Response of Traffic to Increased Road Capacity - A Review of Seven Before-And-After Studies

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ABSTRACT

This report reviews seven before-and-after studies of the effects of new road links. The schemes consisted of four bypasses of villages and towns of varying sizes, a major cross-country dual carriageway completing a link between the M1 and A1, a new cross-river bridge in Belfast, and the removal of an important bottleneck on an arterial into Newcastle-upon-Tyne. The intention of the studies was to identify, so far as possible, any generation of new traffic beyond local reassignment. Five of the studies had to rely on measurements of traffic flow only, while two others were also able to implement roadside interviews. Two studies measured samples of journey times, and the Newcastle study also surveyed public transport services and passengers. All of the studies were able to identify the extent of traffic generation, though in most cases no clear distinction could be made between new trips and wide-area reassignment. Nevertheless, the studies made a clear identification of new traffic(as opposed to wide-area reassignment) in the cases of Quorn/Mountsorrel, where total traffic grew by about 5%, and Shrewsbury and Belfast where the growth was about 10%. There was little overall growth in the cases of bypasses of Little Brickhill and, Market Harborough, while the growth seen in the cases of the M1-A1 link and Newcastle seemed more likely to be connected with external changes than with the road schemes themselves, though in the former case there was also evidence for perhaps 5% growth in relatively local traffic. These studies provide some of the best systematic evidence for the traffic generation caused by new roads, and the report makes a number of recommendations regarding possible future studies.

1. INTRODUCTION

The 1994 Report by the Standing Advisory Committee on Trunk Road Assessment (SACTRA, 1994) concluded that when new roads were built or existing roads improved the generation or inducement of additional traffic, beyond the re-assignment of existing traffic, may have a substantial effect on the net benefits of the schemes. It recommended that scheme appraisals should include economic and environmental assessments made at an area-wide level and based on variable-demand methods.

The debate about generated traffic was not primarily about the principle. The standard four-step transport model used since the 1940's has always embodied mechanisms which would increase the total traffic in an area where additional road capacity is provided. The accepted cost-benefit assessment of new or improved roads according to the COBA procedure has for simplicity been limited to the assignment stage of the modelling process, using fixed trip matrices and merely reassigning the existing traffic across the modified road network. However, it has long been accepted that any substantial change to the road network would also result in redistribution of some trips, as people transfer to destinations made more accessible by the improved roads, and that there may also be some modal shift onto modes which can make best use of the improvements. In principle, also, the trip generation estimated in the first stage of the for-step model may be responsive to changes in the generalised cost of travel produced by the road improvement, so that

trip rates increase as travel times decline, though previous evidence suggests that overall trip rates are probably fairly constant if they encompass all modes, including non-motorised modes (Downes and Emmerson, 1982).

Thus the argument has not been about the principle, but about the size of the effect, and whether it is sufficiently substantial to distort the estimates of net benefit. The SACTRA Report suggested that in some important circumstances it could be, and that traffic generation should not be ignored in the appraisal of future road schemes. However, although SACTRA collected a great deal of case evidence, some of which illustrated the potential importance of the effect in specific circumstances, it could not provide any general quantitative guidance on the likely effects of a particular road improvement.

This remains the weakness of attempts to make allowance for generated traffic. Traditional modelling provides plausible mechanisms which will tend to increase total distance travelled as road improvements increase the average speed of travel (though it ignores shifts in the timing of travel, a potentially important mechanism), but the strength of the factors governing these mechanisms has never been well-estimated. For example, the single most important mechanism is likely to be redistribution in most cases, yet the model calibration is designed to ensure that the model fits the distribution of travel seen in cross-section, whereas for a number of reasons the variation may be quite different to that seen when redistribution responds to a given travel change.

The concern here is not with modelling *per se*, but with understanding a quantified description of human behaviour which, although necessarily grossly simplified at a detailed level, is still sufficiently accurate at an average level to provide valuable predictions of the net effect of specific transport changes. To do this, we need to be able to make useful and quantified generalisations about the strengths of the mechanisms involved, and these generalisations can only follow from a systematic and consistent analysis of the observed response of travellers to a range of transport changes.

In its response to the SACTRA Report, the Department of the Environment, Transport and the Regions noted that it was augmenting its on-going research programme to address these issues (DETR, 1994). Well before the SACTRA study, however, the Department had already commissioned TRL to undertake a series of before-and-after surveys of recent road improvements, with the intention of collecting evidence about the wider effects of road schemes and, in particular, the extent of traffic generation. It is these studies which are reviewed here.

The reviewer is independent of TRL, but this review is not intended to be a detailed technical audit of the individual studies. Rather, it is aimed at summarising what has been learned from these studies, what are the difficulties and deficiencies, how far the findings take us towards the requirements of a properly demand-responsive appraisal of new road schemes, and the best way of making progress in the future.

Section 2 below describes the general approach of the studies. Sections 3 to 9 provide a brief description of each of the seven studies, Section 10 discusses the overall findings, the gaps, and how to fill them, and Section 11 provides conclusions and recommendations.

2. THE STUDIES

Even before the SACTRA Report, the DETR had commissioned Bonsall (1991) to examine the feasibility of undertaking surveys of highway improvements to identify and estimate the different responses of travellers to a given highway scheme. The responses examined were:

- re-assignment of existing road trips to gain benefit from the improvement
- changing the time of travel to take advantage of reduced congestion, normally by retiming towards the peak
- changing mode from public transport to car, or from one public transport service to another which benefited from the road improvement
- redistribution of trips as people transfer to destinations made more accessible by the improvement, or in the longer term changing home to locations made more accessible
- increasing the frequency of travel, as it is made easier by the improvement
- changes in land use, as land made more accessible by the improvement becomes preferred to other possible sites for development.

Interestingly, as part of his study Bonsall sent a questionnaire to 176 transport professionals asking *inter alia* for their estimates of the likely responses to four hypothetical highway schemes. Not surprisingly, there was a wide spread amongst the individual estimates, since respondents were likely to interpret these rather briefly-described schemes differently, and each in their own context, but in aggregate the estimates were unsurprising, with reassignment judged to be the main response, followed in order by exogenous growth, redistribution and, in urban schemes at least, retiming of travel, increased frequency of trip making, entirely new trips, and with modal transfer judged as the smallest response. Overall, effects which could be regarded as "generated traffic", ie redistribution, retiming of travel, increased trip-making, new trips and modal shift, were judged to account for between an eighth and a quarter of the total growth in traffic on the scheme.

It has to be accepted, however, that even those transport professionals with the closest of contact with new highway schemes could do no better than guess at these responses, because they have never had sufficient information about the effects of schemes they have been involved with to identify these different responses. This merely emphasises the importance of the research on which the DETR is presently embarked.

It is notable also that the professionals judged exogenous growth to be a larger factor than traffic generated by the scheme. This is an aspect which is particularly difficult to estimate for any given scheme, since local traffic growth can be very different from the national or regional average. Moreover, its effects on traffic can be very non-uniform, as the traffic patterns affecting the scheme will depend on the geographical detail of local land development.

The remainder of Bonsall's study was concerned with estimating the statistical errors associated with traffic studies, and the sample sizes and costs necessary to achieve acceptably accurate estimates of these various responses. He suggested that it should be possible to organise limited "Level 1" studies using only traffic counts to examine reassignment, retiming, plus all other "new traffic" in aggregate at the relatively low cost of £20K. To identify the individual components of the "new traffic" would require driver interviews or questionnaires, however. These more complex "Level 2" studies would be essential to estimate the strengths of the various model mechanisms discussed in the Introduction, and they were likely to cost around £200K for each study.

The studies reviewed here encompass both Level 1 and Level 2 studies. They are necessarily opportunistic, and in some cases they were organised at shorter notice than is ideal. The Level 1 studies depending solely on traffic counts are:

i) **Little Brickhill Bypass**, A5, Buckinghamshire (Section 3)
ii) **Quorn/Mountsorrel Bypass**, A6, Leicestershire (Section 4)
iii)**Market Harborough**, A6, Northamptonshire (Section 5)
iv)**Shrewsbury Bypass**, A5, Shropshire (Section 6)

In addition, a study was made of the effects of the

v) **Belfast Lagan Bridge** (Section 7)

as part of a continuing study of Belfast, rather than as a specific Level 1 study, but it provides data which can be used in a similar way to that from the other studies.

