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MEASURING THE BENEFITS GAINED BY INDUSTRY FROM ROAD NETWORK IMPROVEMENTS

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1. BACKGROUND

Over the last twenty years, physical distribution has gone through a revolution (McKinnon 1989). Changes in industrial structure, the power structure within the supply chain, service quality standards, marketing and production methods, heavy goods vehicle productivity and capacity, and road network quality have all played a part. External factors such as high real interest rates have made firms acutely sensitive to the costs of holding inventory and to the scope for inventory rationalisation.

The purpose of this study is to examine the contribution of road network improvement to the restructuring of physical distribution. There is a particular policy context to this. At a political level, the Government attaches prime importance to the effects of road investment on economic growth (DTp 1989). But at the level of economic appraisal, it is questionable whether the Department of Transport's (DoT) procedures give adequate weight to the benefits to industry of road network improvements.

The D.o.T. currently take account of the direct savings which accrue from road improvement schemes (Dawson and Vass 1974)(DTp 1981). This allows for changes in mileage related and time related operating costs, including depreciation, based on the simple assumption that time savings are translated fully into proportionate increases in utilisation of vehicles and crews (Nash 1974).

Although at first sight, the existence of scheduling indivisibilities and delivery time constraints might be thought to make this assumption unrealistic, such evidence as there is suggests that it is not an unreasonable rule of thumb (Mackie and Simon 1986).

Economic theory suggests that in addition to the direct transport cost savings from road improvements, some indirect "reorganisation" or "restructuring" benefits should also be expected (Mohring and Williamson 1969)(Dodgson 1973). As real transport costs fall, firms should respond by substituting within the production and distribution process so as to arrive at a more transport-intensive, but lower cost solution. The restructuring of the brewery industry into an operation with a few large plants is often attributed, at least in part, to improvements in the road network.

A number of restructuring responses to strategic road investment may be listed:-

- Centralisation of manufacturing or production

- Concentration of distribution into fewer depots

- Changes to inter-depot boundaries

- Increases in market areas served by regional firms

- Improvements in service quality (24 hour delivery, etc.)

- Changes in distribution methods (e.g. satellite distribution)

This list suggests that the indirect benefits are likely to be some mixture of economies of scale in production or warehousing, inventory savings, and added value to products.
A number of studies have been undertaken in the past into the benefits from road network improvements. It is claim they played a part in the decline of road haulage rates between 1974 and 1984 of 27% (Turner 1987). Their effect on transit times and reliability has been demonstrated (Cooper and Tweddle 1988), as well as on the cost of quality of service enhancement (Walker 1988). Benefits gained in terms of larger trading areas have been revealed by studies of the major estuary crossings, such as the Severn and Humber Bridges (Cleary and Thomas 1973) (Mackie and Simon 1986).

Quarmby's studies of a major retail grocery operation are of particular interest in this context (Quarmby 1989). He examines the effect of reducing the number of depots in a distribution system following improvements to the strategic road network so that each depot now serves a larger area. He finds that the total systems benefits from restructuring the distribution and depot network could exceed the direct transport benefits by 30-50%. He does not demonstrate that either his initial or final depot configuration is optimally balanced with the road network conditions. However, his study provided the stimulus for the research proposal to ESRC and to partner industrial sponsors.

2. OBJECTIVES

The project aimed to investigate the savings which accrue to industry from the improvement of the road network, which result in higher average speeds being attained by commercial vehicles using the system. These savings can be split into three tiers:-

i)Direct operating cost savings, already included in the COBA assessment method.

ii)Long term location and size of plants and distribution depots, which reduce total distribution cost whilst possibly increasing transport costs.

iii)The quality of delivery service offered to customers which enables them to reduce stockholding costs.

All these items are inter-related. The second and third are of longer term effect resulting from widespread road network improvements rather than those involving an individual road link. Nevertheless, we have shown that firms can gain indirect benefits without resorting to depot re-structuring as a result of amending depot delivery boundaries.

