies is possible to give small fuel savings without significantly increasing journey times. The TRANSYT method\(^17\) of optimising traffic signal settings, which is available from TRRL, can be used for this purpose without modification.

Turning now to road improvement schemes, the Department of Transport Cost Benefit Analysis method of evaluation (COBA)\(^18\) is used to help compare alternatives, and to rank projects in terms of net present value to cost ratio. The calculations made in the analysis include vehicle operating costs, which in turn include the contribution from fuel. It is therefore possible, in principle, to identify the fuel element of the costs and benefits of road schemes, and to give them further weighting for future prices. In fact, the current version of COBA does not allow this to be done, but a revised version is in preparation.

It is not certain that even very much higher fuel costs would make significant changes in the selection of road schemes. In the vehicle operating cost formulae, fuel cost for cars accounts typically for 50–60 per cent of the total, but in a sample of 25 schemes evaluated for the Leitch Committee\(^2\), operating cost savings only accounted on average for 11 per cent of the benefits. Junction benefits, link time and accident saving made up the rest. Though particular schemes may have a much larger fuel cost element, it seems likely that selection of road improvements will continue to be largely influenced by the balance between construction costs and time saving benefits. This is a matter which may well merit systematic study when the revised version of COBA is available.

* Though the saving may be offset by a longer distance travelled in extensive one-way systems.
† Robertson, D I – private communication.
Two final examples are given which relate to the operation of the road system, rather than its design or traffic flow. The first is the introduction of speed limits for conserving fuel on motorways and rural roads. Experience in this country in the fuel crisis of 1973/74 was that the 50 mile/h limit was complied with reasonably well during the period when petrol was difficult to buy, but as supplies became easier the limits were exceeded widely. The mean speed of cars measured on M3 and M4 was 54 mile/h in December 1973 with only 1 per cent exceeding 70 mile/h. By February 1974 the mean had increased to 60 mile/h and 13 per cent exceeded 70 mile/h, even though the 50 mile/h limit was still in force.

Saving of fuel was not monitored directly, but estimates from American work suggest that savings for cars were unlikely to be greater than 2.5 per cent of total car fuel, even for 100 per cent compliance with a 55 mile/h limit. However, in the United Kingdom there were significant reductions in accident rates on motorways and all-purpose roads when the 50 mile/h limit was obeyed.

Although the effect of speed limits on fuel consumption appears fairly small, there has been an observed change recently in the speed of cars on motorways, which is not associated with alterations in speed limits. The mean speed of cars in 1976 was 66.5 mile/h (with 36 per cent exceeding 70 mile/h) which was almost identical to results in early 1973. It appears that the long-established upward trend in motorway speeds has been interrupted and this appears to be at least partly attributable to increases in petrol prices. It is suggested that if prices maintain the present relative level, future speed distributions may be substantially constant. It is not impossible that an increase in the real price of petrol could lead to a reduction of the speed of cars on motorways, and thus to a saving of fuel. More recent evidence in a situation of reduced real price of petrol is inconclusive, but preliminary results show more tendency for speeds to rise than to fall.

The second example is the potential saving from better route guidance for drivers so that the shortest route is always chosen. Some tests by TRRL have suggested that 4 per cent of route kilometres are unnecessary, and that about three-quarters of the wasted distance could in principle be 'recovered' by improving road signs, improving maps, or providing an automatic route guidance system. The first estimates of costs and benefits were sufficiently encouraging to justify further investigation of the nature of the annual wastage in vehicle kilometres and of the features of an appropriate electronic guidance system. Clearly the extent to which the 'wasted' 3 per cent of vehicle travel is recovered will depend on the success achieved in encouraging drivers to use better route aids, and their willingness to forego favourite routes. It is not immediately obvious, either, that the shorter routes will save fuel proportionately: they might run through areas of greater traffic congestion. Nevertheless the possible savings in fuel and other vehicle operating costs make route guidance worth further study.