Two Level 2 studies, which include driver interviews, are reviewed:

i) **Western A14 extension of the M1/A1 link**, Northamptonshire (Section 8)
ii) **Cradlewell Bypass**, Newcastle-upon-Tyne (Section 9)

In these cases, information is available not just about traffic flows, but also about travel purpose, origins and destinations, and alternative travel.

3. LITTLE BRICKHILL BYPASS, A5, BUCKINGHAMSHIRE

3.1 Scheme

This is the smallest of the road improvements studies, a new stretch of the A5 about 1½ kms long bypassing the village of Little Brickhill (Winnett et al, 1994). The bypass adds additional dual carriageway to the end of a long dualled stretch of the A5 through Milton Keynes, which then becomes two-lane road to the south. The bypass links with a minor road from the east from Woburn, but overall it adds little to the wider network, and could not be expected to affect travel patterns appreciably. Nevertheless, if reliable guidelines are to be established for the likely response of traffic to road improvements, it is necessary to examine a wide range of circumstances, and this example lies at the minor end of the spectrum of interest.

3.2 Surveys

The Before and After traffic counts were made at 12 sites, on the old and new roads and along a cordon around the village (Figure 1): both were in November across a three-year interval.

3.3 Success in meeting objectives

The bypass clearly relieved traffic through the village, which fell from some 20,000 vehicles per day (vpd) to about 1000 vpd (an unreliable counter for southbound traffic in the village makes the latter figure uncertain). There are no journey time measurements to indicate the extent to which congestion in the village was a problem, though the Before flow is high.

3.4 Evidence of generated traffic

The screenline and cordon counts suggest that total flows have increased by a few percent, but this is in line with growth at the control count sites, and there is no consistent pattern to suggest that the bypass has had any effect beyond reassignment of traffic from the village street. The bypass flows agree well with forecasts from a simple assignment model. There is more substantial growth at the north end of the scheme due to construction of a new link from the A4146 south of Milton Keynes, but there is also an indication that the opening of a major east-west bypass of Leighton Buzzard to the south, on the A505, may have abstracted up to 1000 vpd from the A5.

Overall, the survey has inferred as much as is plausible from the available data, but the situation is obscured by external events. The effect of the bypass seems to be wholly reassignment, and if there is any net growth due to the increased road capacity it cannot be more than two or three percent. Given the small size of the scheme, no appreciable generation is to be expected.

4. QUORN/MOUNTSORREL BYPASS, A6, LEICESTERSHIRE

4.1 Scheme

This dual-carriageway by-pass of the small towns of Quorn and Mountsorrel is some 5 km long in the relatively built-up area between Leicester and Loughborough, and connects with a number of east-west roads joining other small towns and villages in the area (Grigg, 1993). It thus adds appreciably to the local road network, and can be expected to have more substantial effects than the Little Brickhill bypass, though it is still a relatively modest scheme.

4.2 Surveys

Traffic counts were made at 24 sites, along the old and new roads and in a cordon covering all roads into the Quorn/Mountsorrel corridor (Figure 2). The surveys were in November 1990 and 1992, with the bypass opening in October 1991. A subsequent limited After study using number plate matching was made in November 1993.

4.3 Success in meeting objectives

The scheme was very successful in relieving Quorn and Mount Sorrel, with reductions of 63 and 72% in vehicles per day respectively. Moreover, the bypass attracted heavy goods traffic disproportionately. Even so, diversion to the bypass was less than predicted by the modelling (60% compared with 84%), because the model used was not capacity-constrained and could not allow for the fact that reduced congestion along the old road would tend to re-attract some of the traffic. Since bypasses are only likely to be provided where congestion is already a problem, it is odd to read that the consulting engineers considered capacity restraint modelling to be “unnecessary”. As noted in the Introduction, lessons learnt from these Before and After studies can only be applied consistently and quantitatively if they are incorporated into some form of practical modelling. Progress depends on the application and improvement of appropriate models, and it is essential that the models contain adequate and realistic mechanisms which can be calibrated and adjusted as better information becomes available.

An indication of the effect of the scheme in relieving congestion is also given by a noticeable sharpening of the morning and evening peaks, which carried some 30% greater traffic than before, without any appreciable broadening of the peaks. It was not possible to infer anything about retiming of trips within the peaks, however. In general, retiming may simply be a marginal effect as

journey times shrink, so that commuters leave home later to arrive at work at the same time, or arrive home earlier having left work at the same time, or it may be a larger scale readjustment of the times of arrival at or departure from work in order to avoid peak congestion. It seems unlikely that the second effect would operate here, since congestion is not so extreme, but these Level 1 studies do not include journey-time measurements Before and After, and without an appropriate measure of the effects of the scheme on congestion there is no basis for placing these wider effects in context.

4.4 Evidence of generated traffic

Overall traffic growth at the screen lines was of the order of 13 to 19%, while traffic across the cordon increased by 11%. This growth diminished consistently at survey sites further from the scheme, and was zero at the control site. This latter lay on a route which may have lost traffic to reassignment to the new bypass, however, and this is a general problem with "control sites". They have to be sufficiently close to the scheme to share in any exogenous growth, yet for any sizeable scheme this is likely to place them in the range of influence of the scheme on large-scale reassignment. If so, any transfer of traffic from the control site to the scheme will exaggerate the apparent net growth at the scheme relative to "background". In this case, the study also collected evidence to show that traffic on the A6 south of Loughborough had increased by 12%: this is on the route of traffic diverted from the M1 to use the Quorn/Mountsorrel bypass into Leicester, and the absolute increase in traffic at this site would account for about half of the absolute increase seen on the bypass. Thus overall the evidence is compelling that there has been real growth, in addition to local reassignment, of the order of 10%, and that at least half of this is likely to be due to wide-area reassignment. Real traffic "generation", in the sense of additional vehicle-kms, seems likely to be less than 5%.

There is, however, no way of telling whether this additional traffic is due to additional vehicle-kms travelled (due to redistribution, greater frequency of trips, or modal shift), or simply to wider-scale reassignment as traffic with origins and destinations well outside the surveyed area changes route from outside to inside the area to take advantage of the improved road. The geographical spread of the traffic counts was only of the same order as the length of new road, and along the closest parallel alternative routes, so it is quite conceivable that a substantial amount of traffic, with total journey lengths much larger than the 5 kms of the scheme, would transfer to the scheme from routes separated from it by 10 kms or more. This traffic would not be included in the Before counts, and would appear as "new" traffic. Its contribution to congestion and environmental pollution at Quorn and Mountsorrel is however compensated by reductions on the original routes, so that its net effect is likely to be broadly neutral. It will benefit from the scheme, of course, or it would not have transferred, but the net benefit is likely to be more marginal than that of more local traffic.

5. MARKET HARBOROUGH, A6, NORTHAMPTONSHIRE

5.1 Scheme

This scheme provides about 5km of bypass for the A6 from the SE corner of Market Harborough around the eastern periphery to the NW corner (Emmerson et al, 1995).

5.2 Surveys

The road opened in August 1992, and automatic traffic counts were made at 16 sites in November 1990 for the Before survey (see Figure 3). Unfortunately, timing of the after survey was forced by external events, since major sewage works were expected to disrupt traffic around the town from

mid-September 1992 onwards, and the planned opening of the western extension of the A14 (see Section 9) in 1993 was likely to have a widespread effect on traffic patterns in the area. Consequently the After survey had to be done in early September 1992, with an unavoidable mismatch in the seasonal variation. In the event, however, the opening of the A14 was postponed until 1994, and it was possible to make a more reliable After survey in November 1993. Both After surveys counted traffic at 21 sites, providing inner and outer cordons around the town, and screenlines running roughly SW to NE at the far NW corner, across the NW edge of the town, and to the east of the town.

