DANISH PLANNING AND DESIGN PROCEDURES FOR TRAFFIC CALMING

Ole Djurhuus, Danish Road Directorate

INTRODUCTION

Until the late 1970's the Danish planning and design procedures for urban roads and streets were based entirely on the concept of traffic differentiation. This meant traffic separation and traffic classification, where traffic separation is the separation of traffic in space or time such that it precludes conflicts between traffic with different characteristics (for instance separated traffic networks for vehicles, bicycles and pedestrians), and traffic classification is the classification of the links of a traffic network with regard to the traffic functions and characteristics in order to have as uniform traffic flows as possible on the links.

The functional classification used consisted of:

- Primary roads, interconnecting the town quarters and connecting those to the town center. Also giving connection to the interurban road network.
- Distributor roads, interconnecting the areas within the town quarters and giving connection to the town center.
- Stem roads, interconnecting the individual residential groups and connecting those to a local center, if any.
- Access roads, servicing the individual residential groups or town functions at a similar level.

A primary objective for the use of this system was the reduction of the rising amount of traffic accidents.

The system in its entirety was used with a fair amount of success to plan and design new urban areas in the outskirts of existing towns, but the full use of this system inside existing towns, where the lay-out of the street network is several hundred years old, proved difficult, if not impossible.

It will be noted from the above, that the function used for the functional classification was the traffic function, and that alone.

During the 1970's however, there evolved a rising recognition of the ill effects that the exploding development of motor car traffic had on the multi-functional environment of urban areas. This was felt as well by groups within the general public as by groups of town and traffic planners. In residential areas, parents felt insecure to have children play in the street. In shopping streets traffic created a barrier and prevented crossing from one side of the street to the other, growing air pollution and noise made also these streets unpleasant to dwell in. The main street in many smaller towns lost its traditional social and business functions as it turned into a section of a link in the interurban road network, and even though bypasses were constructed around a number of such towns, the residual traffic left in many cases still created a barrier.

Groups of traffic planners eventually recognized that the concept of traffic separation in a number of cases could not solve the problems, and that traffic planning in urban areas had to take account more directly of a range of urban functions than the road classification system based only on the traffic function did. Also it was recognized that as much, or more, than the amount of traffic, the traffic speed gave rise to the barrier effect of the motor car traffic.

Inspiration came among others from the Netherlands, where since the mid seventies the concept of traffic integration was used instead of traffic separation in a number of residential areas, the so called "woonerven". Streets in these areas were reconstructed such that the distinction between areas for vehicle traffic and for pedestrians was removed and speed reducing measures were constructed to ensure that motor car traffic would travel at a very low speed, comparable to walking speed. The necessary legal changes to the Danish Road Traffic Act were made and soon after the first residential areas were reconstructed using the new traffic calming concept.

In connection with the issuing of a perspective plan for the national road network early in the 1980's, the concept of environmentally adapted through roads of small towns was introduced. This was followed by the reconstruction of three such roads through small towns, and extensive before and after studies of a number of social, economic and environmental impacts were carried out in the three experimental towns.*(1,2)*

Five major shopping streets in major urban areas across the country were reconstructed using the traffic calming concept, and the effects hereof were measured by before and after studies.*(3)*

On the basis of the experience from these and subsequent projects, new planning and design procedures for urban traffic areas were developed, and in 1991 the full set of new road standards for urban traffic areas was approved by the Danish Minister of Transport and issued.*(4)*

TRAFFIC PLANNING IN URBAN AREAS

Three main traffic networks should be determined when planning the main urban traffic structure:

- the main road network (traffic roads)
- the main traffic network for light road users (bicyclists and pedestrians)
- the public transport network (buses and trams).

On the basis of the established main road network a number of local traffic precincts are defined, i.e., the areas between the traffic roads.

In accordance with the traffic plan's distinction between a main road network and local traffic areas, the new Danish functional classification for urban roads consists of only two classes.

The traffic roads are the roads that constitute the urban main road network. They serve the through-traffic, traffic between the town and the region, traffic between towns, and between individual neighborhoods or quarters of larger towns.

All other roads are designated as local roads. They serve local areas, neighborhoods and houses, workplaces, institutions and shops.

