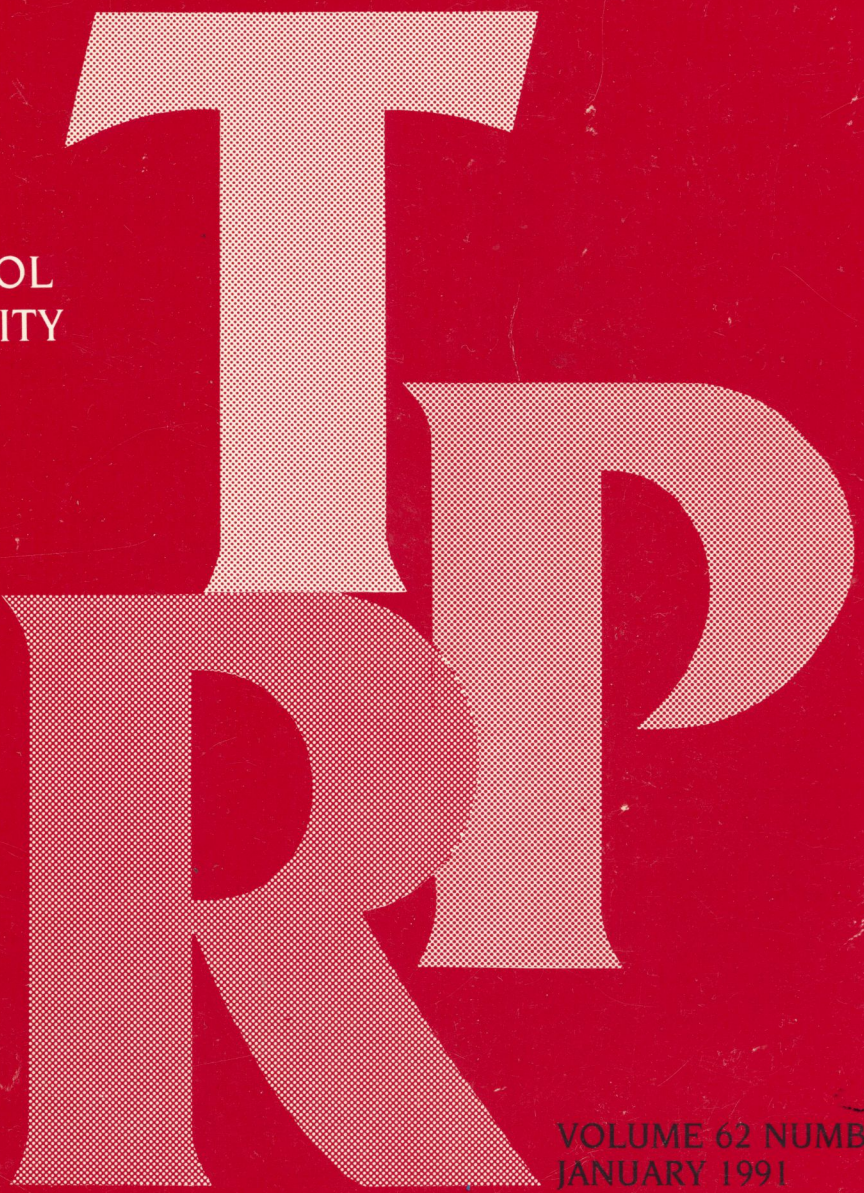
ISSN 0041-

TOWN PLANNING REVIEW

LIVERPOOL
UNIVERSITY
PRESS



VOLUME 62 NUMBE
JANUARY 1991

TPR, 62 (1) 1991

TIM M. PHARAOH AND JOHN R. E. RUSSELL

Traffic calming policy and performance

The Netherlands, Denmark and Germany

Traffic calming objectives are defined and the development of practice outlined, concentrating on the evolution of methods and types of scheme in three countries which have perhaps contributed most to that development: The Netherlands, Denmark and Germany. Results from evaluations are discussed in relation to a range of objective and subjective criteria which have been used as performance indicators. Traffic calming is concluded to be a technical and popular success in widely varying applications, with its methods applicable throughout urban networks on rural roads and national highways, and in the presence or absence of traffic restraint. A more broadly based and integrated approach to objectives, design and evaluation than has usually been obtained in Britain is needed to realise the full potential of traffic calming.

Since the early 1970s attempts have been made to redesign roads in built-up areas to reduce danger, to improve conditions for pedestrians and cyclists, and to improve the local environment. This new style of traffic and speed management has become known as traffic calming. The best known and earliest examples were the Dutch *woonerf* schemes. In the intervening years, traffic calming techniques have been developed to apply not just to individual residential streets, but to whole areas of towns, to main traffic arteries, to villages, shopping streets and town centres.

DEFINITION AND OBJECTIVES OF TRAFFIC CALMING

Traffic calming schemes are associated with a wide variety of planning, transport and environmental policy objectives. Accordingly, traffic calming can be defined in various ways as commentators focus on particular types of scheme or policies which most concern them. The definition we employ can serve as a common denominator and apply to most schemes, if not all. Central to traffic calming is concern with the achievement of calm and safe conditions on streets. Given the strong association with environmental improvements, it also seems appropriate

for the definition to encompass this. Thus traffic calming is defined as 'the attempt to achieve calm, safe and environmentally improved conditions on streets'.

It is acknowledged that there are traffic calming schemes which are almost entirely concerned with improving road safety and perceptions of safety, and for which environmental factors are incidental. Examples are simple schemes involving a few road humps or speed tables where capacity limitations mean that space cannot be reclaimed for environmental treatment. Even so, if a calmer, slower driving speed is achieved there are likely to be marginal benefits in terms of noise and pollution, and the term environment usually embraces the social as well as the physical environment. Since social environmental gains are associated with perceptions of safety in even these simplest of schemes, it is entirely appropriate that environmental improvements enter into any definition of traffic calming.

Traffic calming is often rather casually associated with traffic reduction. This can give rise to confusion. Traffic calming schemes may and often do constitute elements within wider traffic restraint policies, but there are also many schemes where no reduction of traffic is intended. If speed reductions are achieved locally on one or more streets, or within a residential area, by traffic calming measures, this may divert traffic on to alternative routes, or may even be sufficient to reduce total traffic marginally. Such *local* reductions in traffic, however, do not have a significant impact on the level of motor traffic overall, unless combined within a comprehensive traffic restraint policy framework. This distinction is important to clarity of analysis; consequently definitions of traffic calming which imply traffic restraint are resisted.

Moreover, there are traffic calming schemes where an objective is 'improved local accessibility' achieved by retaining or regaining relatively direct routes to property—sometimes, for example, returning one way streets to two-way traffic. Relative to alternative traffic segregation-oriented designs involving road closures and one-way systems, the traffic integration orientation of traffic calming is permissive rather than restraining in its effects on traffic.

For clarity it is helpful to disaggregate the general definition into several basic objectives. Accordingly, the main goals of traffic calming are seen as fivefold:

- to improve road safety;
- to reclaim space (from the carriageway) for pedestrians, cyclists, and 'non-traffic' activities;
- to improve pedestrian mobility and reduce the barrier effects of traffic;
- to promote greater feelings of security, particularly among residents, pedestrians, cyclists, and others engaged in 'non-traffic' activities such as shopping, or play;
- to create environmental improvements, sometimes in order to promote local economic activity.

Traffic calming objectives, and the road safety objectives in particular, are achieved through the redesign of the streetscape to effect speed reductions and to encourage a calm driving style. Surplus capacity or space released as design speeds are lowered can be utilised to achieve the other objectives.

Each of the five main goals of traffic calming identified above has several components. The weightings on these component objectives vary from scheme to scheme, just as the emphasis among the main goals shifts with the nature of the scheme. Road safety, for example, can be measured in terms of reduction of numbers of casualties and reduction of severity; while certain categories of casualties may be specifically targeted for reduction, such as pedestrians or children. Accident numbers rather than casualty numbers may equally be a specific objective. Environmental improvements disaggregate into less noise, less pollution, better microclimate (planting) and better street or area appearance. The reduction of barrier effects subdivides into increased pedestrian crossing opportunities, reduced pedestrian delays, improved perceived safety of crossing opportunities, and reduced delays for vehicles from side streets. Such distinctions are important in that criteria for scheme evaluations are inevitably focused on the individual component, rather than the main aggregate goals.