5.3 Success in meeting objectives

The main effect of the bypass in removing through-traffic from the town is shown by the 12% fall in vpd across the Inner Cordon, with heavy goods traffic diverted disproportionately (HGV traffic across the Inner Cordon fell by a third).

5.4 Evidence of generated traffic

There was substantial growth in total traffic across the Outer Cordon (which included the bypass) and screenlines. From 1990 to 1993 flows into the Outer Cordon increased by 9.5%, while those out from the cordon increased by 11.5%. Increases across the screenlines were bigger still, at 18.5%, 14.5% and 13.6% respectively moving from the line furthest to the NW to that furthest to the SE. There is overlap of screenlines 1 and 2 at site 9, but if this is removed the systematic increase in flow from SE to NW is even greater, rising to 21% at the NW corner. The control site, well to the SW, showed a *decline* in traffic between 1990 and 1993 of 3.9%, so the increase is even larger relative to the background.

Flow changes caused by the bypass were predicted by the consultant engineers, but the details of the model used are not available. In any case, the performance of the model is not very relevant, since the forecasts assumed that the A14 western extension would be open, diverting a substantial proportion of traffic from the A6. Thus the observed flows lie mostly well beyond even the "high" forecasts of the model. Postponement of the opening of the A14 has not merely failed to reduce the A6 flows at Market Harborough, but the previous openings of sections of the A14 M1/A1 link further east are considered to have boosted longer-distance traffic between East Anglia and the West Midlands, contributing to the growth between 1990 and 1993. This argument is based on the surveys of the A14 western link (Section 9), where the permanent automatic count site at Desborough, which is only 6 kms SE of Market Harborough on the A6, showed growth of 41% between 1990 and 1993, an absolute increase of 3470 vpd which is in itself substantially larger than the growth of 2695 vpd on the SE screenline. Once the western and final link of the A14 was opened in 1994, flows through Desborough halved. In fact the A14 study (Section 9) shows that at the western screenline on the A6, which lies to the NW of Market Harborough, the opening of the A14 reduced the flow by 14% or 1400 vpd, which is almost exactly the increase in traffic observed at site 7, on the A6 NW of the town, between 1990 and 1993.

The study analyses the forecast flows for the whole of the A14 M1/A1 link in terms of expected diversion from the A6 at Market Harborough, and concludes that it is likely to account for about half of the difference between the observed and modelled flows. In addition, however, the opening of the eastern parts of the A14 will collect traffic and then transfer much of it onto the A6 north through Market Harborough in advance of the western A14 link opening. It is not possible to make precise quantitative estimates on this basis, but the study's argument that additional long-distance traffic induced by the opening of the eastern parts of the A14 can readily account for the observed increases in screenline traffic between 1990 and 1993 is persuasive. Certainly, this argument is

supported by construction of a southern screenline through count sites 4 and 5, which covers traffic on an axis at right angles to the flow from the A14, and which shows a *decline* of 4% in traffic between 1990 and 1993, in line with the decline seen at the control site. Similarly, sites 1, 9 and 17 to the north of the town, which would not be affected by traffic between East Anglia and the West Midlands, all show either a decline or no change. These are not the major flows on the network, but they could be expected to carry their share of any locally induced traffic.

The study examines the flow profiles by time of day and finds some slight effects of shifts towards the peaks, but the most marked effect lies in a flattening of the heavy goods traffic profile, which again is attributed to the growth of long-distance traffic from the A14, rather than to the local effects of the improved A6. This seems right.

Overall, then, any local generation of new traffic by the road improvement is very small or non-existent, and it is swamped by the diversion of long-distance traffic onto the A6 from the improvements to the A14 further east. Here is yet another study where the major effects are due to causes beyond the change being investigated, but ad hoc analysis of data external to the study has been able to separate the internal and external effects fairly convincingly.

6. SHREWSBURY BYPASS, A5, SHROPSHIRE

6.1 Scheme

This is a sizeable bypass scheme (see Figure 4), providing some 11 km of dual carriageway extension to the M54 west of Telford and Wellington, 15 km of dual carriageway around the south and western perimeter of Shrewsbury, plus 4 km of two-way road along the eastern edge of the town, so that the road surrounds about 270^{o} of Shrewsbury from the NE around the south to the NW (Paulley et al, 1995).

6.2 Surveys

The Before survey was based on 26 automatic counter sites in November 1990, but although an After survey was made in November 1992, this was only three months after the bypass was opened and was deemed too early for much of the response to have settled down, and so the main After survey was in November 1993, based on 40 counter sites. The duplicated sites provided an inner and outer cordon, and three screenlines to the north, east and west (Figure 5).

6.3 Success in meeting objectives

The bypass was effective in reducing traffic in the town, with a decline of 24% in traffic crossing the inner cordon, and 44% in goods traffic between 1990 and 1993.

6.4 Evidence of generated traffic

Total traffic across the outer cordon (which included the bypass) and the screenlines increased substantially. Traffic across the outer cordon (both ways) grew by 8%, and goods traffic by 13% as it used the bypass preferentially. Traffic on the eastern screenline increased by 20%, and on the western screen line by 25%, but there was a smaller increase of only 12% on the northern screenline. No southern screenline was drawn, but this imbalance between E-W and N-S traffic growth is emphasised if sites 8, 10, 11 12 and 13 are used to construct one. Traffic crossing this screenline and flowing north into the town, or south out of it, increased by only 3%. It is not obvious why there should be such an imbalance since the N-S alternative routes are not obviously

easier than E-W, but it may well be a result of the E-W axis drawn by the Shrewsbury-Wellington-Telford corridor, where there may be suppressed demand.

Background census counts by Shropshire CC show an increase of 14% over the period, which more than accounts for the observed growth in N-S traffic, but falls short of the E-W growth by 6-10%.

There is clear evidence of peak sharpening at the eastern screenline, and in the morning peak for the western screenline, though curiously the evening peak for southbound traffic has moved to become about half an hour later, with some broadening. The variability and inconsistency of the 1992 profiles suggest inaccuracies in the survey. On the whole, the peaks are able to carry larger flows without either broadening or narrowing, indicating that there was probably little retiming of trips because of congestion before the bypass, though here again without any journey time information it is not possible to judge how serious congestion might have been.

The forecasts made by the consulting engineers seem to have been based on a simple model, and although they give reasonable agreement with the observed flows at the bypass and outer cordon, they are generally overestimated in the inner areas because the model overpredicted exogenous growth. Had it been more accurate in this, it would have underestimated the outer flows by about 15%, illustrating that mere local reassignment is insufficient to account for the observed growth.

The study argues that the extra growth on the eastern side is relatively local and not due to wide-area reassignment. This argument is based on observed imbalances between traffic heading west and that heading east on weekdays, which is explained in terms of traffic heading west on Fridays and returning on Sundays (the study included weekend counts and analysis). This discrepancy due to longer-distance traffic has actually grown less between 1990 and 1993, whereas the uniform growth observed over the whole day on Saturday and Sunday argues for local generation, especially from Telford, as being the major source. The analysis provided here is ingenious, though not entirely conclusive, since it is not possible to identify unambiguously the different strands of traffic and it is extrapolating behaviour observed at the weekend to apply to traffic overall. Nevertheless, it is consistent with the observed imbalance between growth in E-W and N-S traffic, so in this case the "generated traffic" contrasts with that of the previous studies, in being due largely to redistribution or new trips rather than wide-area reassignment. In this case, there is a net increase in vehicle-kms travelled. The 10% increase observed in traffic to the west of the town cannot be due to this cause, however, and since there are no major traffic generators to the west it seems most likely to be a consequence of wide-area reassignment.

7. BELFAST LAGAN BRIDGE

7.1 Scheme

The opening of the Lagan Bridge (formerly the Belfast Cross-Harbour Bridge) in January 1995 was a major addition to the Belfast road network, providing a connection across the River Lagan closer to the estuary than any existing bridge, and it was intended to relieve the substantial congestion which existed on the other bridges (Emmerson and Gordon, 1995a and 1995b). TRL had a continuing involvement in the planning and modelling work for some time prior to the opening, and consequently the traffic studies made before and after the opening were not intended for the same purposes as the previous Level 1 studies. They were aimed primarily at examining the extent to which the bridge was meeting its objectives. Nevertheless, this offered another opportunity to investigate whether a specific road improvement had encouraged generated traffic, and in the very

important context of a big-city environment where congestion was such that there was likely to be substantial suppressed demand.