The light road users traffic network can also be divided into two classes, namely main paths and local paths.

The main paths, i.e. the light road users' main traffic network as defined in the main urban traffic structure, serve the main pedestrian, bicycle, and moped traffic in a given area.

Just as important, however, is the distinction between three main types, i.e.

- separate paths
- cycle tracks along roads
- main routes using local roads

The description of the public transport network in the main urban traffic plan serves two purposes. First it accounts for the public transport services planned for the following years; secondly it defines other routes which are likely, in the future, to be designated as public transport roads.

When planning these traffic networks, consideration must be given to accessibility, passibility, capacity, clearness of layout, environment, urban architecture, and particularly safety.

To ensure these conditions the traffic system should, where possible, be based on the principle of traffic separation. As mentioned earlier, however, in practice this has proven to be feasible only in new urban developments. Normally the needs of motor cars and of the light road users must be accommodated within one and the same road system, i.e. one must work with some kind of traffic integration. However, many investigations have shown that speed has a significant effect on road safety, security, and on the environment, so one of the means for achieving good conditions is to design both traffic roads and local roads in strict compliance with an initial speed classification.

The more motor cars and light road users such as pedestrians and cyclists, children and elderly people share the same road, the more important it becomes to be able to manage the speed of the motor car traffic.

Therefore, the basis of road design varies substantially from the relatively few new urban areas where car traffic can be effectively separated from other traffic and from the urban functions as such, and to the many existing areas where each road serves many functions and where, accordingly, the various groups of road users must be mixed. There the speed difference between the various groups of road users must not be too great. In other words, if bicyclists and motor cars are to share the same area, the speed should not exceed 30 km/h, and if pedestrians and car traffic share the same area, the car traffic speed should not be much above 15 km/h.

So, the concept of speed classification, using the so - called reference speed, was introduced into the Danish planning and design procedures for urban areas. As part of the traffic planning for a town or an urban area each individual road or section of road is assessed with regard to a number of parameters:

Vehicle traffic: road class (traffic road or local road). Present and future traffic flow. Distribution of the types of vehicles.

Pedestrian and bicycle traffic: road function possibly also as a constituent part of the light road users' main traffic network. Present and future traffic flow of light road users along and across the road. Existing cycle tracks or possibility for constructing cycle tracks.

Bus traffic: present and future bus services along the road.

Other functions: the road as a shopping street, housing access road, etc. and as a public area.

Geometry: road alignment and profile. Free width. The possibilities for redesign.

On this basis it is decided which vehicle speed should be preferred for the road - the reference speed.

In the detailed design of the road it should subsequently be ensured that car drivers will respect this speed. This is achieved by determining the length of the individual road sections, by the design of the individual elements of the road, by incorporating speed reducing measures if necessary, and by a deliberate and consistent use of marking, planting, street layout and materials.

If possible, the surrounding of the road should also be designed in accordance with the reference speed.

When deciding the reference speed, the following speed classes are used:

Traffic roads:

- High speed 70-80 km/h
- Medium speed 50-60 km/h
- Low speed 30-40 km/h

Local roads:

- Medium speed 50-60 km/h

- Low speed 30-40 km/h
- Very low speed 10-20 km/h

On traffic roads, high speed should be used only in special cases, and then only when the light road users, if any, are well separated from the motor car traffic, at least by a curb line. Medium speed, corresponding to the general speed limit for urban areas, is normally used. It may be necessary to ensure this speed by the use of speed reducing measures. Generally, bicyclists and pedestrians should be separated from the motor car traffic at least by a kerb line also at this speed. Low speed is used on traffic roads in the exceptional case of many bicyclists and no bicycle tracks, on sections where many pedestrians need to cross the road, and outside schools, public service facilities, etc. To ensure low speed it will usually be necessary to establish various kinds of speed reducing measures.

On local roads, medium speed can be used where there are only few accesses or only a few light roads users. Otherwise low speed is used, and it may be necessary to control this speed by means of speed reducing measures. Very low speed should be used on local roads and traffic areas where pedestrian activities are of more importance than motor car traffic.

On a number of road sections in the road network, actual speeds may be comparable to the now designated reference speed. Where this however is not the case, it may be necessary to redesign the sections, thus imposing a physical speed reduction on motor car traffic.

