SESSION T - THEORETICAL CONSIDERATIONS

LECTURE T3 - DESIGN INPUTS **PRESENTER: CD SCOTT**

1 INTRODUCTION

The concept of a road being provided to enhance mobility is so entrenched in modern society that it is normally taken for granted by the user. Historically, accessibility tended to lose out, at least from the perspective of the designer. As we will see, these functions are equally important if a well-balanced network is to result. Furthermore, the road reserve is required to serve many other functions as well. In fact, the planners refer to the road reserve as being “hard open space” with only one of its functions referring to the movement of vehicles and pedestrians

With regard to vehicular movement, the design of the road is based on many restricting elements relating to the driver and the vehicle, in addition to the consideration of land use and topography. All these elements have wide ranging characteristics in themselves, and individual characteristics can adopt a wide range of values. These characteristics will be discussed in some detail in this and subsequent lectures. The point of departure of all design is the selection of characteristics which most clearly define the needs to be served by the road and the selection of values of characteristics that best meet those needs.

The relationship between the driver and the vehicle and the range of operating characteristics resulting from this will be dealt with in subsequent lectures. The prime outcome, however, from the designer's point of view is operating speed as discussed later in this lecture.

It is often possible to combine sets of characteristics into single concepts to the extent that what is ultimately perceived is the concept and not its individual components. These concepts however provide a useful framework for understanding design parameters and the most basic of these are introduced in this lecture.

2 FUNDAMENTAL CONCEPTS

2.1 The Design vehicle

Before commencing the detail design of the road, a principal concept that requires consideration is the vehicle for which the road is to be designed. Obviously, a wide range of vehicles will operate on every road, and the mix of vehicles on any given road will vary considerably depending on its function.

Streets in residential areas will almost exclusively serve passenger cars, with some buses and utility vehicles making their appearance. About the only freight vehicles ever seen are the pantechnicon and the refuse removal truck. In shopping areas, although actual numbers will be high, the proportion of passenger cars in the traffic stream will reduce, buses will increase, and freight vehicles increase substantially. In industrial areas, there will be relatively few passenger cars and buses and those present will appear within sharply defined peak periods whereas freight vehicles, of which a substantial proportion will be articulated vehicles, will be in evidence for most of the day.

Although legal limits are placed on vehicle design, differences between the characteristics of the different classes of vehicles are substantial.

Intra-class differences in vehicles are no less dramatic. The low-slung sports car with a ridiculous power/mass ratio, broad tyres and super disc brakes overtaking the elderly, heavy, low performance sedan with inadequate braking and all-round vision are both representatives of the passenger car. Passenger cars are however designed essentially for the single purpose of conveying passengers in low numbers, typically in the range of two to a maximum of six.

Commercial vehicles on the other hand are custom built for a wide number of applications, from rapid delivery of small loads in heavily trafficked conditions over short distances to long distance haulage of mass or volume loads and include special purpose vehicles such as refrigerated trucks, and concrete carriers, bulk freighters for commodities such as fertilizer, grain or cement and tankers carrying liquids such as fuels and hazardous chemicals. Consequently, the spread of values of their characteristics is greater than that found in passenger cars, and they vary from the three-wheel messenger cycle, via the light delivery vehicle and the single unit truck to the articulated vehicle (within which group a large variety of configurations can also be found). On certain routes, abnormal vehicles, i.e. those that fall outside the legal limits, also have to be accommodated.

For design purposes, certain vehicles are selected as being representative of their class and, in this sense they represent a "worst case". The worst case is not a specific vehicle but is a composite of characteristics, referred as the design vehicle.