7.2 Surveys

From the point of view of identifying "generated" traffic, the value of the study must be greatly weakened by the need to carry out the After study within the first month following opening of the bridge. It is true that, over this period, daily counts showed a relative stabilisation after two weeks or so (and a later limited survey in the summer suggested that flows had not changed thereafter appreciably), but obviously such a short response time is unlikely to capture behavioural changes which will give rise to truly additional traffic, and it is to be expected that most of this short-term response will be reassignment, though possibly over a wide area. In the event, however, the surveys showed some surprising results, and more limited later surveys in summer 1995 and spring 1996 provided further evidence about the likelihood of traffic generation.

The study analysed traffic counts from 36 automatic counter sites, organised into three screenlines plus a number of isolated sites, and also measured journey times along 8 routes into and through the city centre.

7.3 Success in meeting objectives

The stated objectives were to relieve peak-hour congestion on the existing Lagan crossings, relieve congestion on the M2-Queens Bridge corridor on the east side of the river and provide environmental improvements to pedestrian links to the centre, and reduce east-west journey times and increase accessibility to the Harbour industrial areas. The new bridge seems to have met all these objectives to a large degree, even at this very early stage in the readjustment of traffic patterns, with reductions in peak flows on the existing bridges of 25% in the evening peak, and 43% outbound in the morning peak, though only 13% inbound. In the M2-Queens Bridge corridor, total flows excluding the Lagan Bridge traffic fell by more than a third. Journey times on most of the routes surveyed were reduced substantially, by as much as 80% and by 22% on average, though times actually increased slightly (but not significantly) on two of the routes heading east.

However, overall the transfer of traffic from the existing bridges to the new bridge was less than the prior modelling had predicted. The modelled results used for comparison in the study refer to TRL's own model of Belfast, rather than the original Halcrow Fox Belfast Transport Strategic Review (BTSR) model, which referred to a slightly different network from the one which existed when the bridge opened. The TRL model is SATURN-based, with proper capacity constraint and full treatment of signal phasing in the central area (though not further out, which accounts in part for the model's general underestimate of journey time reductions), but it is used here to predict only reassignment, and not the distribution, mode shift or generation stages of demand prediction. Final calibration of this model seems to have been post-hoc rather than making a full before-the-event prediction, since work in 1995 to update the O-D trip matrices has greatly improved the model fit to the flows observed in the Before survey. With this adjustment, which could presumably have been made before the bridge opened had resources been available, the agreement between the Before and After observed flows is generally good. Even so, the model consistently overestimates the transfer of traffic from existing links to the new bridge, because the total traffic has grown substantially, producing higher flows on the Lagan Bridge than the model predicts, but also higher flows on the other bridges.

7.4 Evidence of generated traffic

Across the Lagan screenline (which runs along the river and across both new and existing bridges - see Figure 6), total traffic has increased by 13% inbound to the centre, and by 6% outbound, within a month of the bridge opening, and against a background trend in the counts which, in the years prior to opening, had actually been declining slightly. This marked asymmetry in the inbound and outbound flows is disconcerting, since it may reflect an inadequacy in the screenline or in the counting. It seems unlikely that traffic using routes in one direction around the screenline could account for such a large difference.

The original BTSR model, running on a slightly different network, predicted increases of 20% inbound and 10% outbound by 2001, because it included redistribution and modal shift in addition to wide-area reassignment, but these wider effects can be expected to take several years to appear in full. In any case, the traffic growth observed in the study appears to be much more local than this. The Newtownabbey screenline to the north and west of the city showed an increase of only 3% between 1994 and 1995, though it did show some shift in the morning peak on the M2 motorway as commuters set off for work 5-10 minutes later because of the reduced journey times. The eastern screenline showed an increase of about 2.5% inbound, and a decline of 1% outbound in the morning peak, and increases of about 1% in the evening peak. The model predicted similarly slight changes on the outer screenlines in the peaks, ranging from an increase of ½% to declines of 1%, though it predicted larger increases of 2-3% between the peaks, again in line with observed increases of 1% and 2% inbound and outbound respectively.

Thus the large traffic increases seen on the Lagan screenline across the bridges are not seen on these screenlines further out, even though the eastern screenline is within 2km of the bridges. It seems that most of the growth (perhaps 10% inbound and 5% outbound) has arisen very close to the river, and very quickly. This may be a case of suppressed demand in a relatively congested urban area, with a substantial barrier to access in the form of the river crossings. The level of congestion can be seen in the measured journey times, where the delay component is on many routes more than half the total journey time, and has been greatly reduced by the new bridge. Possibly the new traffic is due to the transfer to car of short trips across the river which were previously walked or cycled. Generated traffic from further afield may well appear over a longer period (it will have appeared already, and it is a missed opportunity that later data from Belfast have not been analysed). This longer-distance generated traffic will add relatively more to total vehicle-kms, but the very short-distance traffic suggested by this study will be running cold in the most congested areas, and therefore contribute disproportionately to emissions, fuel use and delay.

Since there are many ways in which additional car traffic might be generated over the longer term, as noted in the Introduction, one would expect to see a growth in the "generated" traffic over time. Curiously, this does not seem to have been the case. The later resurveys were limited in extent, and unfortunately the spring 1996 survey suffered from problems with the traffic counters which prevented measurement of total inbound flows across the Lagan screenline, while only selected flows were measured across the outer cordons. Nevertheless, the later surveys show fairly convincingly that, while the flow across the Lagan Bridge had gradually increased because of reassignment from alternative routes, the overall increases in the cordon flows had stabilised at close to the levels seen in the spring 1995 survey. Thus the generation even in this longer term seems to be very local, and there is no sign of longer-term or wider effects, unless one were to postulate that any longer-term increases had been offset by a subsequent reduction in the local generation: there is no obvious basis for accepting such an oblique explanation.

8. WESTERN A14 EXTENSION OF THE M1/A1 LINK, NORTHAMPTONSHIRE

8.1 Scheme

The effects of the A14 M1/A1 link have already been referred to in connection with the Market Harborough bypass (Section 5), where before the final section opened it funnelled traffic towards the town in a way which dominated any local effects (Emmerson et al, 1996; Emmerson, 1996; Emmerson and Paulley, 1996; Emmerson et al,1996). This is a major scheme, providing 35 kms of dual carriageway from west of Kettering to the Catthorpe interchange (19) between the M1 and M6, completing the 90 km link to the A1 near Huntingdon, and connecting to the existing high-grade routes to Felixstowe and Ipswich, and East Anglia generally (see Figure 7). Its effects on reassignment can be expected to be very widespread.

8.2 Surveys

The link opened in July 1994, and the Before survey was made in June 1994, with the after survey in June 1995. Automatic counts from Highways Agency sites were available along 4 north-south screenlines, two within the area bounded by the M1 and A1, and two to west and east of this area, amounting to 33 sites in all. In addition, data for the possible alternative route from the east coast using the A12 or M11, M25 and M1 were available from the 1990-1 London Area Travel Surveys. Roadside Interviews were carried out at 6 sites, broadly along the inner screenlines, though with several potentially important roads not covered. The interviews covered 14 hours for one weekday at each site, and at a weekend for three of the sites.

8.3 Success in meeting objectives

Both counts and RSIs show that the A14 has provided substantial relief to other E-W routes in the area, with reductions of as much as a third on the A427/A6 route just to the north, and reductions of 5-20% on other routes. Some of these transfers will have conferred considerable benefits on towns such as Corby, Wellingborough and Market Harborough, though the road has also had the effect of increasing flows on the A605 from Peterborough by almost a quarter as traffic switches from the A427 route towards the A14.