It has not proved possible to place a value on the quality of service aspects of changed distribution methods, mainly because of the difficulty in obtaining data. In general the firms we have dealt with determine the level of service they require, or intend to offer, at an early stage in planning any changes to the distribution system in order to equal their competitors, and the cost of doing so is not assessed in detail.

3. METHODS

The approach adopted was to study the operations of four large distribution systems representing different sectors of the market and possessing different characteristics. The firms were a national supermarket distributor, a regional brewer, a national gas distributor (for which about half the operation was studied), and a national distributor of wines and spirits.

In each case the study process has been the same. The first step has been to acquire an understanding of the distribution operation, the sources of supply, the nature of on-site operations and investment, and the salient market characteristics (competition, seasonality, tariff practices etc.). The second step is to model the existing distribution operation. This step makes use of a commercially available vehicle routing and scheduling package (PARAGON2), which also had a depot location module (PADLOC). The software was kindly donated by Paragon Software Systems for use on the project. This software is used in order to represent the existing distribution systems and to test its cost efficiency against alternative configurations of depot numbers, depot locations, and customer allocation to depots. The third step is then to examine the impact of changes in the road network quality on the optimum distribution system and on the costs of operating it.

The project required the close cooperation of the firms involved in the case studies. Firms who finally committed themselves to taking part were very helpful, and apart from financial backing for the study, provided both management and staff time to provide us with information and data. However, some data requirements were either not available (notably concerning inventory holding costs) or difficult to obtain, which at times caused considerable delay to the study. In the case of the supermarket study, the firm made clear from the outset that, while it was happy to supply data on deliveries and customers, it would not provide cost information. This meant that this information had to be generated from source data, including warehouse throughput costs by region and size. As this cost data cannot be checked, there remains some doubt about its accuracy.

Inevitably, the commercial nature of the data meant that significant effort was required in order to gain the mutual confidence required. Unfortunately, the parcels carrier which had originally agreed to take part withdrew, following reorganisation. Though we were unable to replace this operator by another parcels carrier, data has been obtained for the wines and spirits operation which requires a comparable level of reliability. The delays caused by the substitution did affect the project schedule and it has not proved possible to analyze the data set for this carrier. We plan to carry out this analysis as time permits, over the next nine months, and submit a supplementary report to ESRC on completion. The remainder of this report focuses on the three remaining case studies.

For each of these studies, a commercial in confidence report has been produced which was made available to the firm in question (Mackie and Tweddle 1991, 1992b, 1992c).

4.1THE CASE STUDIES

An outline of our findings is given in the following sections. These findings are, in the main specific to the individual case study, but some of the results may apply more generally.

4.1.1Regional Delivery from a Brewery.

In overall terms it was found that the firm's efforts in improving the efficiency of the distribution operation resulted in a system which was near optimum, provided orthodox methods of delivery were continued. However, it was found that significant savings could be obtained by the introduction of new technology in the form of draw-bar vehicles, equipped with demountable bodies.

The use of such vehicles, combined with an increase in the number of depots, though none of them holding any stock, allowed the elimination of a considerable amount of stem mileage by the drays. The draw-bar outfit would undertake this part of the journey more cost effectively, carrying a larger payload, with only a driver rather than a two man crew.

Calibration of the model using the current road network demonstrated that five existing depots were located in the optimum areas, and that a larger or smaller depot network would increase costs. The boundaries of the depots were also near optimum. One of the depots is situated on the site of the brewery, and serves a large proportion of customers in the area modelled. It was found that such an operation, which minimises handling and storage costs, was essential if low distribution costs were to be attained in any of the alternative systems examined.

The sensitivity testing demonstrated the value of the high quality road network, which allow delivery vehicles to cover stem mileage from a depot to the area in which deliveries are to be undertaken, at high average speeds, and at minimum cost. This finding is applicable more generally to all such operations where an orthodox distribution system is in use, though the benefits are higher in the case of the brewery, where vehicles carry a two man crew, and the nature of delivery operation restricts vehicle productivity.

4.1.2Supermarket Distribution.