POLICY CONTEXT IN THE NETHERLANDS, GERMANY AND DENMARK

The practice of three European countries—The Netherlands, Germany and Denmark—is considered in this paper. These three countries have perhaps the most extensive experience of traffic calming and practice in the UK remains undeveloped by comparison.[1]

There are substantial differences in the existing policy frameworks for traffic calming and in the history of its development within these countries. These differences have been discussed elsewhere.[2] More important today are the similarities and the convergence in practice which has occurred over time, as lessons have been learned from experience and the exchange of information. That convergence is reflected in the organisation of the techniques and evaluations sections which follow. Points of distinction between policies or practices in the various countries are introduced where relevant within these sections.

An important common factor in the development of traffic calming has been the fact that local authorities, in all three countries, enjoy a large degree of autonomy from their respective state governments, and have freedom to implement their own policies and schemes. Conformity to nationally devised norms cannot often be enforced, though there are sometimes incentives in the form of financial and other assistance. Advice from national agencies is provided to help local authorities to avoid mistakes and benefit from one another's experience.

Experience of Traffic Calming

Traffic calming is distinguished from traditional 'environmental traffic management' in two principal ways. The first is the aim of reducing the speed of motor traffic in order to reduce its harmful effects in built-up areas. The removal of unwanted through or 'rat-run' traffic from sensitive areas is often desirable, but does not reduce the problems caused by the traffic that remains. In addition, the means used to divert the through traffic (closures, one-way streets, banned turns, etc.) often make access to properties less convenient or direct. Many schemes have

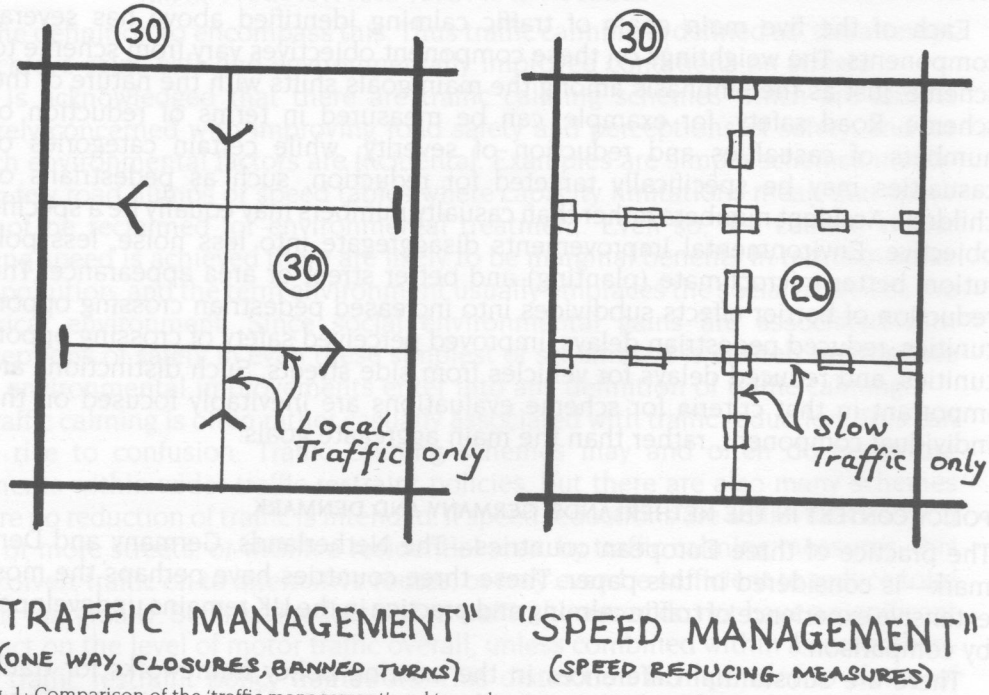


Fig. 1: Comparison of the 'traffic management' and 'speed management' approaches to safety and environmental improvements

foundered because residents and traders have been unwilling to sacrifice access for environmental or safety gains. Reducing traffic speeds has the advantage of tackling directly the main source of the problem while retaining convenient local access. Low speeds will in any case deter 'rat-run' traffic, especially at off-peak times when local activity is most intense.

The second distinguishing feature of traffic calming is its link with the character and function of the road or street. The design of traffic calming schemes is derived from the need to integrate traffic and parking with what the Dutch call 'living' functions, and to give greater priority to vulnerable road users (pedestrians, cyclists, children, the elderly and those with a handicap). The most impressive schemes are also designed to enhance the townscape and environmental qualities of the street. This approach of reducing the priority given to traffic, and enhancing the other functions of urban streets, has led to the use of the term 'traffic integration' rather than 'traffic calming' in Denmark and the Netherlands.

Traffic calming practice in several countries is now consolidated into a coherent framework which combines these twin features of speed reduction and functional priority. This framework finds practical expression in the reclassification of urban roads into two categories, those where traffic has priority, and those where 'living' has priority. The former generally have a speed limit of 50 kmph, the latter have speed limits of 30 kmph or less. By way of example, Figure 2 shows the Danish classification, now incorportated into revised road standards.[3] Thus speed and

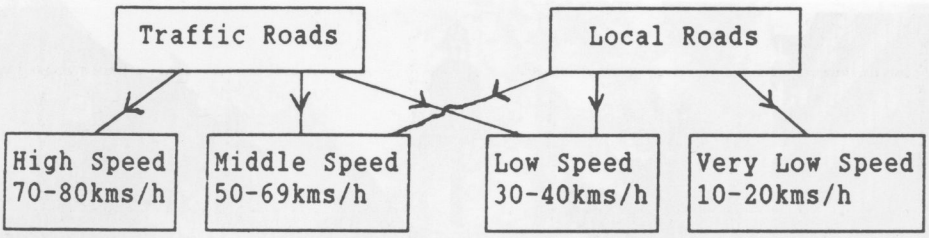


Fig. 2 Urban road classification, Denmark

street function provide a basis for defining urban road hierarchies, as well as traffic function.

A third aspect of traditional practice being discarded is the insistence on continuous traffic networks. Traffic priority may now be interrupted at sensitive locations on the network, for example where a main road passes through a shopping area, or past a college. At such locations, priority is shared between traffic and other street activities, and traffic calming schemes are increasingly being applied to slow down or interrupt the flow of traffic, and to provide more space for other activity. Schemes of this type are now finding favour in the UK as well, as the St John's Hill, Wandsworth, example shows. Unfortunately, the 1990 regulations for England and Wales do not allow the use of 20 mph speed limits on such roads, are found in Denmark, in Cologne and elsewhere.

The traffic calming framework which has evolved then represents a major departure from the traditional approach to environmental management inspired by Buchanan in the 1960s. We now turn to the specific measures used, and the ways in which these are combined to meet the objectives of different types of scheme. By taking each broad category of traffic calming in turn, we are able also to describe the approximate chronology of technique developments.

PEDESTRIANISATION

The conversion of former traffic streets into pedestrian-only zones is not exactly traffic calming, but it represents the ultimate solution to the pedestrian-vehicle conflict and must be considered alongside traffic calming as one of the options available. Moreover, the reallocation of carriageway space to pedestrian areas is sometimes large enough to warrant the description of pedestrianisation rather than traffic calming, as in the centre of Frankfurt for example. Sometimes traffic calming has been seized upon as a compromise alternative by the anti-pedestrianisation lobby (usually shopkeepers) and this emphasises the need to identify the best solution for local circumstances. Compared with the Netherlands, Denmark and Germany, however, the UK record is rather poor, and there is still great potential for full pedestrianisation.

SLOW SPEED AREAS

The earliest and perhaps best known examples of traffic calming were residential streets or areas in Dutch towns reconstructed as 'shared surfaces'. The *woonerf* became the inspiration for similar schemes during the 1970s in other parts of Europe.

Fig. 3 Frankfurt city centre: wide pedestrian spaces have been created from former traffic routes

The basic design concept was to civilise traffic within residential areas. The distinction between footway and carriageway was removed, and greater safety was achieved by redesigning the street to ensure that vehicles could proceed no faster than walking pace (in practice no more than about 12 mph). *Woonerf* designs display considerable variety, but nearly all use a combination of features to change the character and appearance of the street so that drivers are aware of encroaching on a quiet, semi-private residential precinct.