8.4 Evidence of generated traffic

The observed flow on the new A14 link, at 33000 vpd, is some 10,000 vpd larger than prior modelling predicted. The model used was modified from one built to examine the widening of the M1 between junctions 15 and 19, but it covers the study area adequately, with SATURN-based capacity constraint within the area though not outside it, and provides a reasonably detailed O-D matrix after some addition of zones in East Anglia. In general, the model predictions of individual flows are not very accurate, with large over- and under-estimates equally likely, but it consistently underestimates the amount of diversion from alternative routes onto the A14. Even taking this underprediction into account, however, the A14 is carrying more traffic than can come from reassignment across the study area. The study is able to account for much of the change in flow on the major routes, but only be postulating "locally generated" traffic of the order of 10-15% on some of them, and in particular (and plausibly) those near to the larger towns.

The two inner screenlines across the A14 show net increases of 5 and 6%. By contrast the two outer screenlines show increases of only 1% to the east and ½% to the west. Thus, according to analysis of the traffic counts, there is a sizeable generation of traffic, but it comes from within the area

bounded by the M1 and A1, and is not due to wider-area reassignment, suggesting that it is primarily redistribution or new or more frequent trips, since modal shift seems unlikely to play a significant role in this context.

This apparently clear-cut picture is complicated by the RSI data, however. This confirmed the general size of the increase in traffic across the inner screenlines, and the diversion from parallel routes, but not the underlying reasons. The RSIs showed little increase in short-distance trips, some increase in medium-distance trips (though this is subject to the caveat that some traffic may have transferred from roads not covered by the interviews), and the greatest growth in long-distance trips. They also show that the A14 carries an increased proportion of infrequent trip-makers (ie as opposed to commuters), and these are likely to be longer-distance travellers.

The observed growth in trips between Essex and the West Midlands of around 2600 vpd might represent transfer of trips from the A12/M25/M1 route in 1991 to the A14 route in 1995, since the LATS data suggested a sufficient number of trips around the M25 in 1991 to permit such a transfer. Although the RSIs asked a question about alternative routes, in the form of what the driver would do if the A14 section were now closed, analysis of the answers to identify possible previous routing did not show any strong correlation with the observed changes in flow on individual roads, though they did include a sizeable proportion of travellers for whom the M25/M1, and also the A45/M1, were given as alternative routes.

The RSIs also identified strong growth in trips which seem unlikely to have used such an extremely circuitous route as the M25, for example a 50% increase in trips between Cambridge and the West Midlands, and 30% growth in trips between Suffolk and the West Midlands. Such large changes seem more likely to be the result of increased travel between these areas than of wide-area reassignment, but there is no reason to ascribe them to the increased accessibility provided by the improved A14. This effect might be substantial, but the growth seems more likely to be the result of increased economic activity in East Anglia, which has been a major area for economic growth.

Overall, this scheme has demonstrated substantial traffic "generation", especially for long-distance trips, but this cannot all be ascribed to the road improvement. The inconsistency between the traffic counts across the screenlines and the ODs identified in the RSIs makes interpretation difficult. It is perhaps just about possible to reconcile the two, since the *absolute* increase in long-distance traffic identified by the RSIs is not much greater than the absolute increase across the outer eastern screenline. It is considerably greater than the increase of ½% measured at the outer western screenline, corresponding to only 800vpd, but the change across this screenline may be subject to rather larger uncertainty than this, since it includes the M6, M45 and M69 motorways, which collectively carry a very large volume of traffic. There was no counter on the M45, so that the change there had to be inferred from a count further along the route, while the counting accuracy on the high motorway flows may leave scope to accommodate the larger cross-cordon flow suggested by the increase in long-distance journeys identified by the RSIs.

With this reconciliation, the overall explanation would include both an increase in traffic between East Anglia and the West Midlands as indicated by the RSIs, plus an increase in shorter-distance traffic as suggested by the traffic counts, but with the increase in long-distance traffic primarily on the main roads covered by the RSIs, and the increase in short-distance traffic on the minor roads. The picture is one of the more locally-generated traffic taking up the capacity relinquished on the more minor roads as longer-distance traffic transferred onto the A14 and other major roads. The other major roads would attract in their turn additional traffic from more minor roads as they became less congested because of transfer to the A14.

It might be possible to determine whether this picture were valid by further limited analysis of the correspondence between the traffic counts and the RSIs, and possibly by additional study of the alternative routes indicated in the RSIs. Certainly, the RSIs were dealing with a sample of journeys which were remarkably long: the 50th percentile of the RSI trips is 150km, while even for home-based work trips it is 125kms. Assuming the RSIs were representative (and since they sampled 30 to 40% of total traffic it seems unlikely they could be grossly biased), then it is reasonable to assume that most of the shorter-distance trips were carried on roads not covered by the RSIs. This problem arose because the resources were insufficient to provide full screenline coverage by the interviews: if there were a systematic difference between traffic using the interviewed roads and that on other roads the RSIs would be unable to provide a comprehensive explanation.

In summary, the growth in long-distance traffic seems to be due largely to wide-area reassignment and to growth in economic activity between East Anglia and the West Midlands. It does not necessarily represent any increase in total vehicle-kms as a result of the A14 scheme. By contrast, the increase of around 5% in more local traffic identified by the traffic counts, and presumably with the travel primarily on the smaller roads, may be substantially new vehicle-kms.

9. CRADLEWELL BYPASS, NEWCASTLE-UPON-TYNE

9.1 Scheme

This is quite a short length of road improvement, less than 2 kms, but its importance lies in the removal of an important bottleneck on the Coast Road between the inner distributor road and North Tyneside, Tynemouth and Whiteley Bay (Astrop et al, 1998a and 1998b). For most of its length, the Coast Road is a grade-separated dual carriageway, but at Cradlewell it crossed the steep little valley of Jesmond Dene via two single-carriageway approaches to a skew bridge. The bypass provides a dualled bridge at higher level and bypasses the small suburban centre of Cradlewell in a cut-and-cover tunnel. The road carried 40,000 vpd, well above its capacity in the peaks, and removing the bottleneck was expected to reduce long delays in the peaks and relieve traffic on other parallel roads to north and south, and through various residential ratruns.

9.2 Surveys

The Before survey was made in autumn 1991, quite a long time before the scheme opened in spring 1996, but automated counts were available for each year. Because other roadworks in autumn 1996 disrupted traffic, the After surveys were made in autumn 1997. Automated traffic counts were made at 14 sites, with a convenient geographic screenline along Jesmond Dene itself, and there were Roadside Interviews at 10 sites covering three weekdays each to establish variability, public transport surveys on both buses and Metro, and moving-car surveys of journey times (Figure 8).

Curiously, the observed flows across the screenline are unbalanced, with the outbound flow in 1991 appreciably larger than the inbound flow, though since the increase in traffic observed between 1991 and 1997 is larger for inbound than for outbound traffic this difference had almost vanished by 1997. (A similar, but smaller, imbalance was noted in the Belfast surveys.) These imbalances must however raise questions as to the extent to which the screenline used captures all the movements of interest.

9.3 Success in meeting objectives

Inbound traffic on the Coast Road increased by 17%, whereas outbound traffic grew by only 7%. The journey time surveys showed substantial reductions along the Coast Road, with times along the bypass route for inbound traffic halved from 10 to 5 minutes in the morning peak, and reduced by 1-2 minutes during the rest of the day. For outbound traffic, the reductions were about 1 minute, rising to 3 minutes in the evening peak. Thus the bypass was successful in relieving congestion on its own route, even though it attracted more traffic, and since it was in tunnel it obviously removed traffic from Cradlewell centre. It also relieved some of the residential area ratruns, with morning peak reductions in Castle Farm Road, Osbourne Avenue, and Warwick Road.

9.4 Evidence of generated traffic

Across the whole screenline, inbound traffic grew by 12%, outbound by 5%. The bypass has not relieved the main alternative routes to north and south, because the growth in traffic across the screenline has overwhelmed any transfer of traffic to the Coast Road. Traffic has grown on the northern alternative route by 11 to 18%. The situation on the southern route (a mixture of close parallel roads) is complicated by the redevelopment of Quayside and its closure to through-traffic during the period, which caused traffic on City Road, the next southernmost route, to increase by 90%. From the Roadside Interviews, the net growth in trips (over the 12-hour period covered by the interviews) seems to have been about 16% on the northern alternative routes, 9% on the Coast Road, 2% on the Warwick Road/Newington Street ratruns, and 14% on the combined southern routes. There is no evidence of peak sharpening on the Coast Road, so it is not obviously easing a situation of suppressed demand.