Although the supermarket chain examined in this case study had stores throughout the country, certain regions had particularly strong representation. This is typical of the industry, because of the mix of organic growth combined with mergers and takeovers of regional companies. The most obvious examples of such a variation being between Sainsbury and Asda, where the former has a greater number of stores, and sales volume in the south, whereas the situation is reversed in the case of Asda.

The volume of sales in regions where the grocery chain is strong has an effect on the location of its Regional Distribution Centres (RDC's). Nevertheless most such companies have a requirement for a depot near Bristol to serve South Wales and the South West, and to the north of Manchester to serve the northern conurbations. An exception is Asda, which has its northern RDC in West Yorkshire. This is almost certainly the result of a Leeds based company having relatively high volume of sales to the east of the Pennines.

We were aware that the supermarket chain taking part in the research had been unable to achieve their planned optimum system, in terms of both depot locations and size. However, in calibrating the computer model in became apparent that if it were possible to re-shuffle the depot locations de-optimisation incurred a very small cost penalty. It is of course much easier to change the computer model than to actually obtain facilities even in the second best location.

The pattern of depots produced by the model indicated that locations at intersections of the motorway network, close to a conurbation minimised costs. As many of the stores are now located out of town, on main arterial roads and by-passes, the delivery vehicles use the high quality road network extensively.

This resulted in the sensitivity tests showing the high quality road network being valuable to grocery distribution. Although the optimum number of depots did not alter if the best roads available were the equivalent of single carriageway 'A' roads, there locations did tend to gravitate closer to the conurbations. Though not so pronounced as in the brewery case, nevertheless this in effect minimises stem mileage in the final delivery.

Because of lack of information regarding the sources of goods supplied to the RDC's we were unable to model the trunk-in element of the distribution system, except for a fictitious supplier situated at Northampton representing, on average, all trunking movements. However, while this reflects the small changes the transport element of the supply of goods, another important element was not modelled because of lack of data.

If the number of RDC's in a system were to be increased, then some perishable goods, which have to be delivered every day, would arrive in smaller consignments. A multiple grocer receiving chilled poultry in articulated vehicles, rather than consignments of half that size, could reduce trunk-in costs by 10% on a small but unknown portion of receipts. In modelling the supermarket case study, the proportion of suppliers on which a discount could be obtained probably changed little when between five and nine depots are considered, though we have no evidence to support this view. As the total distribution cost curve was relatively flat over this range of depot numbers, the possibility of a change in the proportion of goods to which bulk discounts applied would not invalidate our overall conclusions.

4.1.3Industrial Gas Distribution.

In this study the distribution of liquid petroleum gas (lpg) was considered. The gas was in fact collected in bulk, and the depots fill the cylinders. The investment required to undertake this operation means that relocation of depots will not be considered unless the savings were very high, and restrictions imposed by the hazardous nature of the commodity mean that obtaining alternative sites is very difficult. As a result, in practice it very unlikely that the company can obtain benefits from road improvements, except those which allow it to retain the current depot network.

Nevertheless, for the purpose of the study we adopted the standard method of calibrating the model to current operations, optimising the system and then undertaking sensitivity tests. In this case there proved to be large variations in the individual depot costs, mainly for historical reasons. This resulted in one existing depot being able to supply a large area of the country, even though its location was not ideal, because the cost of re-locating combined with operating the new site at average costs meant the alternatives were not attractive.

If actual costs were ignored, and a system based on average costs was examined then the familiar pattern emerged. The most cost effective solution under this cost scenario was for depots located mainly at intersections of high quality roads near conurbations. This did not apply so strongly in this case when rural areas were considered, and where consumption was evenly spread. In such areas, East Anglia for example, the optimum depot location proved to be near the geographic centre of the region.

Though the sensitivity tests show that the high quality road network is of the same proportionate value as it is to the supermarket chain, when all roads are improved by the same degree no indirect benefits were apparent. This indicates that if a firms vehicles use a variety of road types, indirect benefits from road improvements are less valuable than when one category of road is improved, and this category is used predominately by an operator.