6. CONCLUDING REMARKS

One common thread which connects fuel conservation by driver performance, vehicle design and road systems is the need to balance the value of conservation against other competing factors. For the driver, an economy style of driving may lead to longer journey times, and less individual expression through the scream of tyres on asphalt. For the car designer, there is a trade-off between fuel economy and cost, and often between fuel economy and exhaust emission. Even safety features, by affecting vehicle shape and weight, can influence fuel consumption. Urban traffic management and road improvement schemes seem to be areas where fuel saving and other benefits (like time saving) can be achieved together. Clearly fuel conservation in road transport cannot be an ultimate end in itself, but must reflect the present and future cost and supply...
of fuel so that savings are greater than any penalties. As an aside, it may be noted that the historical high fuel tax in this country and Europe generally must already have influenced the design of cars and the individual drivers' choice of car and driving style more than the past resource cost of fuel would have done. By comparison, say, with the United States, European car designers and drivers have been more conscious of fuel consumption for many years, and there is therefore rather less scope for dramatic changes. In fact, another thread running through the results is that, except for the change of engine, individual factors constitute only 10 per cent improvements, or less.

Nevertheless, the discussion of driver performance has indicated where savings can still be made, if drivers can be made aware of good driving habits. Moderate acceleration, anticipation of braking, and travelling at moderate speeds all contribute to fuel saving without large other penalties. Travelling at off-peak times to avoid congestion and not using the car for very short journeys can also save fuel, but with some obvious reduction of convenience to the traveller. It is difficult to quantify the savings, but an informed guess suggests that eliminating the least economical practices could save nationally the order of 10–15 per cent of car fuel.

This is a smaller saving than could be achieved in vehicle design by the major step of changing from petrol to diesel or other high efficiency engines. Other changes in design, and improvement in the state of maintenance could together lead to a car with a fuel consumption only 60 per cent of today's. Whether this can be done at a cost commensurate with the saving needs further detailed investigation.

The potential savings from changes to the road system seem likely to come mainly from increasing capacity in urban areas so that average speeds, kept low by congestion, increase. Fortunately in this case, fuel saving and other quantified benefits tend to increase together, though if more traffic fills the increased capacity, the saving will be eroded.

One further common thread, this time technical, has emerged in quantifying the driver and vehicle fuel saving. This is the importance of the particular driving cycle used for fuel conservation estimates. The results in this report are largely based on ECE 15 regulations, modified for urban traffic by allowing the driver some freedom in driving habits. However, the detailed results might be different if other cycles were used, and further study and research is proceeding into the sensitivity to type of cycle*.

Finally, additional legislative means, for example, by selective vehicle or fuel tax or by setting regulatory minimum miles per gallon targets for manufacturers†, may also be necessary. Research can help to ensure that the effects of legislation can be predicted and understood.

7. ACKNOWLEDGEMENTS

The work described in this report was carried out in the Assessment Division of the Transport Systems Department of TRRL. The authors are grateful for the help received from other members of the Division.

A shorter version was presented at the Symposium on Energy and Road Transport held at TRRL in April 197826.

* It is relevant to note that the US Department of Energy has abandoned the combined highway and city mpg figure as being unrepresentative of average fuel economy in real driving24.

† A recent publication25 lends some weight to advisory fuel consumption targets for cars.
8. REFERENCES


Fig. 1 TRENDS IN PETROLEUM CONSUMPTION IN THE UNITED KINGDOM
Fig. 2. PETROL ECONOMY OF MODERN CARS
Fig. 3 SIMPLIFIED VEHICLE/DRIVER MODEL
Fig. 4 PERSONAL ENGINE OPERATING REGION FOR A DRIVER
Drivers

Fig. 6  EFFECT OF DRIVER BEHAVIOUR ON FUEL CONSUMPTION

Fig. 7  EFFECT OF ACCELERATION RATE ON FUEL CONSUMPTION
Fig. 8 EFFECT OF POOR SPEED CONTROL

Fig. 9 URBAN COLD-START FUEL ECONOMY (ESCORT 1300)
Fig. 10 EFFECT OF CHANGING VEHICLE MASS

Fig. 11 EFFECT OF CHANGING ROLLING DRAG COEFFICIENT
Fig. 12 EFFECT OF CHANGING AERODYNAMIC DRAG COEFFICIENT

Fig. 13 EFFECT OF CHANGING FINAL DRIVE RATIO
Fig. 14 THE FUEL CONSUMPTION OF A SMALL CAR
(after EVERALL 1968)
Plate 2 INSTRUMENTED FORD ESCORT 1300
ANNEXE 1
ENERGY USED BY TRANSPORT IN THE UNITED KINGDOM (1977)