This general growth on all routes is reflected in the journey time measurements: in the north, inbound journey times between the peaks have increased by 20%, though peak journey times have reduced marginally. On the southern routes, journey times have increased by around 10% in the late morning peak, yet there have been reductions of up to 20% inbound during the evening peak. Thus growth, from whatever cause, has increased congestion overall on these alternative routes, with percentage increases on the northern routes rather less than on the Coast Road and those on the southern routes rather larger, though complicated by the closure of Quayside.

Travel has increased for all the purposes categorised by the RSIs, but the main growth is in Home-based Other and in HGVs. Home-based Work trips have actually declined in the morning peak, though they have increased in the inter-peak, illustrating more flexible working patterns. Work trips to the City Centre in this corridor have declined, and reverse commuting has increased, but since job locations can be expected to respond only slowly to improved accessibility there is no reason to link these changes to the road scheme. Home-based Other trips to the centre have increased, as they have to the south and west of the city, especially towards Metrocentre in Gateshead. There may possibly be some rerouting of trips from the Tyne Tunnel through the centre in the interpeak, but this is doubtful.

The surveys of public transport show little, though it is important to check this potential source of traffic generation. On individual bus services passenger flows have increased and decreased, but overall across the screenline they have fallen by only 2%, against a background trend of bus ridership falling by 19% between 1991 and 1997. Thus there is no evidence here for any transfer to car travel because of reduced congestion on the Coast Road corridor. Metro passengers, by contrast, have fallen by 13%, as has the frequency of service, but this is in line with the city-wide trend, which shows a fall of 14% between 1991 and 1997.

Overall, then, the bypass has certainly speeded traffic on the Coast Road, and growth in traffic on it is somewhat larger than that across the whole screenline, but the substantial growth on all alternative routes to the north and south, and the lack of any improvement on these routes, suggests that any traffic generated by the scheme has been swamped by exogenous growth. This growth is most marked in Home-based Other, ie shopping and leisure, and goods traffic, suggesting that it may be largely due to a widespread economic revival since 1991. Since the relative growth is stronger on the northern and southern alternative roads than on the improved route, there is no evidence here of any generation linked to the scheme.

10. OVERVIEW

10.1 General

Table 1 summarises the main aspects and findings of the various studies, with particular reference to their potential generation of additional traffic.

These are studies of seven very different road improvement schemes, and together they provide a good coverage of situations of interest. They range from the very limited scheme of Little Brickhill, through the rather similar, but larger scale, bypass of both Quorn and Mountsorrel, the substantial bypasses to the sizeable towns of Market Harborough and Shrewsbury, the important big-city links in Belfast and Newcastle upon Tyne, to the very large regional scheme of the M1/A1 link road. Obviously, the extent of the studies has been limited by the resources available in each case, with the first five restricted to analyses of traffic counts while the last two involved much more detailed Roadside Interviews. In addition, moving-car measurements were made of journey times in Belfast and Newcastle.

All the schemes were successful in relieving traffic congestion in their intended areas, but in all cases the transfer of traffic to the new or improved road was less than the prior predictions, at least in part because there was more traffic in the area generally after the scheme opened than had been forecast. The focus of the discussion here is to determine whether this additional traffic was caused by the scheme, or was due to other causes.

In the cases of Little Brickhill and Market Harborough, the study was confounded by important changes to the road network elsewhere. In others (Cradlewell and the A14) the situation seemed to be dominated by external changes in the overall traffic patterns. The studies have tried to take these factors into account, attempting to place quantitative limits on the explanations by appealing to external measurements of traffic on routes far outside the study area, for example, in the A14 case. But whatever ingenuity is used to try to compensate for the external effects, they inevitably leave a question mark over the studies' estimates of generated traffic.

If these studies are to be useful, it is necessary to be able to draw generalisations from them. We need to perceive some consistent and logical pattern to their effects which will enable us to judge that quantitatively similar effects will occur in schemes which are comparable. Identifying such a pattern within the set of studies is not straightforward. If the schemes are to be categorised, then perhaps it is reasonable to organise them as follows:

Table 1 Summary of Before and After Studies

Study description	Survey details	General effects	Potential for traffic generation	Notes
1. Little Brickhill Bypass Limited scheme, 1½ km dual carriageway bypass of village, adds to end of dualled section of A5 at Milton Keynes.	12 site traffic counts on cordon round village. No measure of prevailing congestion.	Bypass relieved village, and effects accounted for by reassignment only. Overall traffic growth in line with background.	**<3%** After allowing for external effects, no evidence of generation: can be no bigger than 2-3%.	Situation obscured by opening of nearby link from A4146, and bypass at Leighton Buzzard, causing changes at some sites un-related to LB bypass.
2. Quorn/Mountsorrel Bypass 5km long dual carriageway bypass of A6 through two small towns in relatively built-up area, connecting a number of cross-routes.	24 site traffic counts in cordon covering all roads into corridor, plus limited number-plate matching. No measure of prevailing congestion.	Reductions of 60-70% in traffic through Quorn and Mountsorrel. Transfer less than predicted by non-capacity constrained model. Some sharpening of peaks.	**~10%, perhaps 5% new traffic** Screenline growth of 13 to 19%, cordon by 11%, diminishing consistently further from road improvement. Maybe 5% from wide-area reassignment, but survey limited in geographical extent and unable to identify all reassignment.	Fairly clear-cut situation without obvious external changes to confuse the counts. But benefits from wide-area reassignment are likely to be different from those from redistribution or increased trip-making.
3. Market Harborough Bypass 5km long bypass of A6 from SE to NW corners of medium-sized town.	21 site traffic counts on inner and outer cordons plus three screenlines. No measure of prevailing congestion.	Relieves town centre: 16% fall in vpd across inner screenline, HGVs fall by a third.	**Zero** Flows across outer cordon increased about 10%, and 14-20% at the screenlines, against background decline of 4%. However, all of the increase is E-W and can be accounted for by effects of partially-opened A14 link (see note), so no growth attributable to this scheme.	At the time of the survey the A14 link between M1 and A1 was only open on its eastern section, and tended to focus traffic through MH, ahead of opening of final western link (scheme 7). Thus external effects dominated those of the bypass.
4. Shrewsbury Bypass 30km new road, 26km dualled, forming extension to M54 W of Telford plus partial outer ring round town from NE round S to NW.	26 site traffic counts Before, 40 sites After, on inner and outer cordons plus three screenlines. No measure of prevailing congestion.	Relieves town centre: 24% fall in vpd at inner cordon, HGVs fall by 44%. Evidence of peak sharpening on E and W screenlines, and bypass carrying larger peaks without broadening.	**5-10%** Flows across outer cordon grow by 8%, across screenlines 20 to 25% for E-W traffic, but only 3 to 12% for N-S traffic, against Shropshire background of 14% growth. Thus ~5-10% additional growth due to scheme. Argues that growth is mainly local Telford-Shrewsbury, ie redistribution/frequency, though evidence not clear cut.	No obvious external confounding factors. Model used to predict flows simple, and underestimated exogenous growth, but reassignment insufficient to account for all observed growth.