Vehicle characteristics that are of importance to the designer are:

- its physical dimensions, being length, width, height, wheelbase, front and rear overhang and configuration, the last-mentioned referring to the number of wheels (including how many of them are driving wheels) and the arrangement of these wheels relatively to the body of the vehicle)
- performance parameters such as engine size, torque, power, mass, braking capability, rolling resistance, virtual mass, air resistance (often referred to as penetration)
- operational restraints such as drivers' eye height and minimum turning circle

Actual values of these characteristics that are selected to describe the design vehicle depend on the intended application of the particular design value and are usually predicated on some or other percentile value of a distribution of values. Wolhuter and Skutil established these distributions by determining the characteristics of a wide range of vehicles within the various classes, invariably from data provided by the manufacturers and relating these to the market share represented by each model of vehicle.

The design of parking bays, if based on the fiftieth percentile, would result in one vehicle in two not being accommodated. On the other hand, the long wheelbase limo beloved of the wealthy ostentatious is clearly an impractical yardstick for all the parking bays in town. The 95th percentile is thus selected.

The lower the driver's eye height, the less sight distance he has over a vertical curve. The fiftieth percentile would suggest that half the vehicles on the road would not have adequate stopping sight distance and the fifteenth percentile is thus selected. The rationale behind not accepting the lowest percentile is that the very low driver eye heights are typically found in high performance vehicles that usually have superior braking abilities. Hopefully, the drivers also have superior reaction times.

Driver eye height introduces another thought worthy of consideration and that is that vehicle characteristics cannot always be divorced from driver characteristics. The designer is thus in the position of being required to consider the composite of man and his means of transport so that the design vehicle tacitly includes the person driving it. This is an important consideration for the developers of simulation programs, who would be ill advised to create a combination of dear, gentle sweet old lady and a 34 tonne twenty-two-wheel articulated vehicle.

The objectives of road provision include in addition to safety, convenience and minimum side effects, considerations of economy. The designer must of necessity, therefore, be somewhat of a composite animal himself. Safety requires pure geometric design; convenience calls for a combination of regional planning, transportation engineering and geometric design; minimum side effects require environmental awareness, artistry, and geometric design. Economic considerations require an ability to combine geometric design with economic analysis and this will be considered in a subsequent lecture. In the economic analyses that the designer will be required to perform, the vehicle parameters of interest are those relating to performance. Seeing that our interest lies in the overall economy of the road, we normally use the average or the fiftieth percentile values.

Classes of design vehicle normally considered are the passenger car (P), the rigid chassis truck (SU), the articulated truck (WB-17) with the abbreviation deriving from the overall wheelbase of the combination vehicle and the bus (B). The articulated bus (ABus) occurs but in such low numbers that it would only be adopted as a design vehicle in very special circumstances. Other vehicles, for example the light delivery vehicle (or bakkie) can usually be contained in one or other of the design classes listed.

In South Africa, the minibus taxi is showing signs of having to be considered as a separate design class. It is typically poorly maintained, heavily overloaded and entirely unpredictable. Very broadly, it combines the physical dimensions of the passenger car with the power/mass ratio of a truck and the psychology of the average suicide bomber.

Strictly speaking, the pedestrian can also be described as a design vehicle that has to be accommodated within the road. Widths of sidewalk are predicated on pedestrian volumes and pedestrian crossings require knowledge of the operating speed of the "vehicle", e.g. walking speed. The fifteenth percentile value of about 1 m/s does not accommodate the aged and infirm who have to take their own chances. The aging population of Europe suggests that a slower walking speed may have to adopted in future. The average age of the South African population is fifteen so that this is not a local problem as yet.

Table 2.1 shows current values of the various parameters of the design vehicle. The values given in the table derive from work by Wolhuter and Skutil[1] and will probably have to be updated in the near future. The figures that follow illustrate turning templates and truck performance.

2.2 Design speed

The design speed used to be defined as the highest speed at which a vehicle can operate safely on a road when circumstances are so ideal that only the design of the road prevails. If you think about it, this definition actually goes around in a circle. These days we simply say that it is the speed selected for design purposes.