The principal features are humps or ramps, the division of the street into short straight sections not in line with one another, the removal of kerbs, repaving with brick and other attractive materials, and the introduction of planting and street furniture to create a pleasant atmosphere and to give definition to the space. To be fully effective, speed limiting measures need to be frequent: no more than 30 metres apart at most. This physical redesign was supported in several countries by special traffic regulations which established, *inter alia*, equal rights for all road users, and prohibited parking except at identified bays. The failure to adopt such regulations in the UK has limited the application of *woonerf*-type schemes, although small-scale examples can be found.[4] The creation of shared surface access roads in new residential areas in the UK has been largely successful,[5] but the legal rights of pedestrians and drivers remain ambiguous.

Although originally developed for local residential areas, the *woonerf* ('home yard') concept was extended to shopping areas, village centres, school entrances and other sensitive locations. To reflect this change, the Dutch *woonerf* regulation was replaced by simpler and more widely applicable *erf* regulations in 1988.[6]

Fig. 4 A *woonerf* in Den Haag, Netherlands: a shared surface design for living rather than for traffic

Following research into *erven*, which indicated pedestrian concerns, more recent designs retain areas exclusively for pedestrians, often protected from vehicles by bollards and other vertical features. Concern over the effect of frequent 'shifts' or chicanes on traditional street character has led to simpler layouts with a more linear style, and greater reliance on humps and ramps for speed reduction.

The main problem with *erven*, however, was not the effectiveness of the design, but limitations to their application resulting from the high cost of implementation (up to about £100 per square metre of street space) and maintenance, and their suitability only for streets with low traffic volumes (about 300 vehicles per hour maximum). Consequently, there was need to find a solution which was less costly and widely applicable. The 30 kmph zone has been the widely-adopted answer.

30 KMPH (20 MPH) ZONES

The 1980s saw the emphasis of traffic calming shift away from shared surface schemes towards a proliferation of street and area-wide schemes within the legal framework of 30 kmph speed limits, and often involving main traffic roads as well as residential areas. The flexibility of the 30 kmph zone allowed its deployment in situations as varied as accident blackspot sites on rural roads to complex junctions in urban areas. In some countries, notably Denmark, 30 kmph 'quiet road' schemes predominated from the outset.[7]

It was found that a high proportion of the benefits of shared surface schemes, especially casualty reductions, could be achieved by simpler and cheaper measures, despite smaller reductions in vehicle speeds. There has, however, been some divergence of approach between the different countries. In the Netherlands,

Fig. 5 Berlin Moabit, showing entrance 'gateway' treatment with internationally-recognised traffic calming sign

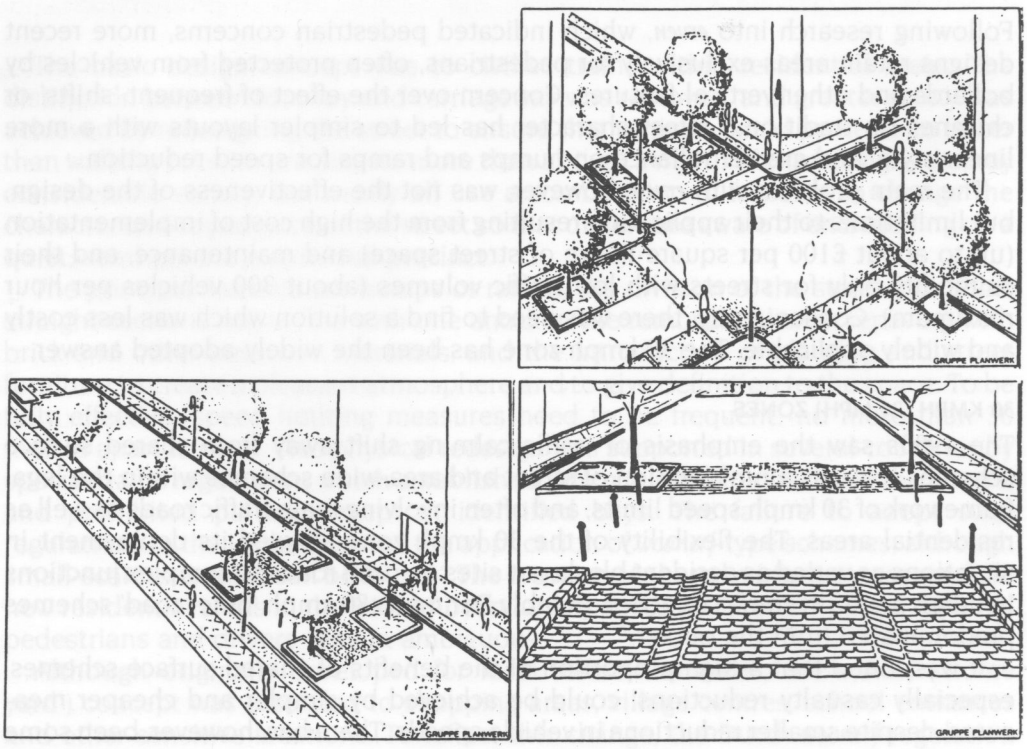


Fig. 6 Perspectives of Berlin Moabit, showing linear character and separate footways retained

regulations established in 1983 ensure that 30 kmph zones are designated only where speeds below 30 kmph have already been achieved by self-enforcing physical measures.[8] This approach has been adopted also in the new 20 mph zone regulations in England.[9] In Germany, however, the emphasis has been on spreading the 30 kmph limit as widely as possible, and putting in physical measures subsequently as and when they are found to be necessary.[10] In Denmark an extremely flexible framework applies, but measures are invariably included to achieve speed reductions. Many schemes are associated with school streets or entrances and there has been less emphasis on achieving area-wide coverage.[11]

In design terms 30 kmph zones differ from *erven* or shared space schemes in two important respects. The first is that speed-reducing measures are generally less severe and/or less frequent. The second is that the extent of reconstruction is usually more limited, the emphasis being on inserting measures at intervals along a street rather than total reconstruction. The Berlin Moabit scheme, although legally a shared space scheme, led the way in Germany in terms of sensitive yet economical design, and has provided a much-emulated model for 30 kmph zones.

As with shared space schemes, the best 30 kmph (or 20 mph) zones combine speed reduction with environmental enhancement, but using less drastic and therefore cheaper techniques. Humps and ramps, for example, can be less steep and more widely spaced. Despite the requirement in the UK for local authorities to adhere to national hump regulations,[12] research and debate continues as to the most effective dimensions, profile, spacing and combinations of humps, ramps and other vertical shifts.

On the principle that effective speed reduction requires some discomfort or perceived risk to vehicle drivers, the most effective measures apart from changes in level are changes in horizontal alignment (tight bends or 'chicanes'), and priority being given to traffic from other directions, such as at roundabouts. Other measures can be useful in support of the speed reduction objective, but they are not usually sufficient in themselves; these include carriageway narrowing, removal of centre lines, reduction of 'optical width', changes of surface materials, rumble strips and signing. Details of speed reduction measures and their application are described in design guidelines produced by Devon County Council.[13]

An important aspect of 20 mph zones is that, with these slower speeds, many conventional road design requirements become superfluous. Thus corner radii can be tightened, carriageway widths can be reduced, and many white line markings and traffic signs can be dispensed with altogether. This gives considerable scope for townscape and landscape improvements and the removal of traffic clutter.