Table 1 (continued)

5. Belfast new Lagan Bridge New bridge across mouth of river closer to harbour than existing bridges. Intended to relieve other bridges and east bank of river, and improve access between east bank and city centre.	36 site traffic counts on three screenlines plus isolated sites, journey times measured along 8 routes into centre. After data only during one month after opening, though limited counts after 6 months to check stability.	Reductions on existing bridges from 13 to 43%, depending on direction and time. Journey times reduced by 22% on average, up to 80% on one route.	**~10%** Total traffic across river increased by 13% inbound to centre, 6% outbound, against declining background trend. Effect is larger than reassignment and transfer to new bridge predicted by model. But traffic across screenlines a few kms from river show traffic increases of only 3% or less, so seems to be very local generation rather than wide-area reassignment.	5-10% of growth seems to stem from either extra trips or mode shift from walk/cycle from origins within 2 kms or so of river. Later surveys in summer 1995 and spring 1996 were only partial, but they suggest changes seen in short-term are stable: no evidence of any longer-term generation.
6. A14 western link between M1/A1 35kms dual carriageway completing important link between M1 and A1, and between E Anglia and Midlands.	33 site traffic counts on 4 N-S screenlines, covering all main E-W routes, plus additional data on some wide-area routes (eg M25). Roadside Interviews at 6 sites, one weekday only plus weekends at 3 sites.	Substantial relief to alternative E-W routes, traffic reduced by a third on A427/A6, and by 5-20% on other routes, providing considerable improvement to some towns in area.	**~5%** Screenlines just to east of M1 and to west of A1 show total traffic growth of 6 and 5%, yet screenlines to west of M1 and east of A1 show growth of only ½ and 1%, suggesting generation is within M1-A1 area. However, RSIs indicate little growth in short-distance traffic and major growth in long-distance traffic between E Anglia and the West Midlands.	Clear evidence of generation, yet traffic counts and interviews produce conflicting explanations. Seems likely that there is a mixture of growth in long-distance traffic on major roads due to wide-area reassignment and exogenous growth, and more locally generated traffic, implying additional vehicle-kms, on smaller roads not covered by RSIs.
7. Cradlewell Bypass Replacement of single-lane bridge and valley approaches by dual carriageway bridge and tunnel bypass of suburban centre on main road to coast from Newcastle upon Tyne.	14 site traffic counts on valley screenline and on alternative routes, 10 site Roadside Interviews, public transport surveys, journey time measurements on improved and alternative routes	Growth in traffic on improved road 17% inbound, 7% outbound, but journey time reductions of 10-15 minutes in AM peak, 1-2 minutes in rest of day. Some relief of residential rat runs, but substantial traffic growth on main alternative routes north and south and journey times show no relief effects there.	**Small** Across valley screenline, total traffic grew by 12% inbound, 5% outbound. This is slightly less than growth on improved road, but worsening situation on alternative routes suggest growth is not primarily due to road improvement. RSIs show main growth in Home-based other and Goods, and that relative growth is higher on main alternative routes than on scheme. Bus and Metro surveys suggest no transfer to car on improved route.	Situation complicated by redevelopment of Quayside to south of route, and closure of some road capacity there, but probably not major influence. Before and After surveys rather a long time apart, giving scope for external effects, though have traffic counts each year. Main effect seems to be economic growth in Tyneside, with little evident generation due to road scheme.

i) Little Brickhill and Quorn/Mountsorrel are similar, with the latter more extensive than the former. Since the "generation" in the former is no more than 2-3% after allowing for the effects of traffic redirected by new roads elsewhere, while in the latter it is of the order of 10%, there is some evidence of scale here. However, analysis of traffic counts alone could give no indication of whether this additional traffic might be due to wide-area reassignment, or to redistribution or more frequent trip-making, and the implications of these two effects for overall benefit can be very different.

ii) Market Harborough and Shrewsbury are both medium-sized towns which have been provided with high-quality bypasses around a substantial fraction of their circumference. Unfortunately, the Market Harborough study has been dominated by the focusing of traffic onto the bypass by the opening of the eastern portion of the A14 M1/A1 link, the western part of which was missing at the time so that the natural continuation of the route was along the A6 and around Market Harborough. Calculation of the quantitative effects of this is not certain, but the study estimates are fairly convincing, and seem able to account for all of the observed additional traffic. Thus there is no evidence for any "generation" of traffic by the scheme: in this case it is entirely the product of wide-area reassignment from road improvements unconnected with it. In Shrewsbury, by contrast, there is clear evidence of 5-10% additional traffic apparently generated relatively locally by the nearness of Telford, and exclusively east-west, for there is no extra traffic on the north-south axis. Thus the amount of traffic generation is, unsurprisingly, closely connected with the geography of the particular scheme, which makes broad generalisation very difficult.

iii) Belfast and Cradlewell both provide important improvements to the road network just outside major city centres, though obviously the Belfast scheme is on a larger scale than that at Cradlewell. Conclusions from Belfast are constrained by the short-term nature of the After study, but there is clear evidence for "generated" traffic across the River Lagan, even if the asymmetry casts some doubt on the precise amount, with a 13% increase in inbound traffic, and only 6% outbound, and these changes are confirmed by the more limited later surveys. Since there is very little increase across screenlines further out, the only plausible interpretation is that people within 2kms of the river are now making car trips into the centre where previously they either did not travel, or walked or cycled. Measurements of traffic delays indicate high levels of congestion, so this conversion from suppressed demand is not surprising even within such a short timescale. Yet there is also considerable traffic congestion at Cradlewell, and the scheme there has clearly reduced journey times appreciably (though by much less than in Belfast), but the sizeable increase in traffic seems to be widespread and unconnected with the particular scheme.

It may be that any "generated" traffic due to the Cradlewell bypass has been swamped by the background changes over the rather long interval between the Before and After studies, but even so if it exists at all it cannot be very large. It might be argued that Cradlewell would be expected to have a much smaller impact than the Lagan Bridge, so that the generated traffic would be only a fraction of Belfast's 6-10%, and therefore swamped by the exogenous changes, but against this the Cradlewell After study has left more time to achieve a fuller response. The Cradlewell study has obtained a lot of detail from its Roadside Interviews and public transport surveys, but the uncertainties relate to what has been happening in Newcastle generally. With hindsight, interviews

outside the area of direct influence of the scheme might have identified tighter limits on the effects of the background trends. It is worth giving thought to the possibility of interviewing at sites away from the scheme as a control, but it is not obvious that, when planning such a survey, it will be possible to make sensible decisions about where to locate such controls. Without prior knowledge of what background issues might have an important influence on the study, locating control interviews will inevitably be ad hoc, and their value may be limited, but they probably offer the best hope of gaining some relevant information about exogenous effects. It is also important that Cradlewell examined the effect on public transport, even though the clear conclusion is that there was no abstraction. Given that public transport use in this corridor is higher than in most cities, the result suggests that it is likely to be difficult to detect reliably the effects on public transport in other urban situations, both because of the difficulty of estimating passenger flows accurately and because any transfer to car is likely to be proportionately small, even with substantially larger schemes than Cradlewell.

The indication from the later Belfast surveys that there has been no further traffic generation in the longer term (1 year) beyond that seen immediately after the bridge opened is surprising. There was considerable traffic congestion on the network, and therefore the immediate local generation seen across the river screenline is not unexpected. But if the suppressed demand gave rise to locally-generated traffic so quickly, probably by mode transfer from the slow modes or by increased car trip-making, why was there no additional effect in the longer-term as travellers' options widened to choose different destinations, and why was the effect not seen over a wider area? Thus Belfast gives convincing evidence of real generation, with a genuine increase in total car-kms, but it is surprisingly localised and quick in response. If this lack of long-term response is sustained, it illustrates our present lack of understanding of some of these effects.

iv) The A14 western section of the M1/A1 Link Road is a much larger scheme than any of the others, and clearly has a regional effect. There is evidence of very substantial reassignment, and of overall traffic growth, though given the scale of the scheme the additional traffic is perhaps relatively modest at about 5%. The inconsistency between the traffic counts and the roadside interviews is troubling, and it is important to try to reconcile them. The counts suggest generation from within the area bounded by the M1 and A1, since the increases in traffic across the outer screenlines are marginal. Yet the Roadside Interviews can identify clearly where the traffic is going from and to, and they show unambiguously that the main growth is in long-distance traffic between East Anglia and the West Midlands. A possible explanation seems to be that the more locally-generated traffic is carried on roads not covered by the RSIs, and that the increase in long-distance traffic identified by the RSIs lies within the margins of error (which are small in percentage terms but sizeable in absolute terms) of the counts on the outer screenlines. It seems possible that some further analysis of the correspondence between the counts and the interviews might achieve better explanation (or at least rule possible explanations out), but the fundamental problem is the lack of full screenline coverage by the interviews.