Various values of the different features of the road are combined in groups representing a combination of factors that will contribute to the driver's interpretation of the environment in which he finds himself. "Design speed" is thus a generic name for the various groupings that result rather than a speed, per se, and the values of the aspects are collectively referred to as a design speed of a specified magnitude. Alternatively, design speed is a speed measure of the standards for these factors, the most important of which are:

- sight distance;
- horizontal and vertical curvature;
- surface skid resistance;
- lane width;
- superelevation;
- vertical grade; and
- lateral clearance.

Table T2.1 : Parameters of design vehicles					
Characteristic	**Class of vehicle**				
	Passenger Car	**Single unit**	**Articulated vehicle**	**Minibus taxi**	**Bus**
Overall length	4,80	9,15*	19,28**	See passenger car	12,00
Wheel base	2,85	6,10	10 + 9,15		6,00
Front overhang	0,75	1,22	0,92		2,50
Rear overhang	1,20	1,83	0,61		3,50
Width	1,80	2,60	2,60		2,60
Height	1,40	4,00	4,11	2,02	4,65
Engine cap (cc)	1 900	10 350	7 000	1 900	8 500
Torque (Nm)	140	330	470	145	600
Power (Kw)	68	89	92	62	155
Mass (Kg)	1 150	14 000	19 150	2 400	14 600
Mass/Power (Ave)	17	157	208	39	94
Mass/Power (95%)	19,6	116,4	227,0	42,0	120,0
Driver eye ht	1,05	1,80	1,80	1,05	1,80
Min turning rad	6,20	12,81	13,72	6,20	13,10

* *The actual 95 % percentile value is 9,70 m which may have been a better design standard*
** *The value quoted above derives from agreement between the provinces, whereas the 95 % value is actually about 17,00 m*

Operating speed has been mentioned earlier. To achieve a desired operating speed, certain characteristics have to be designed into the road, creating in the driver a perception of safety and convenience at that speed. Many physical and visual aspects, in addition to traffic volumes and topography, control this concept.

One of the most important initial decisions in relation to the design of the road is the selection of the design speed. The design speed is chosen in relation to:

- the classification of the road
- the topography traversed, be it level, rolling or mountainous for example
- the location of the road, e.g. in an urban or rural environment