COAL 35%  PETROLEUM 43%  OTHERS 22%

Production of electricity etc.  Industry  Road transport  Other transport  Other fuel use  Non-fuel uses  Refinery losses

Cars  Light goods vehicles  Heavy goods vehicles  Other
### A1.1. The consumption of primary energy in 1977 was:

<table>
<thead>
<tr>
<th></th>
<th>$10^6$ tonnes of oil</th>
<th>$10^{18}$ joules</th>
<th>Per cent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>72.2</td>
<td>3.24</td>
<td>34.5</td>
</tr>
<tr>
<td>Petroleum (inc. non energy use)</td>
<td>90.5</td>
<td>4.06</td>
<td>43.3</td>
</tr>
<tr>
<td>Natural gas</td>
<td>36.9</td>
<td>1.65</td>
<td>17.6</td>
</tr>
<tr>
<td>Hydro electricity</td>
<td>1.3</td>
<td>0.06</td>
<td>0.6</td>
</tr>
<tr>
<td>Nuclear electricity</td>
<td>8.3</td>
<td>0.37</td>
<td>3.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>209.2</strong></td>
<td><strong>9.38</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

### A1.2. The consumption of refined petroleum products

<table>
<thead>
<tr>
<th></th>
<th>Million tonnes</th>
<th>Per cent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Products used as fuels</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary energy products</td>
<td>11.2</td>
<td>12.4</td>
</tr>
<tr>
<td>Industry</td>
<td>20.6</td>
<td>22.8</td>
</tr>
<tr>
<td>Road transport</td>
<td>23.0</td>
<td>25.4</td>
</tr>
<tr>
<td>Other transport:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rail</td>
<td>0.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Water</td>
<td>1.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Air</td>
<td>4.2</td>
<td>4.6</td>
</tr>
<tr>
<td>Other fuels</td>
<td>11.9</td>
<td>13.1</td>
</tr>
<tr>
<td>Total products used as fuels</td>
<td>73.0</td>
<td>80.6</td>
</tr>
<tr>
<td>Products not used as fuels</td>
<td>10.2</td>
<td>11.3</td>
</tr>
<tr>
<td>Total deliveries</td>
<td>83.2</td>
<td>91.9</td>
</tr>
<tr>
<td><strong>Losses and use in refineries</strong></td>
<td>7.3</td>
<td>8.1</td>
</tr>
<tr>
<td><strong>Total consumption</strong></td>
<td>90.5</td>
<td>100.0</td>
</tr>
</tbody>
</table>

### A1.3. Fuel for road transport is delivered as motor spirit (petrol) or derv.

The consumption of road transport fuel by type of vehicle was estimated as:

<table>
<thead>
<tr>
<th></th>
<th>Thousand tonnes</th>
<th>Per cent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars and Motorcycles</td>
<td>14525</td>
<td>63.0</td>
</tr>
<tr>
<td>(Light) goods vehicles</td>
<td>2515</td>
<td>10.9</td>
</tr>
<tr>
<td>Other</td>
<td>296</td>
<td>1.3</td>
</tr>
<tr>
<td>Total deliveries of motor spirit</td>
<td>17336</td>
<td>75.2</td>
</tr>
<tr>
<td>(Heavy) goods vehicles</td>
<td>4709</td>
<td>20.4</td>
</tr>
<tr>
<td>Other</td>
<td>1002</td>
<td>4.4</td>
</tr>
<tr>
<td>Total deliveries of derv</td>
<td>5711</td>
<td>24.8</td>
</tr>
<tr>
<td><strong>Total deliveries</strong></td>
<td><strong>23047</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>
ANNEXE 2
INSTRUMENTED CAR USING MICROPROCESSORS FOR ENERGY STUDIES

Declining natural oil reserves have highlighted the need for conservation. The private car uses about 16 per cent of the total petroleum consumed in the UK and worthwhile savings may be achieved by studying the use of fuel during normal driving. To analyse this effect, a modern front-wheel drive car, an Austin Allegro, has been fitted with transducers and an Intel 8080 microprocessor.