Based on the speed classified road network plan, on observations of the existing traffic pattern, and on predictions of the future pattern, a plan should therefore be worked out for the sections that are to be provided with speed reducing measures.

There are two reasons why part of the road network should be redesigned so as to be physically speed-reducing. Firstly, road signs stating allowed or recommended maximum speeds have proved insufficient. Secondly, it must be considered both psychologically meaningful and generally instrumental in achieving an appropriate traffic flow thus car drivers can see a logical connection between the road design in a wider sense and the stipulated speed.

For the conversion projects, a number of important parameters should be recorded.

The existing and future roadside usage must be identified, i.e., facades, access for pedestrians and cars, and parking. It is particularly important to evaluate the functions not strictly related to traffic.

Motor car speeds should be recorded from a series of characteristic measuring stations.

The volume of car, bicycle, and pedestrian traffic must be measured with the emphasis on determining the peak hour traffic. Parameter changes caused by other conversions in the area should be calculated or at least considered.

The street and its environment should be architecturally described and evaluated. Against this background preferences should be stated regarding architectural finishes, improvements, planting, etc.

The width available for the street should be specified in general for the entire section, and in particular for possible local extensions or narrowings.

The existing cross-section must be described with special emphasis on the location of kerbs, underground pipes, road equipment, etc.

On the basis of the then - established premises and as a starting point for the preparation of the actual design proposal, a sketch of the road section should be prepared.

First, the sketch must show the type and the location of all intersections and junctions according to the proposed road plan. Also it should show such road closures as have to be made in connection with the conversion.

On the basis of the plan for the light road users' traffic network the path/road crossings are determined. In addition, those crossings that are found to be locally necessary must be identified. The sketch of the road section must also include such adjacent facilities as bus stops, parking bays, etc. Finally, the sketch must show the kind and the location of the speed reducing measures, e.g.

- pre-warnings
- gates
- raised areas with ramps
- humps
- narrowings
- staggerings

As a supplement to the sketch of the road section the planned conversion should be described by means of one or more characteristic cross-sections.

DESIGN OF URBAN TRAFFIC AREAS

Once the functional classification and the speed classification have been defined in the traffic plan, and when on the basis of pilot studies it has been determined what should be the number of lanes, whether there is need for bus lanes or parking lanes, whether or not a bicycle track should be constructed, what the need is for pedestrian areas, what the need is for speed reduction, and what the road equipment plan is, there is a basis on which to work out the detailed design of the traffic areas, i.e., alignment elements, cross-section elements, junction design and the choice of types of the speed reducing measures and their placing.

Alignment Elements

In existing urban areas there are only limited degrees of freedom when choosing alignment elements, as the surroundings have normally set a fixed framework in the form of existing accesses to houses, existing pipelines, etc.

One factor, however, decisive for road safety, is a sufficient sight distance to enable road users to stop to avoid collisions — not only for car drivers, but also for light road users. The Danish experience is that a number of accidents involving bicyclist happen because of insufficient sight distances, also in cases involving only bicyclists.

Otherwise, the choice of urban alignment elements for reference speeds higher than 30 km/h are based on the same dynamic considerations as for rural roads, whereas for lower speeds only geometric considerations are taken into account.

Cross-Section Elements

The main governing condition when choosing the types and the widths of the cross-section elements is very often the space available, i.e., the distance from facade to facade.

In order to facilitate the choice, the Danish road standards specify as well normal widths as guidance values for minimum widths of the different cross-section elements, based on different functional requirements. Care should be taken when using minimum values not to do so simultaneously in the cross-section.

Below, a number of the cross-section elements - but not all - are commented upon.

Traffic Lanes

In urban areas the capacity of the junctions most often is decisive for the overall capacity of the total road network. The number of lanes on the road sections therefore is determined on the basis of the capacity and the traffic flow at the junctions.

The width of the traffic lanes is determined on the basis of the chosen reference speed.

Guidance values for lane width are shown in Table 1.

If, contrary to what is recommended, bicycles use the traffic lane of a road on speed class Medium because there is no bicycle track, then the lane width should be increased by 1.00 m. Roads in speed class High must have bicycle tracks if bicycle traffic is not banned. Roads in speed classes Low and Very Low need not to be widened to accommodate bicycle traffic.