the level of service desired

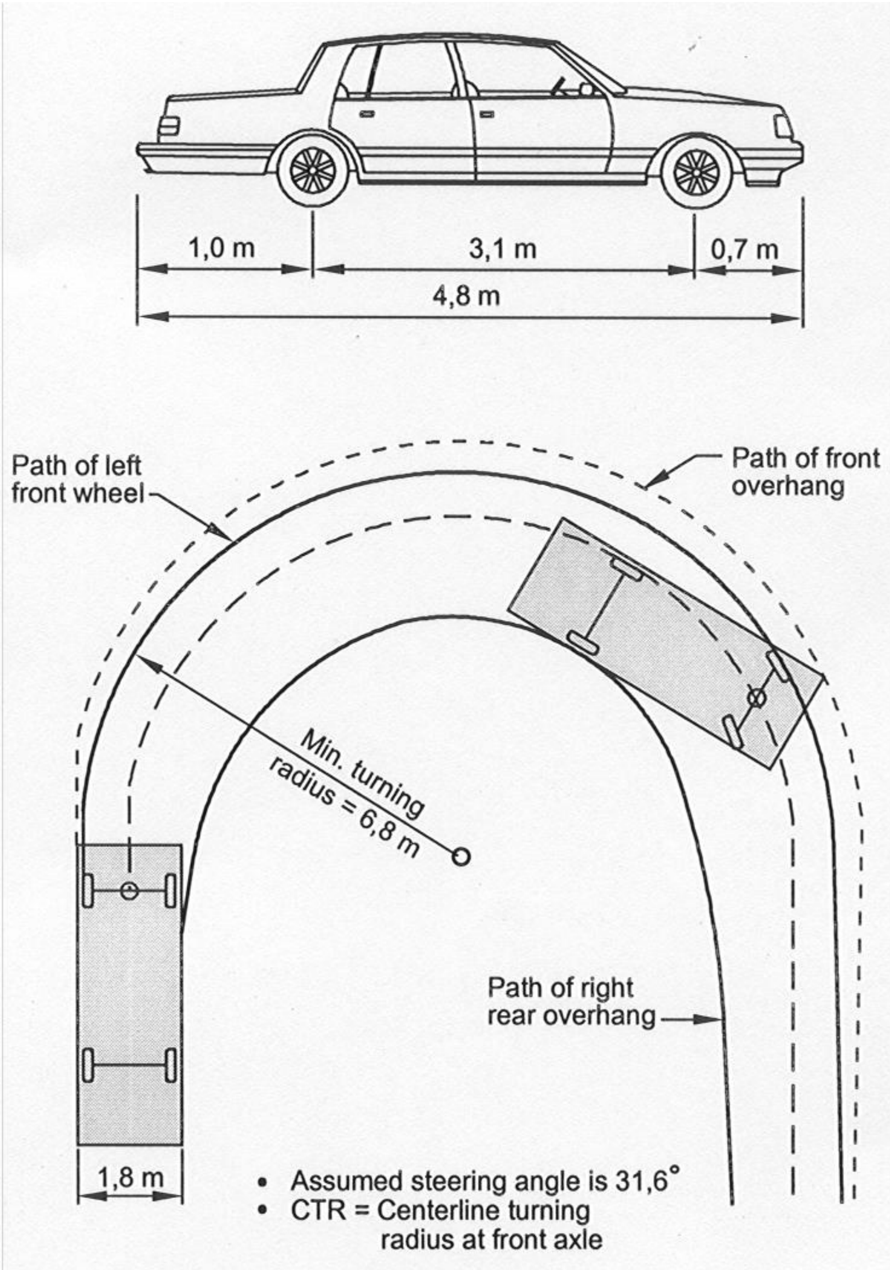

Figure T3.1: Wheeltracks for rigid chassis vehicles

The posted speed limit should relate directly to the operating speed, which is often chosen as the 85th percentile value of observed running speed. Minimum speed limits are seldom used but can be a useful technique for debarring heavy and slow moving vehicles from heavily trafficked roads such as urban freeways. Minimum speed limits are based on the 15th percentile observed speed.

The important concept of consistency of design implies constant design, operating, safe and average speed. Lower design speeds would be acceptable and expected in mountainous terrain and urban areas. Higher design speeds would however be demanded where trip lengths are long and they would also bring about enhanced safety where high traffic volumes have to be accommodated at a good level of service.

The design speed is really only indicative of the lowest standards found on the road and can, thus, be a snare and a delusion for the young designer. A long tangent followed by a 110 m radius curve could be described as being designed for 60 km/h. The driver is not party to selection of the design speed and consistent design would spell out to him what the design, i.e. safe, speed is.

Changes in design speed have to be introduced with great care and forethought. Not to mention signage telling the driver what you have done if this is not obvious from changes in topography and the like.

2.3 Design hour

Traffic flow is measured by the number of vehicles passing a fixed point in a specified period of time, usually an hour or a day. An important value in design is Average Daily Traffic (ADT), which is the average for several days over an extended period, typically of the order of a year. The average, when the information is available for the period January 1 to December 31 (which occurs only at permanent counting stations) is referred to as Annual Average Daily Traffic (AADT).

ADT provides the basis for selection of a design flow but, by itself, it does not reflect fluctuations in flow and hence the operating conditions for which the road must be designed. Daily volumes are subject to seasonal fluctuations, hourly volumes are subject to daily variations and there are fluctuations within the hour as well. As in the case of the selection of value of vehicle characteristic, it would be wasteful to design for the maximum value of flow that is likely to occur and some lower percentile value is selected.