END OF RUN

| JURATION | 290.2 SECS |
| DISTANCE | 2.314 KM |
| TOT. FUEL | 0.211 LITR |
| AV SPEED | 88.71 KPH |
| AVL CON | 9.12 L/100 |
| AV TEMP | 73.9 C |
| AV THROT | -60.5 DEGS |
| STOPS | 7 |
| STOPS/KM | 3.025 |
| AV ENG | 14.54 % |
| AV LOC | 7.76 N/WH |
| AV POWER | 3.70 KW |
| T. ENGY | 0.238 KWI |
| T. ENGY X | 0.270 KWI |

Interior of Allegro showing hand-held unit, printer and logger

Thermal printout

Instrumentation

Transducers monitor the following primary variables.

- Torque: Strain gauge bridges on drive shafts coupled by radio telemetry link
- Road Speed: A Hall effect magnetic transducer responding to a toothed disc on the drive shafts
- Engine Speed: Similar instrumentation to road speed measurement but fitted to crankshaft extension
- Engine Temperature: A thermocouple with the sensor immersed in the engine coolant
- Fuel Consumption: A ‘Transflo’ displacement type meter
- Throttle Angle: A rotary variable differential transformer coupled to the carburettor butterfly shaft.

A signal conditioning unit digitizes this information from which the microprocessor derives 22 items of test data according to the flow chart of Figure A2.1.
Microprocessor

The Intel 8080 is controlled by a small hand-held display and keypad allowing calibration and operation from the front passenger seat.

Any one of 22 variables may be displayed on the hand unit and observed whilst the vehicle is in motion. At the completion of the test the full summary of test data is presented by a thermal printer built into the dash of the car. At any time during the test, the user may, by selecting the sample button, obtain an immediate print out of 14 selected items of test data. This feature enables transient values, for example, engine revs, or vehicle acceleration, to be recorded. The memory capacity of the microprocessor enables up to five data summaries to be stored and subsequently printed out. A data logger is also fitted, and enables a computer compatible record on cassette tape to be made of the primary variables during the run for subsequent analysis on a main frame.

Calibration

Calibration of the system is carried out automatically as part of the software package. At commencement of the test, after a brief warm up period, the hand-held display indicates that calibration is required. With the car stationary and engine off, the user, by initiating 'calibrate' causes the microprocessor to compensate for drift in transducer quiescent readings. These bias values are stored and subsequently used as zero bias when deriving the test data.

FIGURE A2.1 Instrumented Allegro schematic of on-board data processing
Application

The instrumented car has been used to study the influence drivers can have on fuel consumption. The car will provide data to calibrate and validate a computer model of car driving and energy flow, and act as a research tool for engine management and traffic engineering studies.
ANNEXE 3
FUEL CONSUMPTION OF DIESEL AND PETROL CARS

Background

Diesel engines are considerably more efficient in their use of fuel than petrol engines, and they have been extensively used in the UK where fuel costs are a substantial part of total costs (e.g., in heavy goods vehicles, and in taxis). In other countries, where diesel fuel is cheaper than petrol because of tax policy, they have been used in the larger private cars (like the Mercedes).

However, in the past their use in smaller private cars has been minimal, partly because for the same power output they are more expensive in first cost and (in public opinion at least) noisier, and under some conditions more difficult to start than petrol-engined cars.

Recently, technical developments have considerably improved the general acceptability of the small diesel car. Using a Ricardo combustion chamber, Volkswagen in Germany has put into production a 1500 cc diesel engine based on the cylinder block, pistons, and crankshaft of a production petrol engine. The aim, which has been largely successful, has been to provide the power output and 'driveability' of the 1100 cc petrol engine, with the outstanding fuel economy of the diesel. The diesel engine is fitted to one version of the VW Golf, and although the initial price is higher than the smaller petrol-engined version, claims are made of longer engine life, and lower maintenance cost as well as much reduced fuel consumption.