Low speed traffic needs less space for safe movement, which means that more space becomes available for pedestrians, parking and planting, and for seating and other street furniture. Slow speeds also mean that pedestrians should be able to cross the road safely at any point. Nevertheless, at junctions and other locations where pedestrian crossing movements are concentrated, safety and convenience can be greatly enhanced by raising whole sections of carriageway to footway height by means of ramps. Between these raised sections, planted areas in the former carriageway space can define parking bays and reduce the 'optical width' of the street, as well as giving visual emphasis to the location of humps, bends, side

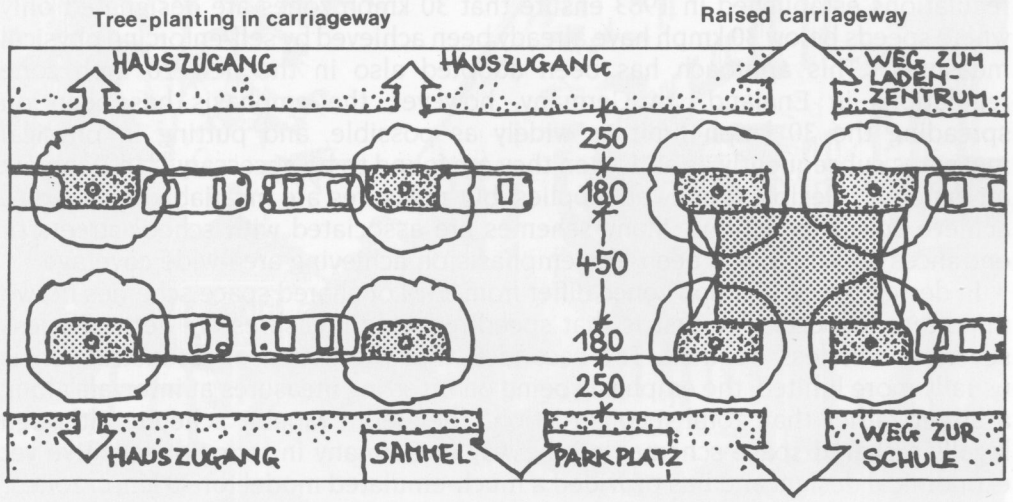


Fig. 7 Plan of typical measures in a 30 kmph zone (source: Stadt Kassel, Germany)

access roads and other features. These planted areas can be placed so that the existing kerbs and gutters remain undisturbed, obviating the need for drainage and other alterations and reducing costs. Successful schemes have been created for less than £15 per square metre of street area.

URBAN MAIN ROADS

The 1980s also saw the first attempts to introduce traffic calming on main urban roads, mostly at places where shopping and commercial activity was concentrated. The creation of effective schemes is usually more difficult in such locations than in residential areas because of the greater intensity of pedestrian and other activity, and thus greater competition for the available space. But the benefits to be gained are potentially much more substantial, not least because accident rates are invariably much higher.

By the end of the 1980s there were still relatively few main road examples of traffic calming, and techniques were often experimental and not yet fully researched. However, some general observations are possible. Firstly, emphasis has been mostly on redistributing street space to provide wider pedestrian areas, cycle lanes, bus lanes, and parking and servicing bays. This has been achieved by reducing the main carriageway, usually to a single lane in each direction, with traffic capacity maintained by retaining extra lanes at principal junctions. A stylised representation of this kind of scheme is shown in Figure 8. Secondly, speed reduction has relied mainly on the prevention of overtaking, interruptions to traffic flow using signalised crossings and bus stops in the main carriageway. Humps and ramps have not been used in most cases, although examples do exist (e.g. Buxtehude, Germany; Alborg and Odense, Denmark; and Borehamwood, Hertfordshire).

There is growing interest in measures which have been developed to obviate the

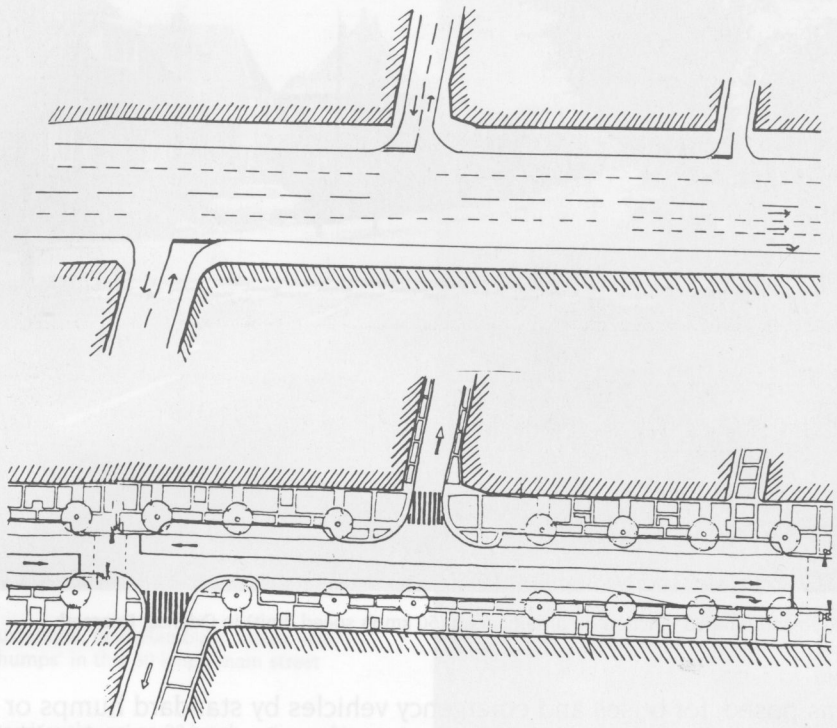


Fig. 8 Before and after plans of a typical main road scheme (source: derived from plans provided by the City of Cologne)

Fig. 9 St John's Hill in Wandsworth, London: a main road scheme with wide footways, sheltered parking and ramped side road entrances, similar to that shown in Figure 8

Fig. 10 Raised and ramped junction on a traffic road (50 kmph speed limit) in Odense, Denmark

problems posed, for buses and emergency vehicles by standard humps or tables. The so-called 'Berliner Cushion' is a raised portion of carriageway of width limited to 1.6 metres, which allows wide-track vehicles to pass with less severe effect (see Figs. 11 and 12). Hybrid humps have been developed and used on bus routes in Denmark which are designed to slow both cars and wide track vehicles equally to 30 kmph.[14]

The British liking for roundabouts as a means of moderating speeds and smoothing flows is now spreading to other countries, despite some doubts about their safety in the urban context for pedestrians and cyclists.

VILLAGE AND SUBURBAN THROUGH ROADS

The other main focus of traffic calming has been on through roads in villages and suburban centres. The problem and possible solutions are shown in Figure 13. Even where a by-pass has been provided it is often not appropriate to pedestrianise such streets, and measures must be taken to secure the environmental and safety benefits in the streets where traffic has been reduced (see Figure 14). This has been recognised in the UK (rather belatedly) by the Department of Transport in deciding to finance traffic calming schemes in some towns due to benefit from the trunk road by-pass programme. Where a by-pass is not possible, traffic calming must itself be relied upon to produce satisfactory conditions in villages. Examples include three demonstration schemes on national roads in Denmark,[15] and the village of Much, Germany, where a Federal through road has been reduced in width to reduce speeds and provide more space for pedestrians and cyclists (Figure 15).

Fig. 11 Buxtehude, near Hamburg: buses negotiate 'soft humps' in this 30 kmph main street

Fig. 12 Speed 'cushions' on 30 kmph main road in Herne, Germany

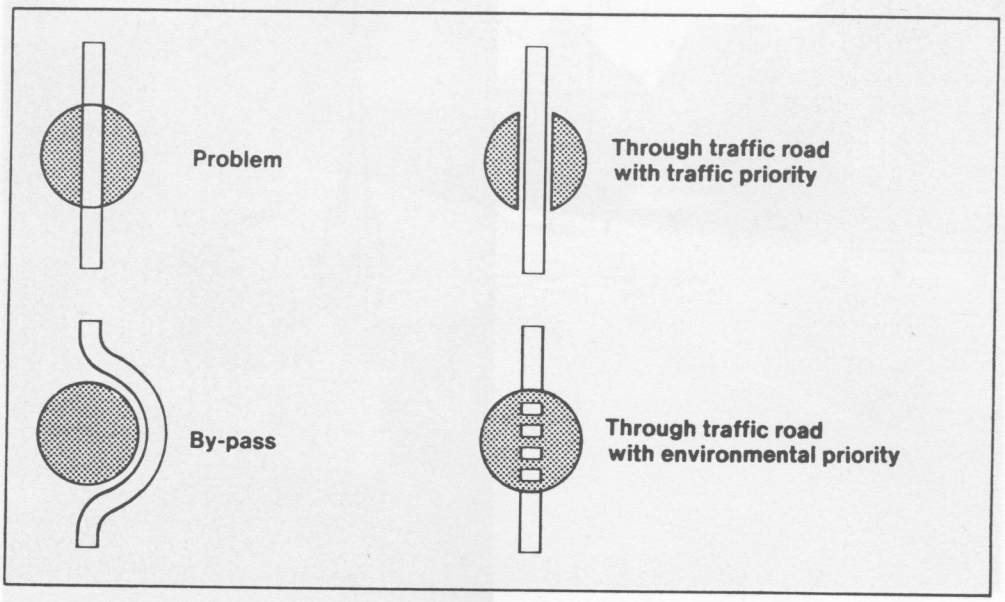


Fig. 13 The through road problem and possible solutions (source: Danish Ministry of Transport, Road Directorate, *Consequence Evaluation of Environmentally Adapted Through Road in Vinderup* [Report 52], Copenhagen, 1987)

Fig. 14 Carriageways can be narrowed within multi-purpose strips (shown here at the side), which provide for large vehicles, parking manoeuvres, cyclists and pedestrians waiting to cross; Hennef, Germany

Fig. 15 Narrowing in progress on a Federal through road: lorries must pass single file between 4.5 metre width constraints; village centre, Much, Germany

As with urban main roads, the emphasis has been on the redistribution of space rather than vertical changes of level. Humps and ramps are rarely used on more important routes, either because of substantial heavy goods vehicle traffic or because such measures are not allowed on roads with a national or federal classification.