TABLE 1 Lane Widths

Speed class (km/h)		Lane Width (m)
High	70-80	3.50
Middle	50-60	3.00-3.25
Low	30-40	2.75
Very low	10-20	2.50

Bicycle Paths

Apart from depending on the volume of bicycle traffic, the widths of bicycle paths depend on the type of path chosen, one-way paths, bidirectional paths, divided or shared paths.

The normal width of one-way bicycle paths is 2.20 m, the minimum width, still allowing overtaking on the path, is 1.70 m.

Sidewalks and Footpaths

If there is pedestrian traffic, roads in speed-classes High or Middle should be equipped with sidewalks.

The widths of sidewalks is determined on the basis of the volume and the kind of pedestrian traffic. The minimum width is 1.5 m based on the need for a wheelchair and a perambulator to pass each other.

Intersections

Traffic Safety

Regard for traffic safety should hold top priority when deciding on the location of a new intersection, for the choice of type of intersection, and for the detailed design of the intersection and for the surroundings.

In existing urban areas and when reconstructing roads, the design of the intersection will usually be of decisive importance for the motor car speed. Therefore, it may be necessary to support the chosen reference speed by means of physical and optical measures in the intersections.

Most importantly, a road user approaching an intersection must be made aware of the intersection at a distance suitable to prepare for the consequent changes in the driving pattern. Road users on the secondary road must have information on the priority conditions in time to be able to give way.

Intersections without marked or signed priority, i.e., give way to traffic from the right, are for traffic safety reasons only used in Denmark on local roads with very little traffic. In such intersections speeds may be reduced by the use of physical speed reducing measures in all branches of the intersection.

Also, due consideration must be given to the light road users: pedestrians, bicycles, and moped riders. Partly because these road users constitute a high risk group and their injuries are often severe, partly because their traffic behaviour is less orderly than that of motor car drivers, and because even small inconveniences, in the form of detours or suchlike, can cause inappropriate behaviour in the intersection.

Design of Intersections

In the design of an intersection, an architectural relation should be sought between the character of the street space and of the surroundings, and of the different elements used in the design.

This should also be the case when the design is intended to reduce the speed of the motor car traffic. In this case the following elements may be used:

- narrowings
- staggerings
- central traffic islands
- ramps and raised surfaces
- humps
- changes in the road surface
- traffic actuated signals.

Further, the positioning of road equipment, signs and road markings should be an integral part of the geometric design of an intersection.

The main types of urban intersections used in Denmark are:

- signal controlled intersections
- priority controlled four-way intersections (F)
- priority controlled three-way intersections (T)
- raised side road junctions
- roundabouts
- intersections without marked priority.

Signal control can be provided in F- and T-intersections, between two traffic roads or between a traffic road and a local road. For new construction, signal control is established only on roads with a reference speed of 60 km/h or less. Signal control may be used for speed reduction on a road section where the actual speed is higher than the reference speed, by using traffic actuated signals that, when not activated, show a red light in the main direction, or in all directions.

All intersections of some importance without signal control should have priorities assigned, i.e., that a primary and a secondary road are identified where the traffic on the secondary road has to give way to traffic on the primary road.

Regarding intersections not controlled by traffic signals, T-intersections are preferred to F-intersection for reasons of traffic safety.

The reconstruction of ordinary urban intersections into roundabouts has increased significantly during the last period of years. Experiences both with capacity and with traffic safety have been positive, especially with regard to motor car traffic.

The Danish conclusion is that urban roundabouts should generally be designed to have a speed reducing effect, so that the speed of motor car traffic is reduced to 15-20 km/h.

Therefore, roundabouts in urban areas should be as small as possible, provided, however, that the central island is so large that, together with any other island in the entrance lane, it causes sufficient deflection of the vehicle paths, and that the lane widths are sufficient for the design vehicle(s) to perform all desired manoeuvres in the roundabout. Also, there should be only one-lane entrances, exits, and circulation areas.

Speed Reducing Measures

Design

As mentioned earlier, a basic problem for urban traffic areas is to have motor car speed adapt to the surroundings as well as to the street layout, for traffic safety and for general environmental reasons.