The Laboratory's main interest is to investigate the total resource cost of buying and operating diesel cars, when compared with the equivalent petrol cars. The saving of fuel may have to be balanced against greater cost of manufacture, though this may be off-set by longer life and lower maintenance.

Trials have therefore been carried out with two VW Golf cars, the 1500 cc diesel and the 1100 cc petrol, which have near-identical road performance. The objective was to measure the fuel consumption as a function of type of road and traffic conditions, and as influenced by different drivers. The work therefore supplements the kind of road tests already carried out by the motoring press, and should give added precision to the results.

The Trials

Two test routes were chosen, one from Crowthorne to London using the M4 motorway and one in central London. Each route was divided into six sections to cover different road types and traffic conditions. The cars were driven over the routes each day for a six week period; the time, distance and fuel used for each section were recorded. The trials covered a range of drivers, loads, traffic and weather. The routes were perhaps more typical of commuting and of business use in London than of private motoring in general.

Results

Table A3.1 shows some preliminary results (which may be revised) for the vehicles with two passengers. For a load equivalent to five passengers the fuel consumption increased by about 10 per cent. The effect of different drivers on fuel consumption is shown in the Figure. These results show that, overall, drivers varied the fuel consumption by about 10 per cent. A full report of the trials is being prepared for publication.
### A3.1. Summary of fuel economy (mpg)

<table>
<thead>
<tr>
<th>Route Type</th>
<th>Diesel</th>
<th>Petrol</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central London</td>
<td>33.4</td>
<td>19.8</td>
<td>1.68</td>
</tr>
<tr>
<td>Crowthorne–London</td>
<td>45.6</td>
<td>31.7</td>
<td>1.44</td>
</tr>
</tbody>
</table>

![Graph showing average fuel economy for different routes and drivers.](image-url)
ANNEXE 4
A GUIDE TO MECHANICAL DEVICES FOR THE
IMPROVEMENT OF FUEL ECONOMY

It is not possible to cover the plethora of fuel-saving inventions individually. The patent literature over the last fifty years is replete with devices, the claims for which are frequently far in excess of their ability to perform, and many inventors' devices have disappeared as fast as they arrived.

However, there are some that do give real effects, though not always straightforwardly. The following guidelines are offered to help the reader give some semblance of order to this ongoing activity.

(a) The device may be entirely bogus.
(b) It may (and often does) cost more than the fuel it will save.
(c) It may (and usually will) alter the tune of the engine: it may exchange power for economy (eg mixture weakeners); it may exchange noise for economy (eg straight-through silencers); it may exchange emissions for economy (eg spark advance devices).
(d) It may affect the way the car is driven (but giving, of course, a valid economy gain): compulsorily (eg throttle dampers); optionally (eg vacuum gauges, speed alarms).
(e) It may affect the heat balance of the engine (eg electric fans, radiator blinds).
(f) It may restore a worn or off-specification part that could perhaps be equally well replaced with a standard item (eg ignition boosting systems).
(g) It may have considerable deleterious side effects (eg mixture weakeners will seriously harm driveability and startability; heat balance changes may affect knock or run-on).
(h) It may make a genuine change in a feature of the engine, but one which does not affect fuel economy significantly (eg fuel atomizers improve mixture quality, but unless the mixture strength is weakened no fuel economy benefit can be seen).
(i) It might indeed be what all others have failed to understand and what the industry thus far has failed to produce: something that gives a genuine increase in economy over that of a well-functioning engine without prejudice to any aspect of performance.

Research on fuel conservation for cars: M H L Waters and I B Laker: Department of the Environment Department of Transport, TRRL Laboratory Report 921: Crowthorne, 1980 (Transport and Road Research Laboratory). Fuel conservation for cars is considered for the short-to-medium term period when natural oil is available, but becoming scarce and expensive.

Conservation measures are considered under three headings:—
driver performance: vehicle design and operations: road layout and traffic.

Examples of potential fuel savings are given from TRRL and other research work. Driver education could perhaps save 10 to 15 per cent of car fuel, and a target fuel economy for a new car design is suggested as 50 miles per gallon, instead of the present 30 miles per gallon. Traffic management schemes to reduce congestion can make some contribution.

The value of research in fuel conservation is emphasised.

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