4.2 RESULTS UNDER EXISTING NETWORK CONDITIONS

Once each case study had been calibrated, and in the brewery and industrial gas studies the calibrated model had been discussed with the firm involved, a number of tests were undertaken to establish the effect on the model. The first of these determined whether the existing system was in fact optimised when data for the sample week was used. Changing the depot numbers and locations demonstrated whether sub-optimality occurred as a result of the structure of the system, and to what extent. Where appropriate, alternative more radical distribution solutions were modelled.

4.2.1Customer Allocation to Depots.

In general the model did not show any significant divergence from the depot boundaries actually used by the companies. However, there was a tendency to draw the boundaries at the half way distance rather than use vehicle travelling time as the basis for the division. This can result in sub-optimality where a depot is served by a network of roads which are of a higher quality than its neighbours, and its vehicles can reach more distant customers within a given time span.

In calibrating the models, the customers had been allocated to the depots from where they are currently supplied. Running the model to allow "free" allocation shows the degree of sub-optimality (Table 1) as a minority of customers are transferred across depot boundaries.

Table 1: Results of Test for Sub-optimal Customer Allocation.
(Coat Index)

	Allocation		Depot
Case study	Fixed Free		location/numbers
Brewery	100	99.2	98.9
Supermarket	100	n.a.	99.0
Ind. Gas	100	99.1	n.a.

4.2.2 Optimal Structure of the Distribution System.

Another source of sub-optimisation is the current location of depots, and the number of depots in the system. A major problem faced by firms is finding a location of suitable size, where planning permission can be obtained for distribution operations.

Table 1 confirms that both the brewery and the supermarket distribution systems were near optimum. The supermarket had to de-optimise in terms of both depot location and restricted throughput, and though in percentage terms the penalty was small, it represent a small part of a large amount.

4.2.3 The Cost Penalty for Sub-optimality.

The results of our work indicate that provided firms can locate within a short distance of the ideal location of a depot, then the loss incurred will be small in overall terms. As the depot location moves away from the optimum position within a region then costs increase on a non-linear basis.

In some areas sites for large RDC's are difficult to obtain. If for example, a firm wanting to located a depot to serve Southern England at Basingstoke had to relocate to Reading, or perhaps Didcot, then the costs could be increased significantly. It is possible to limit the increases in two ways. The size of neighbouring depots could be adjusted so as to at least minimise throughput costs at the sites available. If the system is being planned from scratch, then the locations of depots can be adjusted to minimise the effect of one optimum site not being available (Table 2). In some cases, the most attractive second best solution may be to increase the number of depots in the network.

Table 2: Effect of Number of RDC's on Costs
Supermarket Study.

Number of depots	Difference from base (%)	Notes and locations.
1	+24.84	Northampton
3	+12.20	Hinckley, Middleton, Harlow.
5	+ 0.67	Warrington, Harlow, Doncaster, Chepstow, Basingstoke.
7	0.00	Base case:actual depots; throughput limited.
7	- 0.04	Actual depots; no throughput limits.
7	- 1.02	Optimised locations, Bristol, Harlow, Birmingham, Warrington, Doncaster, Snodland, Basingstoke
9	- 0.05	Heathrow, Southampton, Bristol, Cardiff, Birmingham, Warrington, Doncaster, Harlow, Snodland.

A problem of assessing the effectiveness of distribution systems in the U.K. is the value of land. The very high cost per acre around London and along corridors extending to Reading and Brighton have the effect of deflecting depot locations to adjacent areas, mainly near to the M25 orbital motorway. Despite the density of population in London, many firms find it beneficial to trade off lower land values (or the resultant rents) against a system making more intensive use of transport.

The extent of the cost of a sub-optimal distribution system depends partly on the shape of the total distribution cost curve. Where this tends to be flat, as in our case studies, the effect of sub-optimisation can be limited either by the addition of an extra depot in the system, or altering the size of some or all of the depots.