Therefore one sees today in Denmark as well as in a number of other countries the use of speed reducing measures, especially the use of humps, and unfortunately not always used in the most aesthetic way.

In a good design there should be a clear connection between the elements of the speed reducing measures and the overall design. The Danish road standards for Urban Traffic Areas *(4)* describe about fifteen different types of measures and their individual elements. Further information and inspiration as to the use of speed reducing measures may be found in the growing amount of literature on this topic, for instance in the report "An Improved Traffic Environment" *(5)*, which includes a number of specific examples form Denmark, France, and Germany.

Types of Speed Reducers

Basically, there are two main types of speed reducing measures:

- visual speed reducers
- physical reducers

Visual speed reducers, including road markings, closed road spaces (with trees, gates, buildings, etc.) and attractive design of the street space (walls, floor and ceiling).

Physical speed reducers include rumble strips, narrowing of the road, staggering, and humps.

Bumps and raised areas are effective speed reducers, and it is possible to create a direct correspondence between the reference speed and the geometric design of bumps, as shown for circular bumps in Table 2, listing the recommended radii and chord lengths for the assumed rise of 10 cm.

Staggerings also have a physical speed reducing effect, but it is more difficult to establish a direct correspondence between the reference speed and the geometric design. If heavy vehicles are to be able to pass through, motor cars will be able to do so at speeds well above the reference speed.

The rest of the elements have little or no physical speed reducing effect, but should be considered desirable and/or necessary supplements to the actually speed reducing elements.

In the overall planning of the road and bus networks one should try to avoid the establishment of bus services and speed reduction measures on the same road sections.

If unavoidable, however, the use of circular bumps is advised, but great care must be taken to ensure the right geometry. As shown in Table 2, Danish experience is that bus drivers will accept passing correctly constructed circular bumps at a speed 15 km/h less than the reference speed.

Location of Speed Reducers

Initially, speed reducing measures should be provided for the locations where the need is greatest and where such provision would generally seem logical, for example:

- at intersections
- at path/road crossings
- in front of schools
- in front of shops
- in front of parks or other green areas.

TABLE 2 Design of Circular Humps

Reference speed (km/h)	Radius (m)	Length of chord (m)	Bus speed (km/h)
20	11	3.0	5
25	15	3.5	10
30	20	4.0	15
35	31	5.0	20
40	53	6.5	25
45	80	8.0	30
50	113	9.5	35

Subsequently it is assessed whether additional speed reducing measures are needed. The locating of such supplementary measures may lead to changes of those that were sited initially.

When determining the distance between the individual speed reducers it should be remembered that car drivers tend to accelerate between the speed reducers. Locating well constructed speed reducers in accordance with Table 3 will result in that the average driver exceeds the reference speed by only some 5 km/h between the speed reducers.

TABLE 3 Location of Speed Reducing Measures

Reference Speed (km/h)	Distance Between Measures (m)
10-20	25 (max 50)
30	75
40	100
50	150

CONCLUSION

The volume of motor vehicle traffic rose dramatically during the fifties and sixties, and has, with variations, been rising ever since.

In the 1970's it became increasingly clear in a number of European countries that this rising traffic volume had severe adverse effects on the multi-functional environment of urban areas.

In Denmark this recognition led to the adoption of a new functional classification of the urban traffic network and to the introduction of speed classification. As a means for managing car speed the traffic calming concept was developed and introduced into the design process.

It is recognized that traffic culture and driver behaviour differ from one country, or even region, to another, and that therefore it is not appropriate to offer unambiguous advice on the correct design. It is hoped, however, that knowledge of the Danish planning and design procedures for urban traffic areas may be of inspiration to others.

REFERENCES

1. Road Directorate. Consequence Evaluation of Environmentally Adapted Though Road in Skaerbaek, 1988.
2. Road Directorate. Consequence Evaluation of Environmentally Adapted Though Road in Vinderup, 1987.
3. Road Directorate. Trafiksanering of STORE bygader - nogle elsempler (Traffic Reorientation on MAJOR Town Streets - some examples), October 1985.
4. Road Directorate. Urban Traffic Areas, June 1991.
5. Road Directorate. An Improved Traffic Environment, 1993.