Having introduced the design vehicle, which is not a specific vehicle and design speed, which is not a speed, a notion which bridges the gap between traffic volume and design volume is the design hour. To be consistent, this, of course, is not an hour as normally understood in the chronological sense.

If the design were to be predicated on flows that currently occur, annual increases in traffic would soon cause the road to be obsolete. It is thus customary to design for a future year, typically twenty years hence on the basis of funding of loan finance and the concept that each generation should pay for its own services.

2.4 Traffic characteristics

As discussed in the preceding section, flow varies enormously during the course of the year. The nature of the variation is dependent on the location of the road. Rural roads show heavy seasonal peaking, particularly if they also serve as tourist routes. Daily peaks on rural roads are relatively undefined whereas urban roads show pronounced daily peaks while being less subject to seasonal variation. Traditionally, the volume associated with thirtieth highest hour of the year is used for design purposes. In rural areas, the thirtieth highest hour corresponds to about 15 % of the ADT and, in urban areas, to about 10 %.

Traffic composition is a difficult animal to cope with. Heterogeneous traffic streams do not readily lend themselves to analysis. Trucks and buses, because of their size and operating characteristics, have as much effect on the surrounding traffic as a number of passenger cars. Reference is thus made to Passenger Car Equivalents (PCE's). PCE's are not constant values that can be attached to specific vehicle types. They vary according to the circumstances being considered. For example, in stationery queues, the PCE of a bus could be as low as 2 whereas, when the right-turning movement is considered, it could be significantly higher. On gradients, PCE's can range between 2 and 8 and even higher on very steep gradients. It is necessary to arrive at an assessment of the traffic composition for which provision must be made. From this assessment, the heterogeneous traffic stream is converted to its equivalent passenger car stream. The debate about PCE's is far from over and there are a variety of methods for calculating them, all of which tend to give different results.

A further variable in traffic is the directional split, i.e. the ratio between opposing flows. Even on rural roads, which are not particularly prone to the tidal flows of the urban street network, flows are rarely balanced. The directional split under rural conditions is typically not more than 60:40, whereas, under urban conditions, 80:20 splits are not uncommon. The design hour is thus a representation of the flow in vehicles per hour with a given composition in terms of numbers of vehicles other than passenger cars in the stream and a given directional split for which the design must provide.

The interaction between opposing flows on a two-lane road reduces capacity and trucks also have a disproportionate effect on other traffic because of the need to overtake in the face of oncoming traffic. Design is therefore of both lanes as a unit. In the case of multilane roads, the lanes in the direction of interest must suffice for the design hour volume anticipated. The reverse flow to be designed for will, in all probability, be of the same magnitude but this will certainly not occur within the same chronological hour, underlining the statement that the design hour is not a unit of time.

3 ROAD USER COSTS

Road user cost finds two applications of interest to the designer.

In the first instance, the application is purely concerned with the economics of the proposed road. "Whole life economy", as a frequently used phrase, includes the costs incurred by the road authority in providing and maintaining the road and the operational costs incurred by the user. Road user costs are principally subdivided into standing costs and running costs. Standing costs are time-based and refer to such items as depreciation, licensing, insurance and garaging. These, in fact, are costs that would arise whether or not the vehicle moved a centimetre. Running costs are distance-based and refer to the cost, exclusive of tax, of fuel, oil and tyres and may also include the cost of time and collisions.

A further use of road user cost concerns route selection. A driver selects the "best" route, and what is best is based on many factors. A major factor is minimum travel time. A route may have a longer length than another but, because of lesser congestion, better signalisation or whatever reason, results in a shorter trip duration. The greater length will probably result in higher running costs but, even if only in the mind of the driver, his time is worth more than the actual out-of-pocket expenditure incurred.

4 TRIP GENERATION, ATTRACTION, DISTRIBUTION AND ASSIGNMENT

Having made reference to the design hour and the volume of traffic to be served in that hour, it is clear that a need exists for estimation of traffic demand in some future year.