10.2 Implications for future work

In its own right, each study has provided valuable information about generated traffic, and offered plausible explanations about its origin. Even so, they do not provide sufficient coverage collectively, nor sufficiently unambiguous or consistent results, to permit extraction of a set of generalisations which can be applied *a priori* to new schemes. The set of studies would have to be increased substantially to make this possible. The need for a further programme, and the best approach to it, would depend upon what the Department of the Environment, Transport and the Regions sees as the main purpose of the programme:

- **Assessing the possible effects of generated traffic on net benefit:** Even without a consistent pattern of generated traffic, or a complete understanding of its causes, it would be possible to use an extended series of such studies to establish likely upper limits on the amounts of generated traffic in different circumstances and to assess the possible effects of these on the net benefit of a road improvement. Much of this might be possible from traffic counts alone, although reliable explanations of the sources of the additional traffic can only come from some form of interviewing. In this connection, it is interesting that the observed additional traffic in these schemes is never much above 10%, and in most cases (though not Belfast) some of this will be due to wide-area reassignment where reduction in benefits at the scheme will be balanced by net benefits elsewhere. The extra benefits to the travellers from redistribution, more frequent trip-making, or modal shift (which has not featured in these studies) will be balanced by disbenefits to existing travellers from the extra congestion on the roads, and some general estimates could be made of the potential effect. This might at least provide general reassurance that current estimates of the economic benefits from road schemes are not grossly overestimated.

- **Predicting quantitatively the types and amounts of additional traffic caused by any specific scheme:** This is a potentially more valuable use of the information, but more difficult to achieve. It must depend crucially on an ability to assemble the information into reliable transport modelling, since this is the only effective way of attaining quantified predictions. The models must contain not only adequate capacity-constrained assignment, but also redistribution and trip generation, public transport modes (and possibly walk) in urban areas, and perhaps time-of-day choice in congested situations, although peak shifting or spreading has not been observed to any degree in these studies. The models must cover an area sufficiently large to contain all substantial reassignment of traffic. It is not simply a question of using a comprehensive model to make prior predictions, but of gaining a better understanding and improving the models by making comprehensive After studies and assessing what changes need to be made to the models to recreate the observed situation. Only by consistent and progressive improvement of this sort will it become possible eventually to make reliable predictions of the wider effects of individual schemes. This observation applies as much to public transport schemes or other types of transport projects as it does to increases in road capacity. This is evidently a long-term programme, since it will require a

sequence of Before and After modelling studies to understand the mechanisms and their strengths, and to incorporate them adequately into the models.

11. CONCLUSIONS AND RECOMMENDATIONS

11.1 Conclusions

The studies covered by this Review have added substantially to the available body of knowledge about the wider effects of road improvements, and they include a good sample of different road types. Inevitably, in some cases the results have been obscured by external events, but additional traffic due to the road scheme has been quantified convincingly in most of the studies. However, it has not been generally possible to distinguish clearly between reassignment, on the one hand, and redistribution or more frequent trip making, on the other, and these two sources of "additional" traffic have very different implications for additional vehicle-kms, congestion, accidents and environmental damage.

From this relatively small number of studies, it is not possible to identify a consistent pattern governing the amount of additional traffic in relation to the type of scheme. Additional traffic in the schemes studied ranges from zero to about 10 percent. A wider range of studies will be necessary to establish the effects of road schemes in sufficient detail to provide reliable generalisations about the likely effects of new schemes.

It is important to understand that the value of this type of study is not restricted to assessing the effects of new roads, which may be built less frequently in the future than in the past. In principle, the same measurements of the mechanisms are applicable also to reductions in road capacity, or to the provision of other types of transport service or infrastructure. They are fundamental to all transport and travel predictions and modelling. The Department is to be congratulated on undertaking this programme, for these gaps in our practical knowledge have limited our ability to predict for too long. There are many behavioural and modelling issues which are appropriate subjects for deeper academic research, but the need to build adequate predictive models is an essentially practical matter. The models in use at the moment are far from ideal, but the best of them could be much better still if the information gathered from this programme of Before and After studies could be fed into them.

This is an expensive proposition, but although the costs of Before and After studies are substantial in relation to research budgets, they are small compared with the costs of the schemes themselves. Without substantial improvement in our ability to predict the wider effects of transport schemes, many of the schemes will be less effective than they could be.

Much has been squeezed from the Level 1 studies here, but they inevitably suffer from the difficulty of identifying the underlying causes of the "generated" traffic, and whether it represents a genuine increase in vehicle-kms travelled, or merely a relocation of traffic (though this in itself will have environmental implications, positive and negative). Although CR200 (Bonsall, 1991) does not suggest it for Level 1 studies, it would be valuable to include measurements of journey times, or some

other measurements of congestion delays. However, it would be necessary to carry out several of the more detailed, and expensive, Level 2 studies if there is to be any hope of identifying the strengths of the mechanisms producing the generated traffic. Since suitable opportunities occur infrequently, it is probably impractical, even if the resources were available, to suggest commissioning a comprehensive programme in the immediate future. But Before studies and modelling are carried out in advance of all large transport investments, and much progress could be made by ensuring that these schemes were followed by a suitable After study, perhaps with an updated Before study prior to opening where necessary, and, most importantly, with a re-examination of the modelling work coupled to the After study.

11.2 Recommendations for future studies

Limited resources have meant that the studies reviewed here were unable to cover some aspects which, with the benefit of hindsight, have caused difficulties in the identification of generated traffic. This is understandable, but it is also the case that a trimming of expenditure on some parts of a survey may leave important uncertainties which can substantially undermine the value of the whole study. However comprehensive the coverage of the study, and whatever precautions are taken, it has to be accepted that there will always be unforeseeable circumstances to confuse the analysis, and that some studies will therefore provide less definitive results than others. Nevertheless, if more Before and After studies are to be done, it is important to extract relevant lessons and apply them to ensure that their chances of success are maximised. The following offers suggestions which may form part of a check list for planning them:

i) Level 2 studies are necessary to disentangle wide-area reassignment from truly "generated" traffic, but limits can be identified even in Level 1 studies, as some of the studies reviewed have demonstrated, if they collect traffic information from a wide enough area to encompass all parts of the road network likely to be substantially affected by the scheme. This is best approached by use of an adequate model covering the wider area. When setting up a study, it is also important to try to identify all likely changes in the road network before they proceed, whichever Authority has responsibility for them and wherever they might have some influence on traffic using the scheme to be studied. This will ensure as far as possible that either the changes can be accounted for, or that they will not confuse the study unacceptably. If there is doubt, it may be wiser to avoid the study.

ii) Studies need to be tied to the availability of adequate modelling work, not merely to test the predictions but also to examine how the model might be improved to recreate the observed changes.

iii) Even for Level 1 studies, it is worthwhile to make some measurements of congestion and delay, preferably by measuring relevant journey times.

iv) Level 2 studies are necessary to achieve an unambiguous differentiation of wide-area reassignment and true generation from redistribution, more frequent travel or modal shift. In addition to collecting the usual details of origins, destinations and journey purpose, it is worth considering whether Roadside Interviews can be made more productive by asking a limited number of questions about previous and current

behaviour, even though data based on recall is known to be unreliable. There are practical limits on the amount of information which can be collected while the vehicle is stopped, however, and the possibility of providing postal questionnaires might also be investigated, despite the probability of sampling bias.

v) If Level 2 studies are to be undertaken, it is important to ensure a proper coverage of screenlines or cordons, since coverage limited to certain types of road is likely to sample some types of traffic more frequently than others. Comprehensive coverage is expensive, but gaps in coverage might diminish the value of the whole study.

vi) It is important to gain an understanding of the role modal shift might play, especially in urban schemes, but surveys of public transport passengers are difficult to do reliably and very expensive. In many cases modal transfer from public transport to car seems likely to be limited, and it may be adequate to restrict the data collection to operator counts, and omit interviewing passengers.

vii) Background changes unconnected with the scheme can dominate changes between Before and After studies, and it may be worthwhile to mount Roadside Interviews at sites beyond the expected influence of the scheme to try to establish the causes and extents of these exogenous effects.

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