The techniques used in village schemes tend to focus on the problem of heavy through traffic severing the local community. Solutions are therefore aimed at making crossing of the road easier and safer using measures that are in keeping with the village character. A common measure is to divide the carriageway and (where space allows) provide central reservations of generous width and length which incorporate pedestrian crossing places and planting. Divided carriageways and tree planting have also been used to create a 'gateway' effect at village entrances, to emphasise to drivers that they are entering an area where slower speeds are appropriate, though these have not been effective unless combined with further measures within the village. More recent practice (for example in Denmark, France and Germany) has emphasised an intensification of measures towards the village centre, or at places with the most intense pedestrian activity. Despite some very attractive and worthwhile schemes being implemented, the reluctance to use vertical shifts to enforce slow speeds appears to have placed limits on the benefits to be gained.

Performance

The results of evaluations need careful interpretation. Firstly, the effects of individual measures cannot easily be evaluated in isolation from the scheme in which they are embedded. The particular *combination* of measures in a street has a powerful influence on the behaviour of drivers and others, and on the perception of safety and other aspects. Thus an individual measure may be ineffective or have a different effect when implemented in isolation, but become both effective and popular when used in conjunction with other measures. Secondly, intervention in one street may affect conditions in neighbouring streets, especially if traffic is diverted. Consequently, and quite rightly, most evaluations have been carried out for whole areas, including surrounding roads. This helps to spot any migration of problems, but the larger the area under evaluation the less homogeneous it is likely to be. Thirdly, there are the complexities of the objectives of traffic calming schemes discussed above. Thus in all three ways it may become difficult to say what precisely is being evaluated. A pragmatic approach is to rely on the skill and experience of the designer to produce a scheme which addresses stated traffic calming objectives. Information on the performance of other schemes thus becomes part of the designer's 'toolkit' rather than a set of prescriptive rules.

Monitoring aspects crucial to a scheme's acceptability is nevertheless required, to check that problems have not been made worse and to provide information so that remedial action can be taken if necessary. The basic criteria in terms of road safety are usually regarded as casualty frequency and severity. Gains in safety are not easy to attribute to individual schemes, but the situation is often acceptable so long as casualties have not increased and other objectives have been met. The point here is that failure is easier to measure than success. If there is a clear failure, then objective results will confirm the concerns expressed by residents and road users, and the scheme can be modified or withdrawn. If there is no measurable or perceived failure, then debate centres on the degree of success or value for money, or other aspects less crucial in shaping policies and programmes.

Evaluation measures for generalised goals are problematic, and evaluations have usually been undertaken at a disaggregated level, with specific criteria established to measure the effects of a scheme in relation to component objectives. At this level both objective and subjective assessments can be made as per these study headings. *Objective Studies*: Speed; Accidents; Volumes of traffic; Noise; Air pollution; Parking; Pedestrian and street activity (including 'staying'); Economic and other neighbourhood effects; *Subjective Studies*: Perceived security; Popularity with residents and user groups; Visual appearance and ecology.

SPEED

Speed reduction is a key evaluation criterion. Although not an objective in itself, it is the principal means of achieving road safety objectives. It is also easy to measure. With the direct evaluation of casualty reductions being very difficult for most individual schemes, speed reduction is often used as a surrogate on the assumption that road safety benefits follow automatically if speed reductions are achieved. Conflicts involving vehicle speeds of 50 kmph or more are likely to result

Table 1 *Speeds and traffic calming measures*

Scheme Type	*Speed* *Legal Maximum*	*In practice (Usual V85% values)*
Erven 'Rest and Play' areas or *mischflacher* (mixed precincts)	Walking pace or 15 kmph	12–20 kmph (up to 25–30 kmph in Denmark and Germany)
30 km/h zones	30 kmph	30–35 kmph
Through roads in villages	30, 40 or 50 kmph	>30, 40 or 50 kmph
Urban distributor roads	50 kmph (occasionally 40 or 30 over short sections)	>Legal max. unless humped/ ramped

in serious injury or death for pedestrians, whereas at speeds below 30 kmph the risk of serious or fatal injury is greatly reduced. The effectiveness of speed reduction measures is arguably of even greater importance in the elimination of more dangerous very high speeds than in reducing average speeds. Traffic calming, therefore, in so far as it achieves speed reductions, is certain to yield accident benefits in terms of casualties, unless the risk compensation mechanism were to operate to offset such gains completely. All evidence suggests that it does not.

Target vehicle speeds are set, usually reinforced by a legal maximum limit. The various speed limits, together with indications of the speeds in practice not exceeded by 85 per cent of vehicles, are shown in the Table 1, compiled from scheme evaluation results in all three countries.

It has proved difficult to design *erven* and other 'mixer court' schemes so that drivers keep within the legal maximum speed of 'walking pace', which would be 7–8 kmph. Maximum speeds of 15–20 kmph are more easily achieved, and appear to have become accepted. Indeed, Denmark's 'rest and play' area regulations specify a 15 kmph limit rather than 'walking speed', which is considered unrealistic and unnecessary. There is a fear that very low speeds create driver frustration and thus greater dangers if they are required over long distances. The maximum distance from any part of an *erf* is usually set at 400–600 metres. Effectiveness depends on the design of the individual elements, their combination, and frequency or intensity. Driver acceptance of and compliance with low speed limits depends not only on the physical measures themselves, but also on the visual appearance of the street as a 'living area' rather than a 'traffic road'. Both are necessary for a satisfactory result. A major problem has persisted with mopeds, whose speeds invariably remain 5–10 kmph faster than those for cars. This is partly because a chicane designed to accommodate four-wheel vehicles is less likely to slow a two-wheeler, and because moped riders use 'footway' and other parts of the street not available to cars.

The main focus of attention has now shifted to the 'intermediate' speeds of 30–50 kmph, with 'mixer court' areas increasingly confined to short stretches of streets where pedestrian activities are concentrated, for example around school entrances, and frequently set within wider 30 kmph speed limit zones. It has been proved that streets can easily and cheaply be modified to achieve speeds of the order of 30

kmph. V85 per cent speeds of between 20 and 30 kmph have been achieved in Dutch schemes with varied degrees of through traffic reduction.[16] Similar results have been obtained in Denmark; in 'Quiet Road' schemes evaluated by the Ministry of Transport's Road Directorate average speeds were reduced to well below 30 kmph in well-designed schemes, with virtually no vehicles exceeding 40 kmph.[17]

The speed-reducing effect of physical measures depends particularly on the severity of the elements themselves, and the distance between them. Speed-reducing elements must be placed no further than 50 metres apart, and preferably 30 metres apart or less, to prevent accelerating in between. A 'calm' style of driving is best achieved when the street can be driven at a fairly constant speed, without the driver experiencing major discomfort, or having to make frequent use of gear shifts, brakes or steering.

In Germany the speed 'hump' has been firmly rejected, perhaps because it is considered to be illegal in most *lander*. Preferred instead are changes in carriageway level achieved by ramps, plateaux and raised 'tables' or 'cushions'. By contrast, speed humps are employed extensively in both Denmark and the Netherlands, and humps and other vertical features such as ramps and tables of sufficient severity are regarded as necessaary for effective speed reduction. Evaluated Danish schemes involving no humps or changes of level performed notably less well in reducing speeds.