For the supermarket study, the total system cost was within 2% over a range of between five and nine depots in the system. The other case studies produced total cost curve only slightly less flat being within 5% across a range from two up to eight conventional depots for regional brewery deliveries, whereas for industrial gas the figure was 6% for between two and five depots.

If on the other hand the total cost curve indicated that a particular number of depots gave significantly lower costs than a larger or smaller network, then sub-optimisation would be more costly. The worse case scenario is possibly the requirement of a one depot system with the depot located at Northampton. Using the supermarket delivery data with a one depot system, moving its location 28 miles from Northampton to Hinckley increased costs by 7%; over £65,000pa.

4.2.4 The Scope for Innovation.

In any review of distribution operations a firm will consider a large number of combinations of alternative solutions. Apart from the options available in the number, size, and location of depots, the productivity of labour and vehicles must be considered.

In many situations the cost of trunking per unit mile is less than that of the delivery. However, economies of scale in depot costs and stockholding tend to indicate a requirement for a small number of depots, the overall number of which will also influence the lead time of deliveries from depots.

In recent years many operators have combined these requirements by the use of innovative stockless depot techniques. These are most appropriate when a large number of delivery vehicles are required, possibly undertaking more than one trip per day. Two methods are available. The load of a trunk vehicle can be stripped and transferred direct to a number of waiting delivery round vehicles under cover. Alternatively, demountable bodies can be used which are left standing on legs at satellite depots ready loaded for delivery round vehicles.

The Brewery case study was tested using estimated costs for the use of draw-bar vehicles fitted with demountable bodies, together with a network of satellite depots. In this case the results indicated that significant savings could be obtained from using such a system. Since completing our analysis, which confirmed in-house managerial assessments, the brewery has in fact converted part of their distribution system to the use of drawbar vehicles, eliminating inventory at two depots.

Such innovations were not thought appropriate for the other case studies as both operations involved the use of large articulated fleets for the final delivery, mainly as full load operations. For these operations no further economies of vehicle size or labour utilisation could be identified under current regulations.

4.3 EFFECT OF CHANGES IN THE ROAD NETWORK

One of the main purposes of the project was to assess the relationship between the direct transport cost savings and the total distribution cost savings from road improvements. Previous work has shown that it is desirable to test this at the network level rather than considering the effect of individual road schemes. The latter approach runs into difficulties over the indivisibilities and constraints inherent in schedules.

This type of problem is overcome by considering changes in road quality at the network level. In two cases we consider the effect of replacing motorways by roads which have the same performance as single carriageway 'A' roads. In the brewery distribution study, we dispensed with the motorways in our study area altogether. The results of the supermarket distribution study are shown in Table 3.

Table 3: Supermarket Distribution Sensitivity Test.

	System cost (SC)	Delivery cost (DC)	Change in SC/ change in DC
Base cost (7 depot system)	741,982	173,508	
Motorways replaced by `A' roads. (7 depot system)	762,526	193,280	1.04

In this case the substitution of single carriageway 'A' roads with an assumed average speed of 29.4 mph for motorways (speed 49 mph) does not affect the optimal number of depots. The system cost saving slightly exceeds the direct transport cost saving because the optimal allocation of retail outlets to depots changes slightly. However, in this case the COBA assumption works reasonably well.

In the industrial gas distribution case study, again the test does not affect the optimal number of depots (Table 4). In this case however, the ratio between the system cost saving and the transport cost saving is larger, approaching that found by Quarmby. The main reason for this is only one of the three depot locations is retained when motorway speeds are reduced to that of single carriageway 'A' roads. Instead of the optimum location being near the M1 motorway, two depots have gravitated to sites much closer to the market.

In the third case, that of brewery distribution, the optimal number of depots is sensitive to the quality of the road network. Note that whereas in the other studies, the delivery costs are only around one quarter of the system costs, in this case they are around 40 per cent. This is one reason why the system is more sensitive to network conditions. In this study, we need to examine four cases (Table 5).

Table 4: Industrial Gas Distribution Sensitivity Test.