In rural areas, development and changes in land use are slow. Traffic growth is restricted and can be estimated with adequate accuracy by attaching some constant rate of escalation to present day traffic counts. This is generally referred to as naive modelling.

Urban areas, particularly in an era of rapid urbanisation, are much more dynamic in terms of growth and changes in land use. Methods more sophisticated than annual growth factors have to be employed if reliable forecasts of traffic demands are to be made.

Traffic forecasting is a major field of interest of the transportation engineer and it is useful for the geometric designer to have some conception of the source of his basic information as derived by the transportation engineer.

In the final analysis, any mode of transport provides a link for the movement of a commodity or an individual between two termini, the origin and the destination. The goods or person trip is thus the basic denominator. The town or regional planner will provide information on land usage, with regard to its nature and intensity. A land usage could thus be residential and comprise relatively few but large sprawling properties or alternatively consist of minute apartments in towering high-rise blocks. Another area could serve either light or heavy industry, and a distinction can be drawn between the nature and frequency of the trips that they are going to generate.

The first step in the exercise is to estimate the number of trips that are going to emanate from any given origin and many studies have been carried out to develop trip generation factors for various land uses. A comprehensive set of tables of trip generation factors is presented in the Department of Transport publication "The effect of a change in land use on traffic volumes" (Report TPC 8/80, U10/10/14)

Person trips are attracted to various destinations, such as places of employment, worship, education and recreation in addition to shopping areas, hospitals and the like. Trip attraction factors thus come into play and, for any given land use, it is possible to estimate the number of trips which are going to terminate at a specified destination.

It may see trivial to offer the reminder that every trip has both an origin and a destination. But it is more than likely, in a sketch planning technique with heavy reliance on factors rather than on interviews, questionnaires and similar forms of data acquisition, that there may be more trips generated in total than are attracted to all the possible destinations. Some modest reconciliation is then called for and thereafter, by various methods - with gravity models possibly being the oldest and best known of these - an Origin-Destination matrix is completed.

The third step in the process is the distribution of all these goods- and person-trips among the various modes of transport available. This is also a matter of some sophistication and discrimination. Modal split and its assessment has also been the topic of much study. For example, upper income areas are more likely to generate home-based work trips with their destination in the more affluent of office areas in preference to industrial areas and, furthermore, it is more likely that these trips will favour individual rather than mass transit modes. The preferences of trip makers apart, many trips are captive to a particular mode, either by virtue of economic circumstance or the nature of the person's employment. The latter could require that he has to have a car for his work although a bus may be a more convenient mode for the trip in question.

The final step is to assign all these trips to the network. Network trips are specified in terms of mode and numbers of vehicles, and this is the information that the geometric designer ultimately requires as input to the process of planning the road network and ultimately designing the individual links in the network.

5 CONCLUSION

This lecture has introduced the concepts of :

- ❑ the design vehicle;
- ❑ the design speed; and
- ❑ the design hour

as basic inputs into the design process.

If these are correctly selected and applied, the designer is halfway towards producing a design appropriate to the function of the road. The road, as built, should then be able to accommodate actual traffic volumes at speeds and levels of comfort acceptable to the driver.

The point must be made that there is no such thing as an unlimited budget. The designer must always be aware of the cost implications of his or her actions and, later on in this course, a lecture will be devoted to some of the basics of economic analysis.

Assessment of traffic volumes commences with estimates of trips to be made either by people or by freight. Person trips and goods trips have to be converted into vehicle trips and the resulting vehicle trips have to be distributed to the network. Only thereafter is it possible to proceed with any confidence to the actual process of design.

The above discussion is limited to the mobility aspects of the network. As will be come clearer in subsequent lectures, the network addresses the aspects of both mobility and accessibility and, furthermore, is required to serve other issues of human activity as well. The network arising from considerations exclusively of mobility is thus incomplete and is, at best, the skeleton around which the total network is constructed.