The effectiveness of chicanes and offset carriageways in reducing vehicle speed is much more susceptible to design failure than changes of level. Such staggerings allow individual cars to pass at speeds substantially above those of larger vehicles. Effectiveness will then depend on the presence of slower moving vehicles and other factors, although recent hybrid designs with 'deterrence paving' for cars may improve performance. On the whole, staggerings have been more subject to driver abuse than humps and other changes in level. The use of both techniques together, however, has been particularly effective.

Research in Nordrhein-Westfalen has found that speeds are related to street width, and are reduced by two factors: (i) the *perceived* higher risk of collision in narrower streets and driving lanes; and (ii) the appearance of narrowness created by vertical elements of the street (buildings, trees etc.): the so-called 'optical effect'. Where driving speeds are subject to a legal maximum of 50 kmph (i.e. the usual urban limit) a six-metre width is sufficient for a two-lane, two-way road, and this has been widely adopted. However, this width can create problems for cycles when mixed with heavy traffic, and separate provision is usually made. Larger vehicles requiring wider driving lanes has traditionally meant the provision of over-wide roads which encourage cars to be driven too fast. In Germany this problem is being tackled on main (50 kmph) roads by building one-metre 'occasional' strips either side of narrow driving lanes, which can be used when two large vehicles need to pass. If these strips are in setts or other rough surface, car drivers avoid using them. Thus the effective width of the street can be reduced while still accommodating wider vehicles.

Excessive speeds, especially those associated with aggressive overtaking, can also be reduced by the restriction of the view ahead, for example by chicanes or central islands. These again create hazards for cycles if widths are restricted, and

Fig. 16 Combined hump/chicane feature, used on wide 'school street' (30 kmph speed limit), Copenhagen

separate provision must be made. Some one-way streets have been built deliberately narrow (2.25m) so that cars must follow behind cyclists. This is an effective speed reduction measure where a steady flow of cyclists is expected.

Bus stops can also be located to force other vehicles to slow down, creating additional or more intense chicane effects in the presence of a bus, similar to the effect of alternated car parking. In more extreme single carriageway designs bus stops have been used to hold up other vehicles at points where conflicts between road users are greatest, for example in Alborg, Denmark and Mainz (Bretzenheim) in Germany.

ACCIDENTS

The difficulties in evaluating the road safety success of individual traffic calming schemes have already been referred to. Indeed there is no single criterion of what constitutes success. For example, if the number of serious accidents is reduced, but the total number of accidents increases, is this an improvement? On residential streets in particular, accidents are so scattered, and 'before and after' data sets so small, that it is usually impossible to attach statistical significance to the results. The 'before and after' periods required to accumulate sufficient data are simply too long to permit such analysis. Nevertheless, evidence has accumulated over recent years, from aggregate studies and studies of larger demonstration schemes, of clear success in reducing casualties.

An overall evaluation was conducted of over 600 traffic calming schemes in Denmark in order to overcome this small data set problem. Results showed

reductions in casualties of 45 per cent compared with a control sample of untreated roads over similar three-year before and after periods. Since a substantial proportion of the schemes included are almost certainly substandard designs in terms of achieving speed reduction, these results are impressive. Results for a sub-sample of schemes for which traffic volume data were collected were even more impressive, with reductions of 72 per cent in the casualty rate per road-user-kilometre, and 78 per cent in the rate for serious injuries.[18] Similarly in Germany, despite only partial observance of the lower speed limit, 30 kmph zones have seen reductions in injuries varying between 27 per cent in Hamburg and 44 per cent in Heidelberg.[19]

The majority of calming schemes implemented to date have been in residential areas, which usually account for less than 20 per cent of injury accidents and usually carry less than 30 per cent of total traffic. Nevertheless, accidents to children are heavily concentrated in residential roads, and it is these that residential traffic calming schemes can be expected to reduce. Major reductions in overall accident totals can only be achieved with measures on the main road network.

For the area-wide schemes in The Netherlands and Denmark, data indicate that accidents have been reduced in the long term. Results from traffic calming on important traffic routes such as the Danish Village Through Route schemes also indicate substantial accident savings although a longer period of evaluation is required to confirm the pattern. For urban schemes on major traffic routes, where conflicts between users are at their most intense, results are rather less impressive to date, but more time for evaluation is needed. In any event other objectives, such as reducing barrier effects for pedestrians and increasing pedestrian mobility, are also prominent for such schemes, and these tend to conflict with safety objectives expressed in terms of casualty reduction. In the Hellerup Strandvej scheme (Denmark), for example, additional provision for cycling may have increased cycling activity but exacerbated pedestrian/cycling conflicts. A more exacting evaluation framework is required.

Increasingly, safety is regarded not simply as an absence of accidents, but as related to perception and use of the street.

TRAFFIC VOLUMES

Reducing traffic volumes creates more possibilities for traffic calming measures, although, like speed reduction, it is a means of achieving safety and environmental objectives rather than an end in itself. The smaller the maximum traffic volume, the greater the opportunity for speed and carriageway reduction. Traffic reduction achieved without calming measures can have a negative impact by allowing higher speeds to be driven.

Traffic calming may, of course, be sufficient in itself to reduce traffic on treated routes or to divert it on to alternative routes which are less sensitive environmentally. The extent to which calming measures reduce and divert traffic depends on factors such as: (i) level of congestion on and directness of alternative routes; (ii) the degree of speed reduction achieved, and the relative speed on alternative routes; and (iii) the proportion of 'marginal traffic' such as short trips that might

cease to be made. An example might be school escort trips which may be rendered unnecessary if the walk or cycle route to school becomes sufficiently free of hazards.

NOISE

Fears that slower speeds lead to increased traffic noise through more gear-changing and speed changes have proved without foundation. Vehicle speed correlates positively with noise. Evidence shows that a 4–5 dBA noise reduction can be expected if speeds are reduced from 50 kmph to 30 kmph.[20] For schemes with higher design speeds such as the Danish routes through villages, evaluation indicated only slight reductions in noise levels generally.[21]

Reducing carriageway widths can reduce noise levels in buildings and on footways by taking traffic further away. High frequency sound may also be absorbed by the introduction of trees and planting.

Carriageway surface has a significant effect on noise. Granite setts produce noise levels 3–5 dBA higher than smooth asphalt even if laid only in short sections. Rumble strips have been removed in several schemes because of complaints from nearby residents about increased noise. The noise difference between setts and asphalt diminishes with speed, however, and is virtually unnoticed at speeds below 20 kmph.

AIR POLLUTION

Emissions are found to be lower at 30 than at 50 kmph, and evidence suggests that schemes designed to encourage steady driving speeds are rather more effective in reducing emissions than slow speeds *per se*.[22]

PARKING

Changes in parking provision are not usually specified as an objective of traffic calming, but the impact of schemes on parking is often an important issue. Surplus carriageway width (e.g. when lanes are reduced, or traffic is converted to one-way operation) can be used for additional parking. Angled parking (45 or 90 degrees to the kerb) can be used instead of lateral parking. Angled parking on one side of the road provides roughly the same capacity as lateral parking on both sides. Thus chicanes can be achieved by the use of angled parking on alternate sides of the street without loss of parking capacity. There are also safety benefits claimed from this arrangement because it reduces by half the chance of children being masked by parked cars, as well as reducing the speed at which any impact occurs.

PEDESTRIAN AND STREET ACTIVITY

If 'calmed' streets become safer and more pleasant to be in, 'non-traffic' street activity will increase in response to the higher quality environment. The elasticity of demand for such activity will vary according to a number of factors, including the extent to which activities were suppressed by previous conditions, the density of development, the social composition of inhabitants, the potential for development of street activity (e.g. for pavement cafes or children's play), microclimate, architectural character, and so on.