	System cost (SC)	Delivery cost (DC)	Change in SC/ change in DC
Base cost (3 depot system)	176,133	45,962	
Motorways replaced by `A' roads. (3 depot system)	181,052	49,698	1.32

Table 5: Brewery Distribution Sensitivity Tests.

	System cost (SC)	Delivery cost (DC)	Change in SC/ change in DC
I Base cost with motorways (5 depot system)	172,157	79,374	
II No Motorways (5 depot system)	183,919	90,095	1.10(II/I)
III With motorways (7 depot system	176,918	67,321	
IV No Motorways (7 depot system)	182,269	71,474	1.29(IV/III)

If we examine first the results for a fixed five depot system, we see that the transport cost measure underestimates the system cost saving by 10%. Secondly, for a fixed seven depot system, the system saving is underestimated by 29%.

However, in this case the effect of the motorways is to shift the optimum from a seven depot to a five depot system. The effect of the motorways is to reduce the direct transport costs of the seven depot system by just under 6%. This encourages concentration on fewer depots (substitution within the distribution process), increasing the physical amount of transport in the system by 18%. This is a large response, reflecting the high transport intensiveness of the operation.

Starting from a base position with no motorways and a seven depot system, we can summarise the cost savings as follows:

Direct transport cost saving (7 depots)	£ 4,153
System cost saving (7 depots)	£ 5,351
System cost saving (5 depots)	£10,112

In this case then, where the number of depots is sensitive to the quality of the network, the total system cost saving turns out to be over twice the transport cost saving. Note, however, had we taken the base as the 5 depot system, the transport cost saving and the system cost saving comparing cases I, II and IV in Table 5 are more or less equal to one another.

5. CONCLUSIONS

To generate more secure results, we would clearly need to run a lot more sensitivity tests and to broaden the range of case studies to achieve greater representativeness. We are, therefore, able to report only tentative conclusions on this largely unresearched topic. These are:-

i)In our case studies, there was no sharply defined optimal distribution system. Total distribution costs tended to be flat across a range of depot numbers.

ii)With small numbers of depots, however, system costs are sensitive to depot location.

iii)In two of our three case studies, a large change in network quality (modelled as a decline in road speeds on the current motorway and dual carriageway network to that equal to the single carriageway 'A' road speeds) did not change the optimal depot configuration.

iv)Although the results are volatile, it is clearly the case that distribution system cost savings may be significantly in excess of the transport cost savings in certain circumstances.

v)These excess savings arise from a mixture of:-

a)Re-allocation of customers between depots.
b)Relocation of depots.
c)Changes in depot numbers.

vi)Current Department of Transport procedures, therefore:-

a)Underestimate the economic benefits to the physical distribution sector.
b)Neglect the elasticity of tonne kilometres to transport costs (as opposed to GDP), particularly for the transport intensive parts of the distribution sector such as brewing and oil distribution, etc.

Finally, however, the role of road network improvements in the physical distribution revolution should not be exaggerated. Other improvements have had a considerable effect on system costs.

Areas where the industry has made great strides in recent years are the introduction of information technology, which combined with improved warehouse management has encouraged the introduction of large cost effective depots. The pressure to lower inventory costs has been assisted by the other management techniques, 'just in time', materials requirement planning, and supply chain management. To meet these demands the distribution sector has had to introduce services which provide a high degree of reliability, though the cost of such services may be higher. Physical distribution has tended to become more transport intensive as a result, though the increased costs can be offset by greater savings elsewhere in the distribution, or manufacturing chain.

It is important to avoid falsely attributing to the road network productivity gains which are probably due to these other contemporaneous developments. Nevertheless, we do concur with Quarmby that the direct transport cost savings may in certain circumstances underestimate the total benefits of road improvements to physical distribution of goods. This appears to apply particularly to sectors in which transport costs form a high proportion of total cost, and distribution systems are thus particularly sensitive to the quality of the road network. There is a case for identifying the benefits to freight traffic more clearly, and for attaching rather higher weight to those benefits than is currently done in COBA.

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