Sometimes major beneficial changes in street activity can be achieved where more space is given to 'staying' activities. This involves the inclusion of space where children can play and adults linger to chat or rest, rather than being simply pedestrians walking from one place to another—the enjoyment of the space itself rather than simply access to the activities along it. Reallocation of carriageway or 'movement' areas to 'staying' areas has become a major feature of traffic calming practice. In Berlin Moabit street activities are reported to have increased by 60 per cent, and cafes, restaurants and shops have moved out on to the (larger) footways. Surveys in the Danish village schemes have also indicated substantial increases in pedestrian activities along the main road after treatment; in Vinderup the increase was as much as 47 per cent.[23] Similar effects have been noted in both high density residential areas and on main roads. Such changes are much less apparent in 30 km/hr zones in low density suburban areas. Evidence as to whether calming stimulates more outdoor activity in residential areas then is mixed.

Traffic calming schemes usually entail high priority to pedestrian safety, to enable them to be in the street and to cross it without risk of injury or harassment from drivers. If this greater freedom leads to increased pedestrian mobility, potential accident reduction benefits may be eroded. On main shopping streets where carriageways have been narrowed or central islands provided, pedestrians and cyclists can cross more quickly and thus may do so more frequently. This reduction of the community severance effect of the road is regarded as a benefit. For example, double the number of pedestrian crossing movements, undertaken with half the risk will in theory result in no accident reduction, but the street may still be regarded as safer. Moreover, even where pedestrian mobility increases completely offset casualty reductions, less severe injuries and fatalities would be expected provided that speeds are reduced. Accident evaluations which take no account of changes in pedestrian activity are likely to be misleading, particularly on main shopping streets.

Traffic calming provides a benefit which may thus be 'consumed' in the form of accident reduction or greater pedestrian freedom. While recognised, this concept has not yet been adequately investigated, but it is of great importance to the evaluation of traffic calming schemes.

ECONOMIC AND OTHER NEIGHBOURHOOD EFFECTS

If traffic calming is successful in making streets safer, more attractive and more popular, higher property prices and rents relative to non-calmed areas might be expected. As far as retailing areas are concerned, it is known that rents are on average higher in pedestrianised streets and malls. Traders are almost always opposed to measures prior to implementation, but in favour of them afterwards. Fears of loss of trade are usually proved to the contrary. There are, however, variations between different retail sectors, and possible impacts on retailing in untreated areas that need to be studied.[24]

There is less firm evidence relating to residential property, but some interesting pointers. In Ingolstadt it has been found that private property owners have invested more heavily in their buildings in the reconstructed streets. Moreover, residents have been keen to exploit any opportunities presented for increasing planting in-

their streets, especially if the unsealed areas available can be adopted as semi-private space. This indicates increased pride in the street. In many towns estate agents often refer in promotional literature to traffic calming as a positive feature. Logic would suggest that this would be reflected in property prices, but the extent of this compared with other factors determining property values is not known.

A more direct effect may result from the requirement in some German and Danish cities for property owners to contribute to the cost of street works. This may be translated into higher rents which could be a problem for low-income families. In wealthier districts residents may be more willing to pay for safer and more attractive streets. Discussions with local authority officials on this point did not reveal any major difficulties, but there seem to be little data on the subject. One reason for the lack of data is the fact that many schemes have been implemented as part of wider housing rehabilitation work, which also tends to lead to changes in rents and prices. It is therefore difficult to disentangle the specific effects of the traffic calming measures.

PERCEIVED SECURITY

For traffic calming to be judged successful it is important that the level of risk is in reasonable accord with public perceptions of safety. If residents perceive a street as safe, but their resulting behaviour exposes them to danger, this may aggravate the accident problem. Conversely a street which is perceived as being more dangerous than accident figures suggest is unlikely to have a calm or pleasant atmosphere. Nonetheless it is important fully to acknowledge increased perceptions of security as a valid objective in itself. Easing minds by reducing fears is, other things being equal, a benefit in itself. This is recognised in much continental practice. Thus even in situations where casualty rates remain unchanged, if people feel less afraid to cross the street or less worried for the safety of their children, then benefits have been realised, albeit psychological ones. Obviously if a false sense of security were induced which resulted in increased casualty rates, a negative overall effect would result. Since properly designed schemes result in lower vehicle speeds, with less serious consequences when accidents do occur, it is highly unlikely that such a negative situation would arise. For particular user groups such as cyclists and moped riders, however, whose speed may be increased rather than reduced in some types of scheme, such negative effects are possible.

Surveys of residents, such as those conducted as part of the Danish village evaluations, show major positive effects on feelings of security, for residents as pedestrians and cyclists in particular. In Vinderup, for example, 80 per cent of adult road users felt safe as pedestrians and 75 per cent as cyclists after implementation of the scheme, compared with 51 per cent and 17 per cent before respectively. Even as car drivers a 20 percentage point increase in the proportion feeling safe was indicated, rising from 56 per cent to 76 per cent.[25]

POPULARITY WITH RESIDENTS AND USERS

The general popularity of schemes in Denmark and Germany is evident in the willingness of many residents to pay and in the continuing demand for such schemes, as well as in the results of surveys. There appears to be a strong

correlation between residents' satisfaction with schemes (of whatever type) and their involvement in the planning, design and implementation process.

A general conclusion from the Dutch area-wide projects was that in terms of reducing pedestrian-vehicle conflict, those areas with self-enforcing 30 kmph speed control measures produced as much as, if not more, resident satisfaction than the more elaborate *woonerf* areas. The additional advantage of *erven* is, of course, their ability to create a more attractive living environment as an extension of the dwelling space, but it is clear that popularity with residents cannot be taken for granted.[26]

The popularity of traffic calming schemes with residents or with user groups such as pedestrians and cyclists is to be expected given that such schemes are designed to give greater priority to their needs. Of greater interest perhaps are some of the results of surveys done on other vehicle user groups, such as car drivers and bus users. Surveys indicate driver resistance is less than might have been anticipated, even where schemes are on main roads carrying a high proportion of through traffic. For example, in the Danish village studies surveys indicated 50 per cent support for the schemes from car drivers, with opposition concentrated on those driving through the villages rather than resident in them.[27]

An interesting evaluation in nine streets in Nordrhein-Westfalen measured the reactions of drivers to a pair of badminton players in the street. These measurements were made before and after calming measures were introduced. The 'before' observations found that drivers approached the players quickly, slowing at the last second, and often reminding the players of the driver's right of way by sounding the horn. 'After' studies found a big change in behaviour, with drivers slowing as much as 40 metres before the game, and giving the players time to move away. Where the scheme changed the street scene vehicles were not only driven more slowly, but with greater preparedness to slow down further. Fewer drivers drew attention by hooting; nor did they 'tear away' after passing the players. They became more tolerant of interruptions. What this demonstrates is that the street design affects expectations. If a street gives the appearance of a residential environment, then drivers are more tolerant and careful of pedestrian activity within it.

VISUAL APPEARANCE AND ECOLOGY

Redesigning to calm traffic inevitably alters the appearance of the street, and greater efforts have been made to introduce designs which enhance rather than detract from the street scene. Indeed, calming is seen to be a successful combination of traffic engineering and urban design. There are indications that the popularity of traffic calming is strongly dependent on the quality and appearance of the various elements. Materials are often of a high standard, especially in the schemes involving shopping streets, *erven*, and conservation areas.

Reactions against the *erf* in terms of pedestrian perceptions of safety are in some places matched by reactions against their appearance. Many now believe that the typical *erf*, with its intensive use of coloured paving, frequent visual blocks, different textures and plethora of street 'furniture', is often too fussy and destructive of traditional street character. The product of this reaction is a move towards schemes with clean lines, minimum signing and minimum use of colour and texture changes. The 'greening' of an area is often an integral and major objective of

schemes, introducing planting in order to improve appearance, microclimate, wildlife and other aspects. Trees and other planting also increase the acceptability of calming measures.

Far from being an afterthought, the environmental design of traffic calming has in some cases been the sole means whereby the measures have gained political and popular support, and numerous schemes have implemented in the name of city beautification.

Conclusions and implications

The success of traffic calming techniques has been demonstrated in a wide variety of applications, from quiet residential streets to national highways. Further development and research is required to establish the limits of its potential in more complex situations where greater conflicts between objectives may arise, but traffic calming is now an established branch of traffic management. The potential benefits from its widespread application on road networks throughout Britain will be limited by resources and the will to implement rather than by technical considerations.

Traffic calming practice in Demark, Germany, The Netherlands and other European countries is not uniformly good, but it is better developed, better researched and much more widespread than in the UK. As interest grows, it is important to benefit from countries that have greater experience. Many British local authorities have recognised this and included study tours of European cities in the policy-making process. Central government, however, has been reluctant to provide resources for research or demonstration projects into what is seen as mainly a local authority responsibility. This lack of central initiatives has meant very slow progress. A 'Catch 22' situation has developed whereby the Department of Transport claims to be waiting for the results of local authority innovations and experiments, while local authorities for the most part are unwilling to embark on schemes which do not have specific Department of Transport approval.

The most important lesson from experience elsewhere has not yet been fully learnt, namely that successful traffic calming requires not just a few extra traffic engineering techniques, but a different approach to the management of urban spaces. As described at the start of this article, the objectives of traffic calming are (or should be) multi-faceted: the different interests in urban streets are diverse, and the conflicts between them often too great to be resolved from a single standpoint. Those authorities responsible for successful traffic calming schemes have mostly been those which have achieved cooperation between the different professional disciplines, between different authorities, and with the people who eventually have to live with the scheme.

Aspects of UK practice which reflect too narrow a view include the promotion of 20 mph zones mainly as an accident reduction measure, with Transport Supplementary Grant payable only for the accident remedial aspects of schemes. Similarly, the Urban Road Safety Projects largely neglected environmental objectives, and had some difficulty in gaining public support as a result. Safe routes to school are being promoted as an educational and publicity approach, largely

divorced from traffic calming programmes. It is this failure to achieve the necessary integrated approach which provides the sharpest contrast with other European countries. The integrated approach to traffic calming evident in those countries is reflected also in more sophisticated evaluation procedures. In the UK there is a heavy reliance on accident reduction as the justification for traffic calming, and on schemes being able to show a positive rate of return on investment from an assessment of 'costable' effects. Indeed, funding for traffic calming is often available only from road safety budgets.

The cost-benefit assessment procedure is of dubious validity. Firstly, there are difficulties associated with scheme selection. Priority attached to schemes on the basis of currently high accident rates may have no medium-to-long-term validity due to 'regression-to-mean effects'. This has been demonstrated in a before and after comparison of accident sites which showed larger accident reductions in Lothian Region where no money had been spent than in Hertfordshire where more than £7000 per site had been spent.[28] There are other problems to contend with, such as possible risk compensation effects, and the arbitrary nature of values attached to accidents and time savings. The latter are particularly irrelevant to traffic calming appraisal, where some 'savings' derive from excessive speeds.

In Denmark, The Netherlands and Germany, the temptation to calculate a financial rate of return is usually either resisted altogether, or set within the context of wider evaluation methods which emphasise subjective as well as objective criteria. For the Vinderup through road scheme (Denmark), the finding that 72 per cent of residents found the town easier to move about in, for example, was considered to be more relevant to judging overall success than the finding that average motorist journey times had increased by nine seconds.[29] In Den Bos (Netherlands) two-thirds of residents had a more positive attitude to 30 kmph zones than before the scheme, while 60 per cent believed such measures should be repeated elsewhere. The number of people who felt drivers in the area gave adequate consideration to vulnerable road-users doubled after the scheme was implemented.[30] Such investigations help to reveal the true success of schemes in meeting the objectives of traffic calming.

In contrast, progress in Britain has been hampered by narrow objectives, rigid application of traffic regulations, obsession with financial rates of return, minimal national research and guidance, and lack of resources and autonomy at local government level to counterbalance these failings. Nevertheless, many authorities are determined to make up some of the lost ground during the 1990s.

NOTES AND REFERENCES

1 Beth, L. and Pharoah, T. *Adapting Residential Roads for Safety and Amenity* (Occasional Paper 3/88), London, Department of Planning, Housing and Development, South Bank Polytechnic, 1988.

2 Pharaoh, T. and Russell, J., *Traffic Calming: Policy and Evaluations in Three European Countries* (Occasional Paper 2/89), London, Department of Planning, Housing and Development, South Bank Polytechnic, 1989; Russell, J., 'Traffic Integration and Environmental Traffic Management, *Transport Reviews*, 8 (1) 1988, pp. 39–58.

3 Danish Ministry of Transport, Road Directorate, Vejregelsekretariatet, *Byernes Trafikarealer*, Part 1: 'Introduktion og Forudsaetninger', Copenhagen, 1985.

4 Beth and Pharaoh, op. cit., N1.

5 Noble, J. and Jenks, M., *Safety and Security in Private Sector Housing Schemes*, Amersham, Housing Research Foundation, 1981.

6 Stitchting Centrum voor Regelgeving en Onderzoek in de Grond-, Water- en Wegenbouw en de Verkeerstechniek (CROW), *Van Woonerf tot Erf*, Ede, Netherlands, 1989.

7 Danish Ministry of Transport, op. cit., N3.

8 CROW, ASVV (*Aanbevelingen voor verkeersvoorzieningen binnen de bebouwde kom*), Ede, Netherlands, 1988 (third edition).

9 Department of Transport, Circular, Roads 4/1990; *20 mph Speed Limit Zones*, London, 1990.

10 Topp, H., 'Perspectives for the Moderation of Traffic in Germany', paper presented to the Conference on New Ways of Urban Traffic Management, Paris, June 1989; Hass-Klau, C., *The Theory and Practice of Traffic Calming: Can Britain Learn from the German Experience?*, Oxford, Transport Studies Unit, University of Oxford, 1990.

11 Danish Ministry of Transport, op. cit., N3.

12 Department of Transport, *The Highways (Road Humps) Regulations* 1990 (SI No. 703) and *Speed Control Humps* (Traffic Advisory Leaflet 2/1990), London, 1990.

13 Devon County Council, *Traffic Calming Guidelines*, Exeter, 1991.

14 Kjemtrup, K., 'Speed Reducing Measures', *Proceedings of the Australian Road Research Board Conference*, Part 2, Canberra, 1988, pp. 125–32.

15 See, for example, Danish Ministry of Transport, Road Directorate, *Consequence Evaluation of Environmentally Adapted Through Road in Vinderup* (Report 52), Copenhagen, 1987.

16 Neeskens, J., *Effects on Life and Safety of the 30 kmph Demonstration Project in s'Hertogenbosch* (translation), Nijmegen, Institut voor Toegepaste Sociale Wetenschappen, 1987; Netherlands Ministry of Transport and Public Works, R.V.V. *Berichten over Verkeersveiligheid*, issue devoted to 30 kmph zones, December 1986.

17 Danish Ministry of Transport, Road Directorate, *Undersøgelsen i 15 §40-omrader*, Copenhagen, 1984.

18 Engel, U. and Thomson, L., §40 *Gaders Sikkerhed* (Notats 1 and 2), Copenhagen, Danish Council for Road Safety Research, 1989.

19 Topp, op. cit., N10.

20 Just, U. and Potthoff, U., *Neue Erkenntnisse über die Zusammenhange zwischen Fahrverhalten und Kfz-Larm*, Dortmund, Institut für Landes- und Stadtentwicklungforschung des Landes Nordrhein-Westfalen, 1988.

21 Herrestedt, L., 'The Experiences from the Danish Road Directorate's Experiment with Environmentally Adapted Roads in Three Pilot Towns', paper presented to the Danish Road Directorate/AICPR Conference on Speed Management, Copenhagen, May 1990.

22 Umweltbundesamt, *Information on Federal Research Project, Zonal Environmental Traffic Restraint in Buxtehude*, Berlin, 1987.

23 Danish Ministry of Transport, op. cit., N15.

24 Hass-Klau, C., *New Life for City Centres: Planning, Transport and Conservation in British and German City Centres*, London, Anglo-German Foundation, 1988.

25 Danish Ministry of Transport, op. cit., N15.

26 Netherlands Ministry of Transport and Public Works, *Residential Neighbourhoods and Traffic Zones*, The Hague, 1986.

27 Danish Ministry of Transport, op. cit., N15.

28 See table based on unpublished research by D. McGuigan in Russell, J. and Pharaoh, T., *Speed Management and the Role of Traffic Calming in Road Safety* (Research Paper No. 35), Edinburgh, Department of Planning and Housing, Edinburgh College of Art/Heriot-Watt University, 1990.

29 Danish Ministry of Transport, op. cit., N15.

30 Neeskens, op. cit., N16.